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DEVELOPMENT AND FIELD VALIDATION OF AN INNOVATIVE APPROACH TO SUSTAINABLE CULTIVATION OF DURUM WHEAT IN ITALY.

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1 Foreword

1.1 Definition of sustainability

The term *sustainability* comes from the word "*sustain*" that means keeping in existence, maintaining alive. In Latin the word "*sustinere*" explains the human capacity to hold, to conserve and to save resources in such a way that they are not depleted or damaged (Mitchell, 1998).

Although the concept of sustainable development is intrinsic in our mind, the first fixed point about this issue has been identified in 1987 with the sentence *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs".* The definition has been enunciated in Switzerland and attributed to Gro Harlem Brundtland, Chairperson of the World Commission on Environment and Development. The definition was included in the Brundtland Report as the most general and primordial definition of sustainable human development (Fricker, 1998). In the following years, the definition of sustainability evolved and followed different paths according to objectives and productive sectors, without, however, losing the native meaning.

In the agricultural sector, the term "sustainable agriculture" did not emerge into popular use until the late 1980s, even if the research of high quality in life of human, animal or vegetal communities was not a new philosophy. In 1990 the term sustainable agriculture has been finally defined, by the U.S. Government Public Law 101-624, as the will to *"enhance environmental quality and the natural resource base upon which the agricultural economy depends"* and *"enhance the quality of life for farmers and society as a whole"* (Gold, 1999).

During the Conference on Environment and Development, held in Rio de Janeiro in 1992, the United Nations defined sustainability as an essential goal of worldwide food and goods production. Concurrently, it was defined that the precautionary principle and the study of suspected risk of toxicity should be considered as major approaches to regulate the use of chemicals affecting humans' health and environmental degradation (Hammond et al., 1995).

Moreover, the Conference of Rio de Janeiro established the onset of the concept of sustainable land management, issue that, in the last years, is receiving considerable attention from scientists and policy makers (Syers et al., 1995). In 1998 Smith and Mc Donald provided the clearer and the best fitting definition of sustainability for the primary sector: "*A farming system is durable when it fulfills the following sustainability requirements:*

- *the development is compatible with the maintenance of ecological processes (ecological sustainability);*

- *the development is economically feasible and socially acceptable (economic and social sustainability)."*

Subsequently, the European Commission (2001), in harmony with Agenda 21 of the United Nations, set forth that: *"The concept of sustainability is multidimensional. It includes ecological, social and economic objectives. Between these different elements, there is interdependency. Research results, indeed, confirm that the relationships are strong, numerous and complex. Strengthening the economic viability of rural areas is the basis for providing the means of preserving their social and environmental functions. Social implications result from the provision of rural employment opportunities, the diversification of economic activities and the promotion of local products, services, craft activities and agri-tourism".*

According to European Commission (2001) the three pillars of sustainability (economic, social and environmental) should be developed through relevant synergies, despite they are not always mutually supportive and they even can compete with each other. To avoid this, sustainability requires a right balance between its three basic elements in order to avoid mistakes in the impact's assessment and characterization.

Also in the U.S.A. the definition of sustainability follows the distinction between economic, social and environmental subsets and, in fact, the American Sustainable Agriculture Research and Education (SARE, 2014) fixed the following three main pillars of sustainability for agriculture: *"profit over the long term"*, *"stewardship of our nation's land, air and water"* and "*quality of life for farmers, ranchers and their communities*". These statements prove the necessity of a reconciliation between economic demands, social respect, equity and environmental compliance also for farmers that, therefore, must comply with the three pillars of sustainability.

Nowadays, a farming system is considered sustainable if it is productive, useful to the society, oriented to resources' conservation (soil, water, energy), commercially competitive and environmental friendly over the long term. In other words, sustainability in agriculture can be explained as the ability to produce goods (biomass and/or materials) and food (cereals, fruits and vegetables) in a cost-effective way, environmentally friendly and socially respectful of farmers and community quality of life. Sustainable production patterns must be able to provide satisfactory crop quality and yield, defend the environment and at the same time do not negatively affect farm economic return (Pannell and Glenn, 2000, Osinski et al., 2003, and Lien et al., 2006).

The instruments available to date to move from a conventional to a sustainable agriculture range from (Bockstaller et al 2009):

- new methodologies, such as innovative agriculture practices;
- the use of Information and Communication Technology;

- the availability of a new generation of pesticides;
- new approaches that could be included in the Integrated Farm/Crop/Pest Management;
- the organic and biodynamic farming systems.

With the introduction of sustainability in agriculture (and not only) the urgent need to provide tools for its evaluation arose (Girardin et al. 2000). The authors highlighted that these tools should be able to characterize the effects of cropping systems on human health and ecosystem, but at the same time should be tailored to users, user friendly and scientifically oriented. Since 2001 an European Directive (Directive 42/2001/CE) is fostering the implementation of widely shared methods in order to reduce human environmental impacts. The Directive provides for the implementation of a procedural tool called Strategic Environmental Assessment (SEA), namely a structured decision support framework aiming to support more effective decision-making for sustainable development (Loiseau et al., 2012). Later, also Bockstaller et al. (2009) highlighted that the availability of operational assessment tools is a prerequisite for judging if farming and cropping systems are efficient and modern and for achieving a better management of environmental risks. From a more agro-ecological point of view, Zaks and Kucharik in the 2011 noted as the gaps of currently tools for more ecologically sound agro-ecosystems remain to be solved yet. The quality of data, availability of them, integration between models, data integration, farmers acceptance, social barriers, dissemination are the main drawbacks for the implementation of decision support system for the agro-ecological technology transferring.

As soon understood, the keystone for the success of sustainability principles is the awareness that sustainable agriculture should never ignore the economic aspects (Tisdell, 1996, Bräuer, 2003, and Archer et al., 2007). The returns of agricultural production are likely to decline because of higher costs due to environmental actions. Thus, it will be very important to assess the cost of application of sustainability measures, evaluating their impact on the farmer's economic balance. Indeed, there is a high risk that the environmental commitment will cause a financial burden that will not be sufficiently covered by production and community supports (these are expected to decline by 15-20% in Italy compared to the Common Agriculture Policy of 2007-2013). Consequently, it is clear that the economic aspects of sustainability will play a major role in the future as precondition for the achievement of environmental goals. As suggested by Burja (2012) the environmental costs (emission to air, price per unit for GHG emissions, recycled waste, destruction of natural habitats, etc.) are elements that strongly influence farm profit size. The introduction of environmental management strategies requires the development of a financial accounting system to report economical sustainable performance. Economic efficiency and earth preserving must go in the same direction and the sustainability financial reporting promoted by Burja (2012) is an option to mark out, in monetary term, the impacts of environmental costs on farm profit. However, the difficulty to gather information in monetary term about these costs is calling to question their consideration into firm financial accounting.

If in the agricultural sector the success of environmental strategies is closely related to economic constraints fulfillment, in the commercial and industrial sectors however the success of production and consumption patterns is related to a change from existing unsustainable environmental pattern toward a less pressures on environmental limits (Alonso et al., 2013). Both agriculture and industrial sectors are called for a new global development strategy where environment protection is seen as an opportunity, not a threat.

On the other hand, the increasing request by consumer to improve the quality of food and environment is directing the human efforts towards environmental issues. This is leading to a renewed perspective in agriculture, from a maximization of crop production to a higher respect of human and environmental health. Consequently, food production systems are changing their goals and managing strategies, in order to reply to consumers' necessities. Therefore, the new food producers' challenge is to balance natural resources use, to preserve landscape, to reduce pesticide impact, to improve environmental biodiversity protection and, simultaneously, to guarantee abundant and healthy yields. Reaching this high level of sustainable food production requires time, knowledge and expert assistance. The awareness that also the primary sector must contribute to decrease the environmental degradation and resources depletion is leading to new environmental-oriented agriculture solutions, as later argued. This tendency should, actually, be a reference point for all human activities, not only for the agriculture sector. Fortunately, the shift to sustainable production patterns has already begun. The increasing demand for resources' protection is leading to new effective polities and initiatives implemented worldwide. As proof of this, the Global Outlook on Sustainable Consumption and Production (SCP) identified many case studies (patterns and polities) addressed toward the green growth strategy and the reduction of resources depletion (UNEP, 2012).

Although sustainability features and goals are rather intuitive for public opinion, the way how to measure it is still unfamiliar to most people. Often sustainability is a messy list of thoughts that we attempt to reorganize through indicators, measuring and monitoring issues and phenomena. Sustainability should be seen through a holistic perspective, i.e. the current and future goals of the whole system should be taken into consideration, and its evaluation should be considered as a dynamic process. Since sustainability is more than a "thing" to be measured, rather than asking us how we can measure sustainability, it may be more appropriate to ask us how we measure up to sustainability (Fricker, 1998). Paradoxically, it is easier to measure un-sustainability than sustainability and this kind of measurement is performed unconsciously much more frequently than we might think. Smith and McDonald (1998) highlighted that indicators of un-sustainability are more available and measurable than indicators of sustainability. Moreover, with unsustainable impact indicators, cause and effect relationships are usually more well-known and indicators of un-sustainability are more able to detect the shortages of management practices. The assessment of un-sustainability, as the assessment of sustainability, needs several indicators in order to consider all potentially unstable aspects of the system (Smyth and Dumanski, 1993).

1.2 Current legislation on sustainability

In Europe, the development of a more sustainable agriculture is regulated by a comprehensive legislation framework. The main documents are: the Regulation concerning the placing of plant protection products on the market (Regulation 1107/2009/EC), the Directive about the machinery for pesticide application (Directive 127/2009/EC), the Regulation concerning statistics on pesticides (Regulation 1185/2009/EC), the Directive for community action in the field of water policy (Directive 60/2000/CE), the Nitrates Directive (Directive 676/1991/EC) and the Directive establishing a framework for Community action to achieve the sustainable use of pesticides (Directive 128/2009/EC).

The latter requires, among other things, the development of tools and strategies for risk mitigation and the identification of indicators for the assessment of human and environmental risk, associated with the use of Plant Protection Products (PPPs), and the evaluation of the level of sustainability achieved by the farms. This can be obtained only with an appropriate legislation for sustainable agriculture specific for each European Member State. Each Member State submitted to the European Commission a National Action Plan (NAP), which includes the different sustainability strategies that can be adopted for pesticide risk reduction, taking into consideration local farmers' needs. In other words, the NAP provides a practical pattern of how each European country will implement the principles and the measures of sustainability required by the Directive. The goal of the NAP is the identification and development of suitable strategies for reducing the potential risk caused by the use of PPPs and for the simultaneous monitoring of the results of the actions undertaken to this purpose. Moreover, the NAP should specify the indicators to be used for monitoring the use of PPPs, taking into consideration the social and productive structure of the country. The use of indicators can be performed through the provisions set out in Appendix 3 of the Directive on the sustainable use of PPPs.

Sustainability in agriculture is also one of the main objectives of the Common Agricultural Policy (CAP) "post-2013". A significant share of European funds, from 2014 to 2020, will contribute to improve the sustainability of food production. In particular, the founding bodies of Community Assistance wish to deliver bonus or direct subsidies to farmers who will carry out all measures set to "greening". Regarding these payments a significant share (30% of the expected resources) will be used to defray the costs of environmental and ecological actions undertaken by farmers. Thereby, the delivery of some financial resources to beneficiaries will be made only if they will carry out specific actions in order to reduce environmental risk achieving greater sustainability of productions. The European economic subsidy, for these issues, is therefore gradually moving from an income support to a new form of assistance, that supports the costs of implementation of measures mitigating the environmental farm impact (Comegna and Sacchetto(1), 2014; Comegna and Sacchetto(2), 2014; Frascarelli and Cecci, 2014).

From this point of view, sustainability indicators will become an important “estimator tool” for pursuing the minimum criteria required to gain access to Community supports. Already in the year 2000, the European Commission published a document called "Indicators for the Integration of Environmental Concerns into the Common Agricultural Policy" (European Commission, 2000). In this paper agri-environmental indicators are listed as useful tools for analyzing the positive and negative effects of the European rural policies and to study the relationship between agriculture and environment, in order to find out the future trends of the sector. The environmental indicators are matched with financial and physical indicators, in order to illustrate the progress of the implementation of the EU Rural Development Programs not only from the environmental point of view. All these agri-environmental indicators and measures are used by the European Commission to assess the extent to which Rural Development Policies are promoting ecosystem friendly farming practices and sustainable agriculture at the macro area level.

1.3 Assessment of sustainability through indicators and models

Sustainability can be evaluated not only by indicators, but also by models simulating phenomena. Girardin et al. (2000) highlighted as the choice of variables assessing environmental impacts of farm practises can follow two pathways: the *use of models*, able to simulate the farm system, and the use of *bibliographic analysis* together with *human expertise in order to develop indicators*. The difference between the two paths is that through a model approach the reality is simulated, whereas the indicators attempt to simplify the reality’s complex relationships (Girardin et al. 1999).

Alongside these two methodologies, there is the assessment of environmental impacts by means of direct field measurements. Direct data collection is linked to the model approach, because accurate measured data are often required as model inputs. Nonetheless, the direct data collection depends on the complexity of performing field tests, surveys and samplings, since measurements are frequently costly and time-consuming. Unfortunately, the complexity of interactions between parts of an eco-agro system and the costs of field measurements makes often every attempt vain. Moreover, it is impossible to characterize the whole variability of an eco-agro system by means of direct measurements because they depend, in turn, on other variables and parameters. To overcome these limitations, models usually use estimated data. Indeed, Bockstaller et al. (1997) have highlighted the possibility to use models to simulate field situations and environmental conditions and, therefore, substitute the direct measurements. At the same time, the authors noted that models are not adapted for use at farm level, require too much data and are not validated for several conditions far from the setting of implementation. Nonetheless, in the last decades some scientists developed simulation models to describe the complexity of agro-systems and to study their sustainability (Girardin et al. 1999), even if the low accuracy and high complex input requirements of these models are discouraging their use.The main limit is the lack of accessible data required to describe in an objective way each environmental compartment. The impossibility to include in the evaluation all ecosystem compartments and the physical, chemical and biological processes, decreases the models reliability. Consequently, the use of indicators has been supported, even if sometimes the distinction between indicators, direct measurements and simulation models can be barely detectable, since results of indicators can come from field measurements, calculated indexes or model outputs, as described later on. For this reason, the use of indicators doesn't mean the complete discarding of the other two methodologies (Bockstaller and Girardin, 2003).

Many authors proposed to resort to indicators assessment, as if it were a kind of process of regression toward the hub of the problem by means of a simple method. Indeed some authors and sector experts have judged the use of indicators as the best known and handy method to assess the environmental impact (Girardin et al., 1999 and Pervanchon et al., 2002).

Girardin et al. (1999) proposed a step-by-step technique to develop indicators for the evaluation of sustainability, starting from a method implemented by Mitchell et al. (1995). A seven stages procedure was then prepared:

- definition of objectives (main and specific goals);
- choice of the type of users (policy makers, companies, scientific, general public, etc.), in order to produce clear and attractive indicators;
- development of the indicators;
- determination of thresholds and standard values;
- sensitivity analysis to estimate the most important parameters and variables;
- probabilistic test to assess the accuracy of indicator values with observed variables;
- usefulness (efficacy) test to control whether goals have been reached.

The procedure to assess sustainability based on models**,** instead of indicators, is similar for certain aspects, although not completely. Also in this case, according to the authors, the main steps are seven:

- definition of objectives;
- choice of fundamental hypotheses and identification of main variables;
- construction of equations including parameters and variables;
- verification to check out the quality and the magnitude of the outputs;
- sensitivity test to evaluate the usefulness of variables;

- evaluation that goals are pursued;
- validation of simulated outputs compared with observed ones.

Two main weak points, simplification and subjectivity, often lead to a non-complete acceptance of both sustainability assessment methodologies from experts or scientists. The use of indicators attempts, for definition, to simplify agri-ecosystem reality and, for this reason, its acceptance is not complete. However, Girardin et al. (1999) points out as also the model approach is based on aggregate and simplified data processing and, usually, on levels of information with lower accuracy than an hypothetical situation with a complete and exhaustive characterization of an ecosystem.

Regarding subjectivity, the opinion of scientific community is less restrictive and negative than the aptitude to simplify. This happens because often there are not viable alternatives and subjectivity is used during the use of models as well as indicators. The subjectivity in the model approach is used for example for the definition of the level of acceptability of the model itself and for the criteria to evaluate its quality. Also the decision of the model developer to accept or to reject the model according to objectives is subjective and as a consequence also the validation of a model, usually based on observed data instead of users judgments (typical of indicator methodology), is only seemingly objective. Also in the use of indicators subjectivity is present in several phases: the choice of the indicator and the variables used for its calculation, the identification of the reference values, and the results management. Outcomes are usually managed for building synthetic indicators, such as weighted and ranked scores or indicators based on multi-criteria methods. The scale of outputs' representation and the use of scores are again often subjective, because these choices rely on practical considerations. Despite the subjectivity weakness, the easy communication of the outcomes is the indicators' strength. This fosters their usage, even though they are subjected to scientific discussions and not always their selection lies on explicit and transparent choices (Andreoli et al., 1999 and Bockstaller et al., 2008). It is the consensus which develops around the formulation of an indicator, that gives to the indicator itself its scientific value. Only a rigorous procedure of its formulation allows an expert consensus achievement. Furthermore, to increase consensus the scientific bases of an indicator must be guaranteed by thresholds and norms used like landmarks by evaluators to make judgments (Girardin et al., 1999).

In the future, when all direct environmental measurements will be technically and financially possible, the application of models should substitute the use of indicators to simulate the functioning of a system. Nevertheless, the use of composite indicators will be still necessary to help end-users to understand the state of the system and to synthesize information for decision-making by user-friendly outputs (Girardin et al., 1999). The diatribe concerning which one is the best method for sustainability assessment is still open. The choice can be oriented towards models when detailed information is available or towards indicators when an objective data collection is not affordable. Bockstaller et al. (2008) proposed the possibility to use both methods at the same time: the combined use of models and indicators increases the quality of judgment because in this way the assessment relies on measured, objective, and model-based indicators at the same time. With this hybrid situation, indicators can be derived by a model output or, from more complex models, by matrix of simulations. Some model simulations can be used to descend an indicator of impact: for example MACRO (Brown et al., 2003), a decision support tool about groundwater fate and mobility of pesticides in the soils, assesses pesticides contamination and the outputs of several simulations were collected into a matrix (table), which was then used for the implementation of indicators of impact.

1.4 Sustainability indicators

One of the most famous and complete definition of an indicator is: something that helps you understand where you are, which way you are going and how far you are from where you want to be. A good indicator alerts you to a problem before it gets too bad and helps you recognize what needs to be done to fix the problem (Sustainable measures, 2013). Since the 80s, different authors tried to define what the use of indicators means. For Germes (1981) the use of indicators is a priority pathway, both modest and flexible, pragmatic, but based on scientific knowledge, to shed light on and control an action. Ten years later, Kuik and Verbruggen (1991) specified that an indicator is a compromise between scientific results and the need for concise information, while Adriaanse (1993) pointed out the fact that indicators allow to better understand those situations where it is not easy, or impossible, to make direct evaluations. Mitchell and collaborators before (1995), and Fisher later (1998), showed how indicators are able to transmit information concerning complex systems so as to make them more comprehensible and, therefore, they relay a complex message in a simplified manner. From these comments it comes out how an approach based on indicators can be considered as a method to clarify an intricate system into an easier entity, studying it through a scientific procedure.

Indicators for sustainability are different from all other indicators normally used for other sector studies because of the holistic approach of sustainability and the strong interconnection of its three pillars. The indicators used for sustainability characterization have to operate synchronized: not only indicators of the same category, but also indicators belonging to other pillars should have a strong relationship. The use of indicator is an analytical approach to describe a system as a whole: it has to be seen as a holistic methodology that deals with several environmental compartments and several environmental issues at the same time.

From farmers' point of view, indicators are instruments that foresee the future risks and aim at assessing the potential negative effect of the agricultural practices performed. With the use of indicators it is also possible to follow the progress achieved over time by the new actions performed to alleviate the negative effects of what has been done before (Halberg, 1999, Lenz et al., 2000, van der Werf and Petit, 2002). Their aim is to help farmers to improve their crop management for reaching sustainable goals and to simplify complex phenomena and systems into a simple quantitative and qualitative procedure improving the ability to assess human impacts (Girardin et al., 2000). It means that indicators for farmers must be, first of all, decision aid tools or decision supports. Once actions has been taken, indicators help to quantify their beneficial effects and to estimate the degree of reaching of objectives that have been fixed by implementer, as described before for the agri-environmental indicators used at Community Agriculture Policy level (Girardin et al., 1999).

Many people, companies, non-profits, universities, government agencies and policy makers have tried to assess the impact of food production through indicators of sustainability. In order to explain the big increase of methods based on indicators assessing the sustainability of agricultural system Bockstaller et al. (2009), recovering a citation of Riley (2001), defined this phenomenon as **"***indicators explosion***"**. This explosion proves as from the '90s the use of indicators has been considered a valid alternative to other methodologies, such as fate simulation models and field impact measurements, as before extensively argued.

The best approach to use indicators for agriculture issues can be described by a flow chart. Figure 1 shows a design-assessment-adjustment cycle for the definition of sustainable management strategies and their evaluation through indicators. An always higher level of sustainability and eco-compatibility between farmers and environment needs is searched by means of a never-ending process.

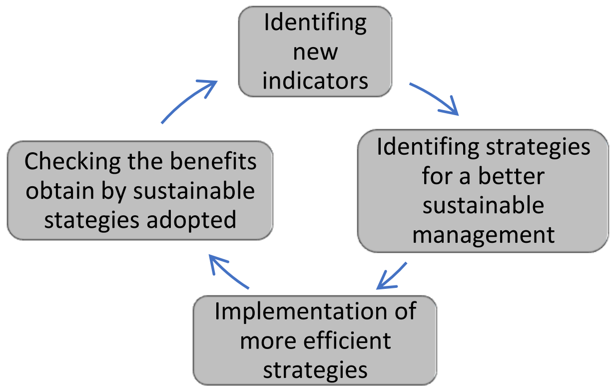


Figure 1: Design-assessment-adjustment cycle for the definition of sustainable management strategies and their evaluation by means of indicators.

1.4.1 Characteristics of indicators

An indicator is defined efficient when it is: i) able to describe the behavior of a phenomenon in time and space, ii) relevant, easy to understand, reliable, concise, and iii) based on accessible data.

An indicator is relevant when it is suitable to the purpose of measuring, i.e. it answers to an objective; it is easy to understand when also common people can easily know how it works and the meaning of its results. When an indicator provides accurate data and estimates what developer want to calculate, it is defined as reliable. Furthermore, for a realistic, objective, and feasible sustainability assessment, indicators should be limited in number, simple, understandable, easy to interpret, and unambiguous in order to make them useful and manageable.
Last but not least, an indicator should be based on accessible input data. In fact, the possibility to gather information is often one of the main limits and frequently the data inaccessibility compromises the identification of the best indicator. Nonetheless, it often happens that the best indicators are those for which there is no data, while the indicators for which data are available are the least able to measure sustainability. Therefore, if at the beginning of the use of a particular indicator implementers find out that this is not immediately measurable, they don't have to reject it but they have to try to develop or find better data sources (Sustainable measures, 2013).
Indicators should also be scientifically justified, flexible (i.e., can change through time), appropriate and meaningful, linked with economy and society aspects, useful to achieve in any situation community's goals, and robust enough to catch the behaviour of a phenomenon nowadays and in the future (Rossi et al., 2010).

Indicators can be classified as *qualitative* or *quantitative* indicators. *Qualitative* indicators are preferred by communities (e.g. consumers and non-expert policy makers), are generally based on subjective analysis and, therefore, sometimes are not directly measurable. Nonetheless, they are useful for sustainability assessments because they don't exclude its intangible and irrational features and allow to show some important aspects of sustainability that other indicators would not be able to describe. On the other hand, *quantitative* indicators are derived by actions or phenomena easily traceable to a number (such as percentages or values with or without units of measurement) and therefore allow to perform a more objective analysis. This kind of indicators is usually more used by experts (e.g. scientists).
An indicator can be a *single variable***,** such as the amount of water used for irrigation, or a *composite indicator***,** also called index, such as the assessment of environmental impacts of pesticides. A composite indicator is typically based on several criteria and sub-indicators with complex relationships (Girardin et al., 1999). Generally, indicators on potential risk of chemicals or crop practices are composite indicators based on intermediate data or sub-indicators.
According to their level of complexity, indicators can be distinguished into 3 three main categories, as suggested by Bockstaller et al. (2009):

- The *first group* consists in simple, low quality of prediction or approximate indicators, whose outcomes are single values obtained by surveys, data on farmers' performances, databases and general environmental characteristics. In this group are included indicators not directly measured, or measured in an easy way. They are ratio or efficiency studies based on the estimation of balances (such as nitrogen fertilization, pesticide impacts and energy efficiency indicators), and are frequently used to understand the behaviour of the phenomena without a high detail.

- The *second group* includes indicators with a higher level of complexity that work on several factors at the same time. They are usually indexes based on several parameters and variables. The majority of such indicators work on farm practices, on soil conditions, greenhouse gas emissions, indirect estimation of biodiversity and landscape, erosion assessment, pollution effects of stressors into water compartments etc. Indicators built like mechanistic simulation model are also belonging to this group. In this case, the connection between predicted effects and causes of a phenomena improves the quality of assessment, making the output of indicator more scientific, but the higher quality of assessment implies a higher complexity. Moreover, frequently the results are only predicted values, such as concentrations, rates, etc. derived by a model simulation.
- The *third group* includes indicators focused on direct measurements on the field. All biodiversity indicators based on scouting and counting of species and their density quantification, as well as indicators based on laboratory analysis concerning crop quality, soil fertility, water pollution by nitrate and phosphorous can be categorized in this group. Often they are utilized to replace the use of models when these are not accurate enough, even if they are time-consuming, expensive, and they hardly describe cause-effect relationships. Furthermore, results from measurements are not immediately available to advice farmers on the deficiencies detected.

Due to the high number of different indicators available, the choice of one or the other set of indicators should be a balance of many different needs (Sustainable measures, 2013): the *region*, the *magnitude of the evaluation*, the *native goals* of the appraisal, the *sector* and the *type of results* that evaluators want to obtain. No less important, the choice and construction of an indicator depends also on the *available information*, the social and economic context, the *time* available to search and collect data, the current *state of knowledge*, the orientation to a long or short outlooks and the *needs of the users* (Girardin et al., 1999). For instance, an evaluation of environmental sustainability of a farm in the south of Europe will use different indicators respect to a farm in the north: in the first situation, water indicators have an high relevance due to high risk of dryness, while in the second situation indicators on irrigation appear less important and the attention should be focused more on the low temperature and the higher risk of pesticides persistence.

According to the goal, the impact estimation by means of indicators can follow two ways: the use of indicators to study single aspects, such as the risk of pesticides, the fertilizers loss, the emission of greenhouse gasses, the impact of soil activities, etc., or the use of indexes to study the sustainability as a whole. For example, in European rewarding projects**,** that aim at evaluating farmers' management as whole, indicators are applied to pursue generic goals of sustainability, while indicators for detecting farm specific weak points are not essential. A set of different indicators should be also used when a sustainability self-certification is performed in contrast to a classic third party evaluation. The self-assessment is generally performed using questions with a yes/no answers, i.e. the primary aim is to make a photography of the farm context without the attempt to increase the sustainability, while when the evaluation is performed by a third party the increasing of sustainability is known to be the main goal.

The choice of the use of an indicator or the other should match up with the goal one want to achieve and should also be connected with realistic thresholds and/or target values that developers and users are going to achieve. Results are then compared with reference values to judge the quality of the indicator's outcome. This last aspect is significant because an indicator is informative only if it is related to a reference. The identification of right thresholds and the study of the indicator's deviation from them allow the indicator to functions as a diagnostic tool (Girardin et al., 1999). Therefore, setting a reference value has the same importance that the indicator development itself, and both, reference values and indicators, can be subjected to criticisms. Especially for indicators on environmental impacts, it is often not clear what type of reference values must be used to compare results. The lacking of scientific relevance in the reference values choice may raise to a rejection of the indicator by the scientific community (Oenema et al., 2005; Bockstaller et al., 2008). Typically, the low reliability of reference values arises when these are established by stakeholders and not by scientists and sector experts. To increase the trustworthiness, the choice of thresholds might follow one or more of these advices: being in accord with norms, referring to previous studies, knowing limit of measurement, considering number zero as optimum for performance indicators, regional standards or thresholds compared to previous year values. Sometimes, the ability of indicators to describe a specific phenomenon is assessed using the values of the indicators obtained by the first survey as initial values; this is a procedure not sufficiently accepted by expert opinion. Equally frequent is the use of average values obtained by a rough study of the system; these can lead to a comparison between two values, allowing to say whether a value is better of another, but not to affirm that a value describes a less impacting situation than another (Bockstaller et al., 2008).

Moreover, according to goal, the monitoring of actions for a long period could be more important than studies relating to short term. In fact, a long-lasting perspective enables to study the past and the present to understand the future trends, to study the development of negative impacts over time and, consequently, to implement procedures able to provide a long period judgment of impacts. In such a way indicators work as warning tools for the future (Sadok et al., 2007). In other words, indicators can be used not only before new environmentally friendly actions are implemented (upstream steps) but also at the end of a meandering route of sustainability (downstream steps). The first situation is a prospective evaluation whereas the second is a retrospective evaluation**,** since historical data are used to build indicators which capture past trend (Girardin et al., 1999). Evaluating sustainability over the time with indicators can be used as gauge to monitor positive movements as well as negative ones, can enable to alert if environmental impacts exceed a threshold or give information on impacts before they occur (Bockstaller and Girardin, 2003, Reus et al., 1999).

Some other more specific aspects have to be considered when choosing an indicator: it has to i) answer to environmental needs, ii) give clear and understandable results, iii) be users-friendly.

The importance of the definition of the end-users of a particular indicator has been highlighted by several authors (Mitchell et al. 1995, Girardin et al., 1999, Yli-Viikari et al., 2007). If an indicator is tailored to specialist, such as agronomists, farmers, technicians and advisors, the complexity of information given can be elevated; while if the indicator is meant to policy-makers or consumers it should be more intuitive and easy to understand. In fact, since the users' requirements are so different, it is unlikely that an indicator can be simultaneously efficient for different type of stakeholders. Moreover, it often happens that people doing the assessment through indicators and people using the outcomes of it are often different (Bockstaller et al., 2009). Not only the type of information, but also graphical representation of the outcomes has to be tailored to the end-users: for scientists the most important issues is to find indicators and their quantification methods, for people responsible for communication of results, the most important issue is to find a way to aggregate them for a best communication to stakeholders. Hence, for public, consumer and not expert people (community) the simplification is even more essential than other indicators choice criteria.

Finally, according to Piorr (2003), for agriculture evaluation plans, the indicators choice depends also on their ability to fulfill specific requirements:

- *inform about status and development of complex systems;*
- *provide sufficient information about sustainability of land use systems;*
- *be responsive to changes related to human activities to indicate rapidly success and failure of activities;*
- *able to show trends over time;*
- *work as umbrella indicators summarizing different processes and/or environmental impacts.*

1.4.2 Methods to evaluate sustainability through indicators

The philosophical conceptualization of the use of indicators to assess farms impacts must be adapted to a logical and handy framework for their use in a sustainability step-by-step proceeding.

Several methods have been implemented to study sustainability through indicators. An attempt to categorize the most common methods has been made by Sustainable measures, (2013). Four main categories have been described: i) list of indicators, ii) goal-indicator matrix, iii) driving force - state - response, and iv) comparison of the same indicator used in different times.

Probably the most famous and used method is based on a mere *list of indicators*. This method is rather intuitive and, therefore, easily understood by people with different backgrounds. The list can be more or less elaborated and set up in different ways, considering the goals, experts consultations, specific needs, basic intuitions or, as suggest by Hess et al. (1999), using a Delphi technique. The Delphi technique is an interactive forecasting method, which relies on a panel of experts that answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round and the experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. It is believed that during this process the range of the answers will decrease and the group will converge towards the "correct" answer.

The method of the *goal-indicator matrix* is focused on the relationship between indicators and goals of the assessment. For each evaluation process the usefulness of an indicator is tested according to its ability to answer to a purpose.

The method *Driving force - state - response* or *Driving force - pressure - state - impact - response* was proposed by the Organization for Economic Co-operation and Development (OECD) to help understanding the logical flow of the actors and forces involved in the negative impact occurring. Human activities and natural conditions (driving forces) exert pressure on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems and materials, which may elicit a societal or government response. Therefore, this method is useful to study, through a cause-effect approach, the relationships between human actions and environmental effects (OECD, 1994 and Benini et al., 2010).

The last cited method is based on a comparison of the same indicator calculated at different times (e.g. now and in the future). It is based on the study of what is happening to understand indicators evolution over the time and to understand how human activities and their effects will change in time. This method enables a long-term sustainability assessment.

1.4.3 Problems related to the use of indicators and sustainability evaluation

Problems and hurdles that might occur during environmental sustainability estimation are countless: one of the most important is how future human needs will get along with the wish to increase the respect of environment.

During the process of quantification of impacts, implementers try to put aside human needs and priorities, focusing only on earth's resources preservation. In this way the sustainability makes an effort to preserve ecological integrity through a displacement from human to environmental issues. But unconsciously human interests are hardly ever shelved and it often happens that an evaluation of sustainability turns into a proof that actual agriculture features are already environment friendly. In this context, the use of indicators can lead to wrong evaluations since they might be used to justify our current actions rather than improve them. Implementers should, therefore, consider the risk that the positive human activities are highlighted, while weaknesses and vulnerabilities remain unknown. This risk occurs mainly when it is proved that current agricultural patterns and strategies are already to some extent sustainable: people and farmers will keep those patterns of development and crops productions. Sustainability concept should help people to look ahead and not considering only the positive aspects of the present (Fricker, 1998).

Different issues arose in the sustainability evaluation in the last decades: the comparison of results, the compensation between negative and positive outcomes, the research of ready to use indicators and the tendency to merge multiple indicator into an overall composite indicator, are some of the most important items to consider for improving the quality of assessment. Only if these set of problems are accounted, developers will increase the scientific nature of the evaluation.

Literature regarding comparison of impacts of human activities on environment calculated through indicators is quite poor, however, the work of Bockstaller and colleagues (2009) includes a comprehensive comparison between methods used to assess sustainability for farm (Eckert et al., 2000; van der Werf and Petit, 2002; Meyer-Aurich, 2005) and cropping system (Bockstaller et al., 1997; López-Ridaura et al., 2005). In particular, Bockstaller et al. (2009) report four cases where different indicators and processing methods used to assess impacts on the environment were compared.

The first is a case study for the comparison of nitrogen losses indicators, especially nitrate leaching at farm and regional level. Feasibility, agronomic relevance, time of interpretation, threshold values and spatial scale were used as evaluation criteria to assess and compare 23 indicators (CORPEN, 2006).

The second explains a comparison of 43 pesticide risk indicators in order to find the best indicators according to the French Ministry goals and policies. A list of 25 criteria were used to study mainly: indicators characteristics, end-users, method feasibility, relevance, readability, reproducibility, the list of parameters and variables used, the spatial scale and the environmental compartments taken into account (Devillers et al., 2005).

Another comparison of five methods to assess sustainability was performed by a French regional organization called Agro-Transfert. The comparison aims at finding the best adapted tools to characterize the environmental impacts of agriculture in France. In one of them, called IDEA (Indicateur de Durabilité des Exploitations Agricoles), also social and economic indicators were included in the quantification of impacts. Also for the comparison of these five methods a set of criteria were selected to evaluate their efficiency (Galan et al., 2007).

Lastly the COMETE project compares four farm management tools upper Rhine plain on 13 farms by means of a list of scientific soundness, feasibility and utility criteria (Bockstaller et al., 2006).

Nonetheless, Bockstaller et al. (2009) highlighted also as the tentative of all the previous authors to categorize approaches used has been vain, at least partially, owing to the great variability of the methodologies. Only evaluation criteria (i.e. feasibility, relevance, utility, etc.), the scale of evaluation (i.e. qualitative, semi-quantitative or quantitative), how appraisal has been performed, and the use or not of tables can be efficiently compared.

Comparison on criteria and approaches used by developers should lead to a contemporary comparison of strengths and drawbacks up to the comparison of final results.

Moreover, comparison between indicators of different studies is difficult because, although they may seem similar they could not have the same *unit of measurement*, *boundaries* and *calculation methods*. There is, therefore, the urgent necessity to plan comparative analysis and validation procedure to test the quality of the available sustainability assessment through indicators (Bockstaller et al., 2008 and Meynard et al., 2002). To overcome the problem of comparison, aggregate indicators were developed by the aggregation of simpler indicators. Nevertheless, though often necessary, this strategy showed to be too simplistic and risky. Moreover, the use of aggregate indicators could be useless when the method of evaluation is based on a *compensation approach*. In fact, when an indicator describes a high negative impact on an environmental aspect and another is, instead, markedly positive this last one is not able to compensate the first indicator, because the environment is an interrelationship system where, if a compartment is polluted and another is cleaned, the outcome is not a middle pollution. Therefore, compensation is not acceptable for sustainability issues because when a threshold is exceeded for one parameter, the sustainability is put in question even if all other environmental parameters describe limited or nil impacts.

Another shortcoming concerning the use of indicators relies on the difficulty to provide a complete set of “ready to use” indicators for all possible setting. Some international organisations (for example the Sustainability Assessment of Food and Agriculture system (SAFA) or Cool Farm Tool of Food and Agriculture organization of the United Nations (FAO)) are attempting to build indicators and standard procedures that give a quick route to calculate food production sustainability. Approximate standards can be seen as a progress toward the construction of a ready to use list of indicators. It is nearly impossible to develop a suited framework for all possible scenarios because the purposes of impact characterization are unlimited. As a consequence, the concept of sustainability is too complex and multifaceted, with an intrinsic subjectivity that does not make it feasible (IN-STREAM, 2011).

Until now, the attempt to develop one complete list of all-embracing indicators is failed. An alternative could lead to build an overall indicator characterizing the sustainability as a whole (Girardin et al., 2000), but different authors do not agree. According to Tisdell (1996) the process of building a single indicator, does not allow to consider all problems and to characterize the holistic nature of the topic. The effort to sum up several indicators in a single indicator could be too risky and simplistic, sure enough useful for data dissemination (Nardo et al., 2005, Jollands, 2006).

Another issue under expert discussion is the chance of using indicators not only to have a look on sustainability performance, but also to exploit their outcomes in order to undertake purposeful actions and decisions to increase sustainability itself. All around the world, multinational companies use sustainability evaluations as parameters to influence their choice towards suppliers and to prove their green commitment to consumers. However, the use of indicators to distinguish food producers could be too hazardous because the goal of indicators is to address critical issues rather than obtain a trustworthy and objective screening of numerical value or score. A correct use of indicators could be found in the words of Sustainable measures (2013): "*indicators are just vague clues for measuring progress, to create a shared vision of what society should be, to understand the right route to solve a problem or inefficiency and to monitor how the farm ecosystem is working".* As a consequence, the use of indicators to influence economic strategies could be risky and might entail injustices and unjustified discrimination.

The two protocols called *Sustainable Agriculture Initiative* (SAI Platform, 2014) standards and *Sustainability Assessment of food and Agriculture Systems* (SAFA, 2014) are two examples of certification tools that have been recently developed for the food sector. SAI standards is the result of a study performed by Sustainable Agriculture Initiative (SAI) Platform, whereas SAFA guidelines were provided by Food Agriculture Organization (FAO).

Both are excel tools under construction, generic checklists, frameworks based on list of objectives and have been designed by authors as subjective questions with yes/no answers. The list can be used by food chain stakeholders to check compliance with protocol standards. The questions change according to farming target group, purpose and level of detail. They are a standard, a certification scheme, which each enterprise can adhere to.

These protocols are food sector oriented and are addressed to upstream and/or downstream companies, included in the same chain. They aim at the implementation of a *step-by-step methodology* to help enterprises to account their impact from an environmental, social and economic point of view. Nevertheless, they also aim at foster food multinational corporations to account the environmental, social and economic impacts of their suppliers, such as a single primary sector farm. In other words, they are a compliance check concerning sustainability issues. The certification of a company, performed according to these protocols, will guarantee an higher transparency towards the consumers, but, on the other side, the approximations and the great subjectivity of the methodologies could imply unjustified discrimination between evaluated farms. Building a single standard protocol to assess sustainability for all type of farmers in the world, including any type of food chain, won't ever be a correct way to chase the real sustainability purpose.

1.4.4 Sensitivity and validation of sustainability evaluation

The judgment of variables and parameters relevance during the evaluation process, as well as the validation of the assessment procedure are the main steps to assess sustainability through both indicators and models. The *relevance judgment* and the *validation* are usually performed through sensitivity analysis, usefulness tests and collection of end-users judgments. Bockstaller and Girardin (2003) defined, following the Oxford Dictionary definition, an indicator is validated if it is "well founded", it "achieves the overall objectives" and it "produces the intended effect to assure its credibility".

Especially when an indicator is a melting of different variables and parameters (a composite indicator and hence an index) it should be tested to analyze whether its outcomes are sensitive to the input variables**.** With other words, a *sensitivity analysis* is recommended to increase the scientific quality of indicators and to focus only on inputs really influencing the outcomes. To find the affecting and strong variables and to discriminate them from minor affecting variables, it is useful to test an indicator in different settings and environmental situations (Bockstaller et al., 2008).

The validation, on the other hand, explains the indicators ability to fulfill the goals of the assessment. According to Bockstaller and Girardin (2003), *"an indicator will be validated if it is scientifically designed, if the information it supplies is relevant, if it is useful and used by the end users"*. The most used and simple method to validate indicators or models is to compare predicted values with observed or measured data. It enables to evaluate the accuracy of the method applied, as well as, to carry out a sufficiently accurate validation of all environmental indicators, even if they are very simple.

Notwithstanding its high importance, validation is hardly ever performed by developers of indicators. Bockstaller and Girardin (2003) highlighted as the scientific validation is mentioned by different authors, such as Mitchell et al. (1995), Crabtree and Brouwer (1999), Smith et al. (2000) and Vos et al. (2000), but without proposing a methodology to perform it. Moreover, the lack of competition between various sets of indicators discourages developers to dedicate time to validate them and the long term acceptance of indicators used in the evaluation is often considered sufficient to vouch for their soundness and credibility (Bockstaller and Girardin 2003). Besides, as noted by Bockstaller et al. (2008) and Rigby et al. (2001), the validation is difficult for simplified indicators.

To stop this trend Bockstaller and Girardin (2003) have proposed a new validation procedure based on a three steps methodological framework. The first step, called "designed validation" or "conceptual validation" (Mitchell and Sheehy, 1997), evaluates if the indicator is scientifically founded by submitting it to a panel of expert and for this reason Bockstaller and Girardin (2003) re-called this step "global expert evaluation". The second step consists in the comparison of outputs with other similar models or indicators: if a simulation model is used its evaluation through experimental data is already a validation, while if simpler indicators are used, a dedicated probabilistic test has been proposed by the two authors. The probabilistic test assesses the performance and precision of the indicator by comparing predicted value with observed ones ("output validation") in order to assess the soundness of indicator outputs. A subsequent evaluation of their differences acceptability is then performed by end-users to find out the utilization weaknesses ("end use validation"). This last step is similar to the "usefulness test" proposed by Girardin et al. (1999) and it guarantees that users understand indicators significance and realise indicators role in the environmental impacts processing.

Validation of composite indicators is a bit more complicated: a single validation for each different indicator component or module should be theoretically done. Nonetheless, an approximation is needed when a composite indicator is a mix of variables and parameters of different types. For example, when environmental data coming from simulation models are joined with toxicological and eco-toxicological data, the validation might become complicated. The completely different frame of data makes comparisons of simulated data with direct environmental measured data very hard. Therefore, in many situations environmental data could be solely validated through an estimation of environmental concentration (Bockstaller and Girardin, 2003).

Even if characterized by a more subjective nature**,** the *strictness of the methodology* and the *degree of consensus* by experts are also very important aspects. Only considering implementers, experts and end-users opinions, indicators can be the most powerful vehicle to understand complex system relationships, to find in a short time the best strategies to raise the sustainability of agricultural systems and to find the right actions to increase economic and environmental performances.

To study if indicators are used by and useful for end users, the identification of inconveniences of the impact assessment process is very important. The often high inapplicability of methods should foster the identification of meeting point between the scientific approach, required by the indicator developers, and the feasibility required by end-users. According to Bockstaller and Girardin (2003) different reasons can be the basis of indicator uselessness: a target of great relevance for the user may be missed, some data needed to calculate them are not available or the outputs of the indicator are not understandable or legible. Moreover they noted the importance to collect information from users, such as suggestions for improvement of the method, problems of implementation and misunderstandings, to avoid that indicators remain confined to the office of the developer. For users the main qualities are simplicity, flexibility, legibility and understanding of the usefulness of an indicator.

2 Background and objectives

The increasing awareness of society that agricultural growers contribute to resources depletion and climate change in an irreversible way is fostering the implementation of more environmental-friendly strategies and actions at field scale (Winograd and Farrow, 2010).

Cereal crops are highly cultivated all around the world and their cropping systems are often intensive and seldom represent potential habitats for floral and faunal biodiversity. The maximization of crops' yield and quality is leading to an increase of inputs and the consequent occurrence of negative environmental impacts on ecosystems (Andreoli et al. 1999, Lenz et al. 2000). Consumers, media and public opinion have agreed to interrupt this tendency and divert towards more sustainable cropping systems. Different measures can be adopted to enhance resilience and self-regulating of cereals cultivation, but growers still do not use them widely. One of the reasons for low acceptance of these measures is insufficient evidence of their efficacy from agronomical, environmental and economic point of view.

To answer to these new needs, the UN Conference on Environment and Development in Rio de Janeiro (UNCED, 1992) launched the paradigms for the implementation of sustainability principles (as reported previously in this dissertation). However, if the drawing up of these principles was relatively simple, their implementation is still far from being achieved. Indeed, tools, strategies, methods, and actions to increase sustainability of food production are still not evenly shared by opinion leaders.

A comprehensive comparison of different production choices and actions would be essential in order to provide to the food production sector new ideas, advices and guidelines to answer to consumers' needs (i.e. more countryside eco-functional services, less environmental impacts of food production and, at the same time, a social and economic high performance of cropping systems).

These arguments fostered this PhD study that aims at developing an innovative approach for the cultivation of sustainable durum wheat in Italy. To reach this main objective the work was divided into three steps:

1. selection of the indicators and methodologies that developers can use to assess the environmental sustainability of agricultural production;
2. development of tools for sustainable management of wheat production;
3. evaluation of both indicators and tools by means of field comparisons between actual and innovative (i.e. following the tools) wheat cultivation.

To perform step number three a 4-year project was carried out in collaboration with:

- Horta S.r.l., a spin-off company of the Università Cattolica del Sacro Cuore, based in Piacenza (Italy). The Horta's mission is to increase the value of research by transferring the technological innovation to practical agriculture at national and international level, by developing new cropping strategies, methods and products. The core activity of Horta is the development of Decision Support Systems (DSSs) for sustainable crop production based on new Information and Communication Technologies (ICTs).
- LCE S.r.l., a research and consulting engineering company based in Torino (Italy). LCE works on sustainability by using Life Cycle Assessment (LCA), eco-balance, environmental engineering and management, green marketing, environmental communication and reporting and carbon management (application of the Kyoto Protocol).
- Barilla S.p.A, one of the main food companies in Italy, Barilla is the biggest Italian food player, the most sold worldwide pasta brand, the biggest Italian bakery and the third bakery in Europe.

This project used as background a former study LCE and Barilla performed together that resulted in the Environmental Product Declaration (EPD) of pasta (Barilla, 2014). In this preliminary study Barilla decided to undertake the analysis of different steps of pasta and bakery products chain with a LCA approach, in order to understand, and consequently promote, actions able to decrease emission during durum wheat cultivation and/or industrial processing.

The LCA is an environmental impacts analysis methodology of consecutive and inter-linked stages of a production system: from raw material acquisition to final disposal or as colloquially said "from cradle to grave" (Baldo et al. 2008). Since the year 2000, the LCA has evolved as an important method for improving the environmental performance of food systems (Jungbluth et al., 2000 and Ruini and Marino, 2008) and it is a relevant tool for industries that invest money to improve eco-efficiency of food chain.

The mentioned study performed by LCE evaluated the emissions generated during the durum wheat cultivation, the mill phase, the pasta production phase, the packaging production, the transport, and the cooking by consumers (Figure 2).

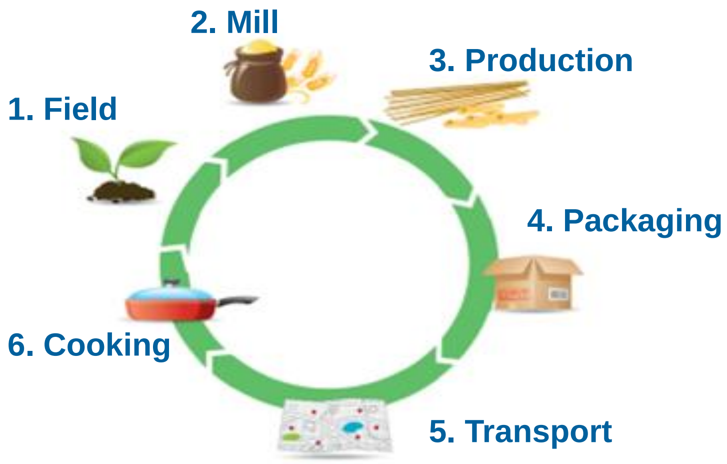


Figure 2: Pasta chain steps. Developed by LCE S.r.l. (Life Cycle Engineering) and available from: http://gryphon.environdec.com/data/files/6/7968/epd217_rev2.1.pdf

The LCA showed that for making 1 kilogram of Barilla "Spaghetti n°5" the higher impacts occur during raw material cultivation and cooking phase (Figure 3). Cooking of the pasta is the most impacting stage, although it depends on consumer habits (the quantity of water used and cooking times). Surprisingly, the less impacting processes are the manufacturing of packaging and the transport (less than 5% each).

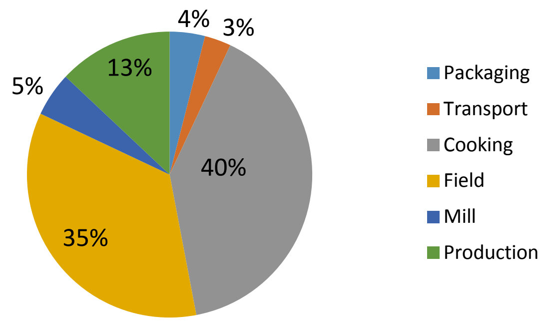


Figure 3: Share of environmental impacts of pasta chain steps. Processing by Barilla S.p.A. and LCE S.r.l.

Three main indicators were considered to evaluate the environmental impacts during the LCA study in order to produce the EPD of pasta: i) ecological footprint (ecological load), ii) carbon footprint (CO_2 emission) and iii) water footprint (water consumption). Considering that the phase of home cooking is not directly manageable by the company, the durum wheat cultivation represents the most impacting phase to focus on for improving the environmental performance of the pasta chain. In particular, cultivation is responsible for 84.5% of the ecological footprint, for 59.7% of the carbon footprint and for 99.6% of the water footprint (Figure 4).

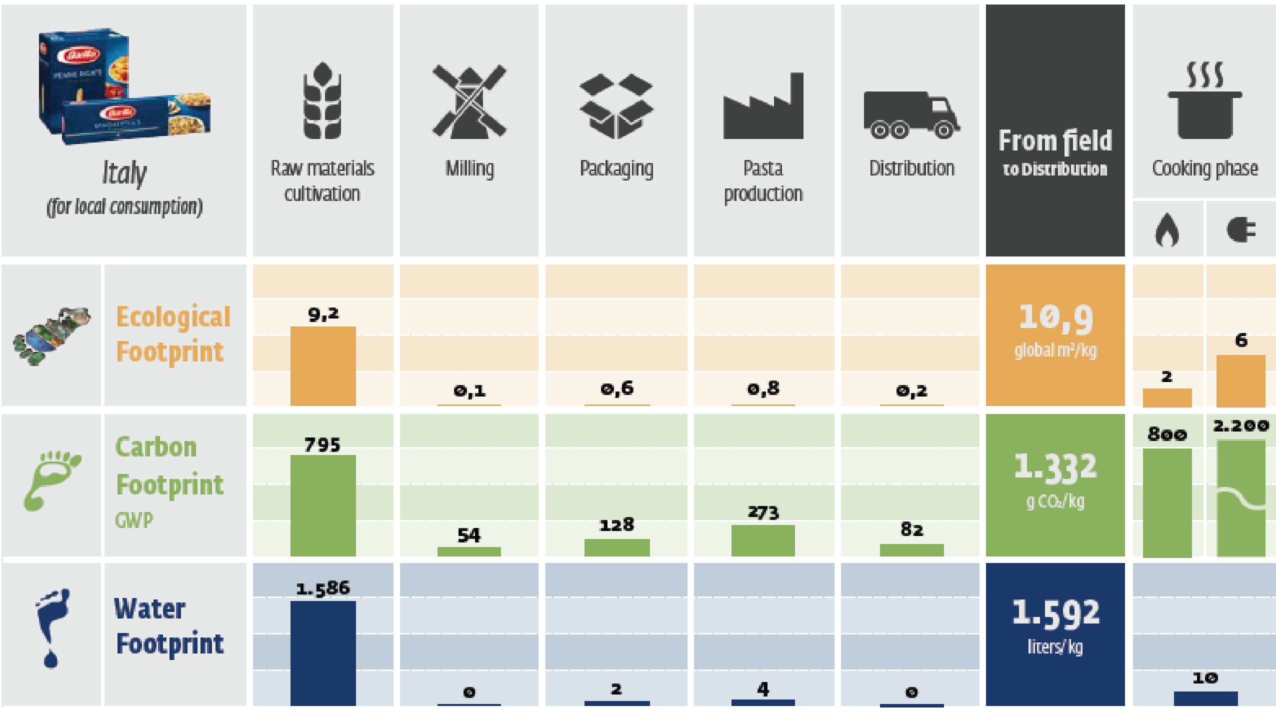


Figure 4: Quantification of environmental impacts of pasta chain steps. It is the EPD (Environmental Product Declaration) of "Durum wheat semolina dried Pasta" of Barilla S.p.A. Processing by LCE S.r.l. (Life Cycle Engineering) and available from: http://gryphon.environdec.com/data/files/6/7968/epd217_rev2.1.pdf

Gan et al. (2011) presented a study on the sources of CO_2 emission during durum wheat cultivation in North America. Omitting the CO_2 lost by the crop residue decomposition, the main source of CO_2 emission was the use of fertilizer (Manufacturing N and N fertilizer emissions in Figure 5) and other chemicals, such as pesticides (Manufacturing other in Figure 5), to which is connected the fuel used for the distribution machines. Therefore, the choice of different crop management systems may highly influence the environmental impacts of crop production.

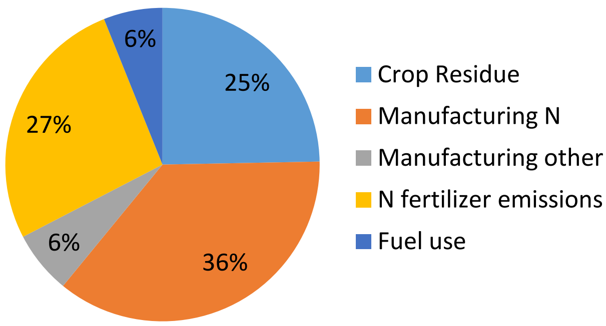


Figure 5: Adapted from Gan et al. (2011). The main sources of emission during durum wheat cultivation.

This project was designed following the strategy proposed by Von Wirén-Lehr, (2001).

- *Identification of the purpose and state of art*. The purpose of the project was to evaluate tools able to increase the sustainability of durum wheat cultivation. In the years 2009/2010 and 2010/2011, a study was carried out to: i) identify the main cropping systems used in Italy for durum wheat cultivation, and ii) use the expert's knowledge to develop new, alternative systems able to potentially increase the environmental performance under specific conditions.

- *Choice of indicators and their characterization*. The following indicators were selected for the evaluation of impacts of the different crop management strategies: Carbon footprint, Water footprint, Ecological footprint, Net Income, Agronomic NUE, Carbon sequestration and DON index. The evaluation was therefore based on eco-balancing and production-oriented indicators.

- *Assessment of sustainability following a strategy based on normative, goals, users thresholds and tolerance values*. Field trials were arranged in the cropping seasons 2011/2012 and 2012/2013 to compare the farmer's usual crop management and the innovative management based on: i) strategic advices provided by a 10-rules handbook for the sustainable cultivation of high quality durum wheat in Italy; and ii) tactic advices of the Decision Support System (DSS) *granoduro.net®*. Comparison of these two crop management practices was evaluated using the above mentioned indicators.

- *Identification and implementation of strategies and tools for the supply of management advices*: by integrating the use of *granoduro.net®* and the *"Handbook for sustainable cultivation of quality durum wheat in Italy"* a new "wheat fine-tuned tool" was implemented to help growers transferring theoretical constructs of sustainability into practice.

The project was goal-oriented (i.e. decreasing impact), means-oriented (i.e. fostering new cropping systems), and single crop and site-specific-oriented (i.e. durum wheat of Italy). This dissertation wants to overtake the main drawbacks of an assessment of agricultural sustainability based on goal-oriented concepts (Von Wirén-Lehr, 2001):

- *"the lack of systemic and transferable indicators which characterise agricultural and other eco-systems regarding all dimensions of sustainability;*

- *the deficit of an adequate evaluation of agro-ecosystems;*

- *the lack of principal guidelines for the formulation of management advices for practical application."*

3 Results and discussion

3.1 Selection of sustainability indicators for the environmental assessment of agricultural crops

After a comprehensive study of literature about sustainability indicators, the indicators described below were selected as the ones more suitable for the quantification of the sustainability of specific durum wheat cropping systems and not for the estimation of farm sustainability as a whole (farm management). The majority of indicators selected concern environmental impact, only a few social and economic indicators has been taken into account. Therefore, economic viability, social respect and acceptability, as well as all other aspects regarding quality of production are considered only marginally.

The most important indicators selected is called "Carbon Footprint (CFP)" (PAS 2050, 2008). It represents the amount of greenhouse gases released directly or indirectly from human activities and it can be expressed in two measurement units: tons of CO_2 equivalent/tons of product (when it is referred to a quantity) or kilograms of CO_2 equivalent/hectare (when it is referred to a surface). In particular, it measures the impact of goods production and all other human activities on climate, taking into account all greenhouse gases, produced by several sources that can modify the balance of carbon dioxide. The main greenhouse gases (GHGs), listed in the Kyoto Protocol, are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and some particulates (United Nations, 1997). Each greenhouse gas can be converted into carbon dioxide (equivalent of CO_2) through a particular conversion factor that was defined by the Intergovernmental Panel on Climate Change (IPCC, 2001). Hence, the CFP indicator is used to estimate the Global Warming Potential (GWP) of each human activity or system. Depending on the system under evaluation, the identification and quantification of emissions will change: for example, in agricultural systems the emissions of manufacturing, farm use and disposal of fuel, fertilizers, and pesticides are mainly taken into consideration. Nitrous oxide (N_2O) emissions come from nitrogen fertilizer use, soil tillage, manure management and peat land cultivation and its greenhouse effect is around 300 times more powerful of Carbon dioxide. Whereas methane (CH_4) comes from the fermentations of the digestive system of livestock, paddy rice cultivation and manure, and sewage management and it is over 20 times more powerful than CO_2. Therefore, strategies and methods reducing emissions of N_2O, CH_4 and CO_2 are increasingly requested, in order to decrease the constant flow of GHGs into the atmosphere (van der Werf and Petit 2002).

The indicator called *"water footprint"* (Hoekstra et al., 2011) was exploited for the water compartment since it measures the water consumption. This index is made up of three components: the "green water", that evaluates the water evapotranspired by plants, the "blue water", that considers the irrigation water or, more generally, the water needed for a manufacturing process, including wash water by industrial consumption, and the "grey water". The last one represents the fresh water needed for the dilution, up to legal thresholds or to a concentration close to natural concentration, of contaminated (waste) water by chemical treatments and fertilization during crop production and industrial processes. The units of measurements used are liters/hectare for "green water", m^3 of water/tons for "blue water", and liters/kg for "grey water". The unit of the overall indicator (*"water footprint"*) is m^3 of water or tons of water depleted per tons of product.

Equally important is the evaluation of resources depletions: an overall estimation can be performed by the indicator *"ecological footprint"* (Kitzes et al. 2008). This indicator is an assessment of the amount of biologically productive land and sea needed to provide resources for human needs, included waste disposal. With other words, it is an estimation of the amount of productive land required to produce tools, materials, goods and energy required to bear and to absorb the wastes generated by human activities. Therefore, the ecological footprint is a measurement of human dependence on land resources. The unit that quantifies the bio-capacity of earth is the global hectare (gha), therefore the ecological footprint is quantified as gha/tons of field product or global m^2/tons of field product. The *"ecological footprint"* estimates outflow and inflow of resources from and to a bordered scenario that could be a country, a city, a farm and even a single farm plot. To calculate the hectares required for resource production and waste disposal the indicator incorporates in the assessment six elements:

1. the land needed to produce energy: it consists of an afforested area required to absorb the emissions from the use of fossil fuels (energy land);
2. the agricultural land for food production (crop land);
3. the grazing land for livestock sector (grazing land);
4. the forest area for wood (forest land);
5. the developed land (built-up);
6. the sea surface dedicated to the growth of resources for fishing (sea land).

For the estimation of durum wheat ecological footprint in particular, only the first two points are meaningful.

Carbon, water and ecological footprint was referred to the environmental management standards belonging to the category ISO 14000. For the first three years of the field validation the footprint indicators were based on already existing LCA databases (Ecoinvent, an international inventory of LCA data), while in the last year property databases were implemented to improve the quality of assessment, making it closer to Italian features.

The agronomic indices *"NUE (Nitrogen Use Efficiency)"* and "*Agronomic NUE"* were selected to quantify how much of the nitrogen applied to a crop is actually adsorbed by plants. This allows the estimation of its potential losses in the environment. For the time being, other more sophisticated indices on nitrogen efficiency such as *"nitrogen uptake efficiency (NUpE)", "NUtE (Nitrogen Utilization Efficiency)"* and *"nitrogen harvest index (NHI)"* (Foulkes et al., 2009 and Rahimizadeh et al.,2010) are not considered.
The *"NUE"* represents the kilograms of grain dry mass at harvest per kilogram of available N (from soil plus fertilizers), while *"Agronomic NUE"* represents the kilograms of grain dry mass at harvest per kilogram of supplied N (from fertilizers). *"NUtE"* represents the kilograms of grain dry mass per kilogram of N of

harvested biomass (above-ground N), and *"NUpE"* represents the kilograms of N into harvested biomass (above-ground N) per kilogram of available N (from soil plus fertilizers), whereas *"NHI"* is the proportion of N into harvest grain (above-ground N). These indices are influenced by the crop, the years of rotation, the kind of fertilizer used, the crop residues management and the weather conditions. The loss of nitrogen fertilizers in the environment is a combined effect of denitrification, volatilization, leaching and run off and it could cause serious environmental problems to fresh and ground water as well as economic drawbacks for high productivity agriculture.
All the indices mentioned above are used to evaluate the efficiency of nitrogenous fertilizers applied during crop production. Knowing this efficacy allows to identify the portion of nitrogen removed by wheat and, consequently, the amount left that leached, runoff, volatilized or stayed into the ground. Once estimated the amount remaining in the soil and the amount volatilized the remaining is leached into underground water bodies or run off by surface water. Moreover, the evaluation of the effectiveness of fertilization can be used as an indirect assessment of drinkable water quality. Finally, NUE allows economic considerations: the use of nitrogen fertilizers in an efficient way (high NUE) involves a decreasing of fertilizers needed for growing, with a subsequent cost savings.
The reduction of carbon dioxide in the air can be performed by removing CO_2 from the atmosphere storing it as carbon molecules or organic matter in soils and standing biomass. To understand to what extend agro-technical measures can promote soil carbon long-term storing, a study of carbon sequestration in durum wheat was included in the field evaluation. Organic Carbon is correlated with many factors of agricultural productivity and sustainability of agri-ecosystems: climate (water and temperature trend), cover vegetation (land use and agronomic practices), topography, crop practices and crop residues quality. Goreau (1990) and later López-Bellido et al. (2010) provide examples of use of Carbon sequestration indicators and debate the possibilities of controlling atmospheric carbon dioxide by balancing the sources and sinks of the gas. López-Bellido et al. 2010 explains the effects of tillage system, crop rotation, and N fertilization on the *"soil organic carbon (SOC)"* storage over 20 years.

"Yield per hectare" (Simon, 1989), *"quality specifications"*, *"net income"* (Chen, 2000) *and "costs"* are some economic indicators that has been monitored in this study to understand how farm practices can influence both qualitative and quantitative productive outcomes.
"Yield per hectare" is the amount of caryopsis as tons/hectare obtained in compliance with Good Agricultural Practices (GAP). In the project the yield is related to specific quality or harvesting parameters. For instance, in cereals, kernels are referred to a moisture of 13%; for tomato the yield refers to a quality of 5° Brix Tomato, while sugar beets refers to 16 degrees of polarization.
The *"risk of mycotoxins (deoxynivalenol contamination)"* is an example "quality specification" that was monitored in the field evaluation. This indicator evaluates the risk of toxic molecules to human health originated by the proliferation of pathogenic fungi *(Fusarium graminearum* and *F. culmorum)*, producers of

secondary metabolites called mycotoxins. The indicator describes in particular the risk of mycotoxin deoxynivalenol (DON) occurring in ears and grain. The development of these fungi and their toxic secondary metabolites depends on meteorological factors and growing, as well as on more specific factors linked to cropping system, such as varietal susceptibility, rotation of crops and tillage of soil. Therefore the amount of mycotoxins changes depending on the choices made by farmers and on seasonal trend during crop season. DON content in wheat for animal and human consumption is limited by law: for unprocessed durum wheat the law limit is 1750 ppb of deoxynivalenol contamination (Reg. CE n. 1881/2006). The *"DON index"* is calculated on a scale 0 to 9, where 0 means no risk and 9 means risk of contamination, i.e. high probability to overcome the law limit (Rossi et al. 2003). The estimation of the presence and quantification of mycotoxins in cereal crops give the social dimension of sustainability of this study. The risk of mycotoxins in food is one of the most important aspects of food safety and it is an issue highly felt by policy makers in the last decades.

Finally, the *"net income"* indicator represents a difference between the Gross Marketable Production (GMP) (yield of crop multiplied by the price) and the crop production costs. The GMP generally does not take into account the direct market support of Common Agricultural Policy (CAP), while cost of production takes into account only the direct costs of cultivation (field operations and technical tools and resources). Indirect costs (i.e. land use, financial interests, taxes, etc.) are not taken into account. The Net Income is measured as €/tons or €/hectare.

In the first field evaluations (2009/2010 and 2010/2011) different "yes/no" indices were also considered (only few data will be shown in the thesis due to their scarce application). These indices belong to the "Good environmental practices" category:

i. *use of cover crop;*

ii. *use of buffer strips and hedges:* indicates the presence or absence of vegetative barriers between plots for limiting the drift of PPPs spread out with non-optimal environmental conditions.

iii. *use of anti-drift nozzles:* their use can decrease the risk of PPPs spreading out of the target.

iv. *mitigation measures of runoff (hilly ditches, etc):* allow to assess, especially in hilly areas, the presence of small seasonal ditches to collect the water runoff. They restrict erosion and water surface runoff occurring during heavy rain falls.

v. *subsurface drainage:* indicates if networks of sub-surface tubes are implemented in areas with shallow groundwater and/or stagnant surface water.

The decision to use a limited number of indicators comes from the belief that the identification of many parameters of evaluation leads only apparently to a right assessment of sustainability. The potential increasing of accuracy obtained by using a lot of indicators fail at the moment of the collection of information. The risk of getting unrepresentative data increases with increasing of the human resources and timing required to obtain them. Nonetheless, the list of indicators was not strict: in different years the indicators used changed according to company's priorities and needs.

3.2 Innovative tools for the sustainable durum wheat management

3.2.1 *granoduro.net*®

granoduro.net® is a web-based decision support system (DSS) developed by Horta S.r.l., spin off company of the Università Cattolica del Sacro Cuore, for the sustainable management of durum wheat. The 1.0 version of the system is on the market since 2010; during this PhD study a 2.0 version was developed with new services, to make it more competitive, and an improved interface, to make it more user-friendly.

The system is intended to help farmers and agricultural advisors in decision-making for cultivation of durum wheat (from sowing to harvest) following the principles of sustainable agriculture requested by the Directive 2009/128/CEE. Moreover the tool plans to overcome the constraints of on-web agro-ecological technologies argued by Zaks and Kucharik (2011).

Through *granoduro.net*® a farmer can manage all tactical decisions in order to maximize yields and kernels quality. Decision supports provided by *granoduro.net®* are designed on a holistic and site-specific approach, taking into account weather conditions and plot-specific peculiarities of the crop. Indeed, *granoduro.net®* outputs are tailored to a crop-unit (CU), a wheat field sown on an uniform piece of land (i.e., same characteristics of the soil, with the same wheat variety, same rotation, same soil tillage) and cropped in a uniform manner all season long (from the previous crop to harvest). Each CU is characterized by means of site-specific information both static (i.e. do not change over the season and are provided *una tantum* by the user to the DSS), and dynamic (i.e. change over the season), that represent the input variables of the simulation models running within the system. The DSS provides decision supports for all key elements of the production process, including: seeding, crop growth and development, timing and amount of fertilizers (nitrogen, potassium and phosphorus), weed control and risk of occurrence of the more important fungal diseases. All services are based on expert knowledge and epidemiological models.

Based on the previous considerations, the DSS for durum wheat production was designed following the conceptual diagram of Figure 6 (Rossi et al., 2010). As indicated in this figure, both static-site profiles and site-specific information (data) are viewed as flowing from the environment via instrumented sensors or human activities (scouting, analyses, etc.) to a database. The information is manipulated, analyzed, and interpreted though comparison with available expert knowledge as part of the decision process. The information is processed for producing a decision support. The decision itself is the responsibility of the user, and the DSS is not designed to replace the decision maker but to help in making choices by providing additional information. A decision results in an action to be executed within the crop environment. After the action is carried out, the environment is again monitored to begin a new cycle of information flow. Thus, information flows to and from the environment in an endless loop that begins with sensing and ends with action (Sonka et al., 1997).

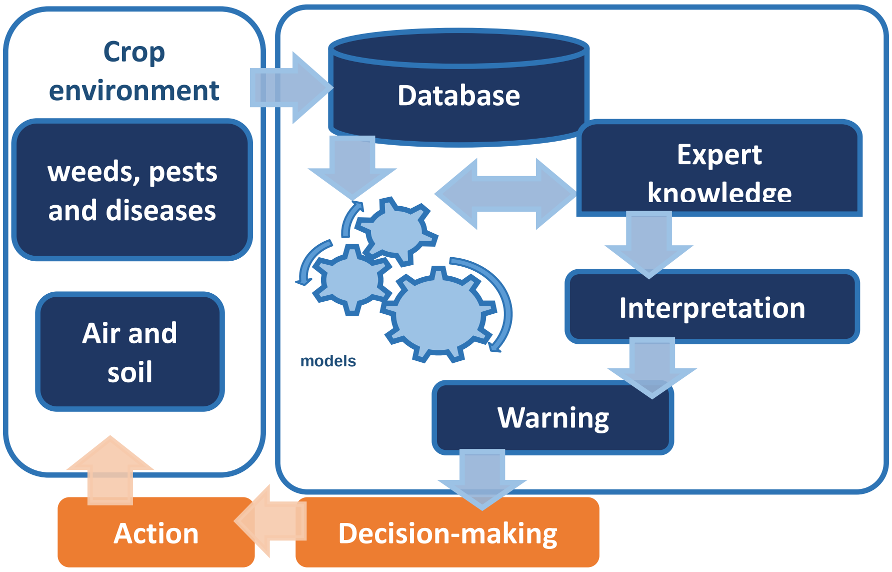


Figure 6: Conceptual diagram of granoduro.net®.

Users access to the DSS from the company website (http://www.horta-srl.com/) by means of a user name and password. At the beginning of durum wheat cropping season (October and November in the north and in November and December in the south of Italy) users have to fill out a data sheet regarding the crop unit features. An example of data gatherer is illustrated into Figure 7. With more details, for model initialization, the main data request to users are: user name, nearest weather station, a free name of crop unit, hectares, if crop unit is into a nitrate vulnerable zone, farm name, province, municipality, altitude, mean slope, farm management (conventional, integrated or organic), variety of durum wheat, expected yield, rotation, date of sowing, soil characteristic (texture and endowment of nutrients), soil tillage, sowing conditions, and information about organic fertilization. Other inputs not compulsory but recommended are the soil analysis and personal details of farm and/or membership organization.

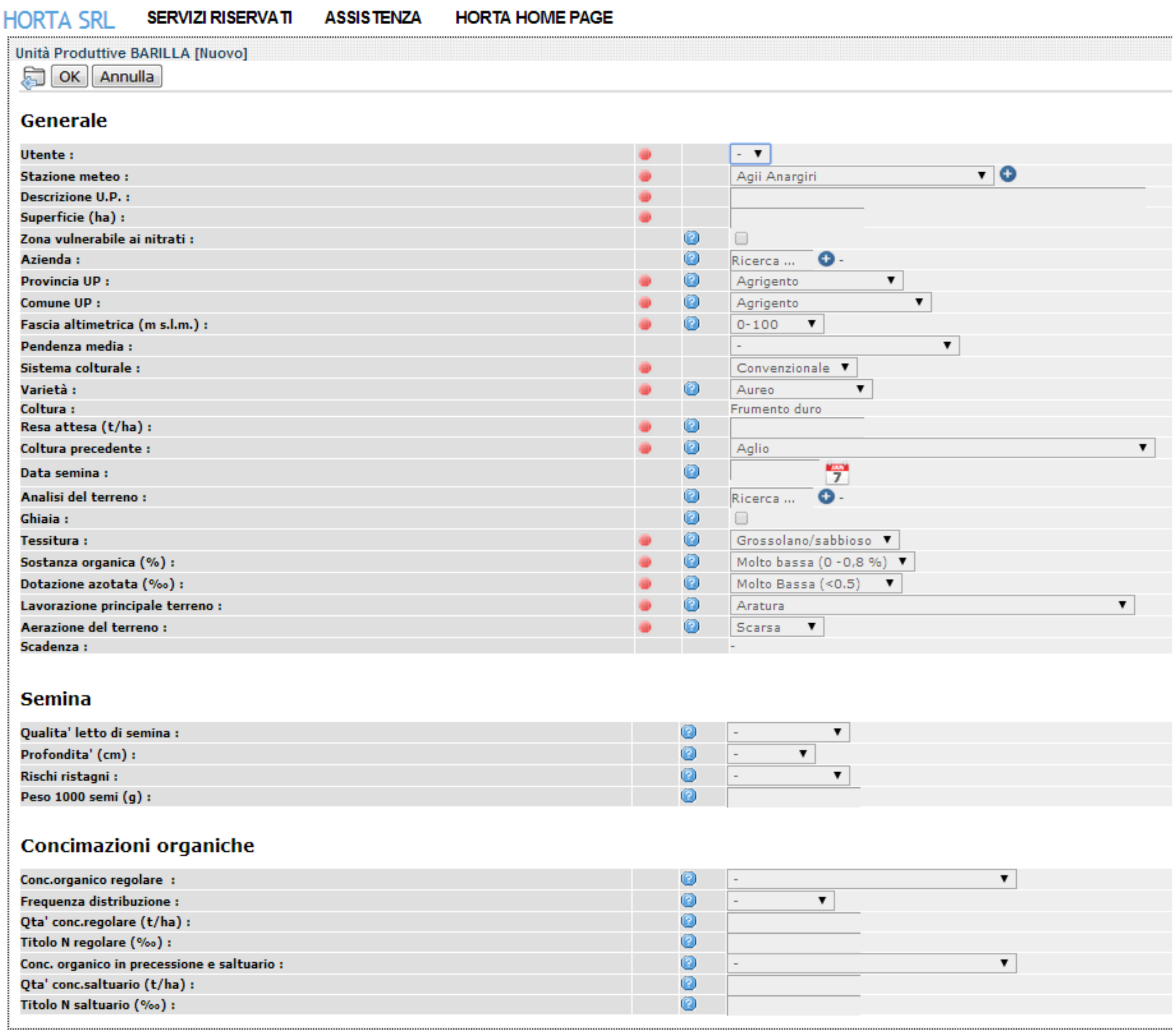


Figure 7: The main data sheet gatherer used to collect information about crop unit. Data are collected regarding: growers, location, tactic crop grower choices (variety, high or low input orientation, rotation, etc.), soil characteristics, sowing conditions and organic fertilization.

Each crop unit has to be collected to a nearby weather station, therefore, a network of weather stations was implemented in the most important region for durum wheat cultivation (Figure 8).

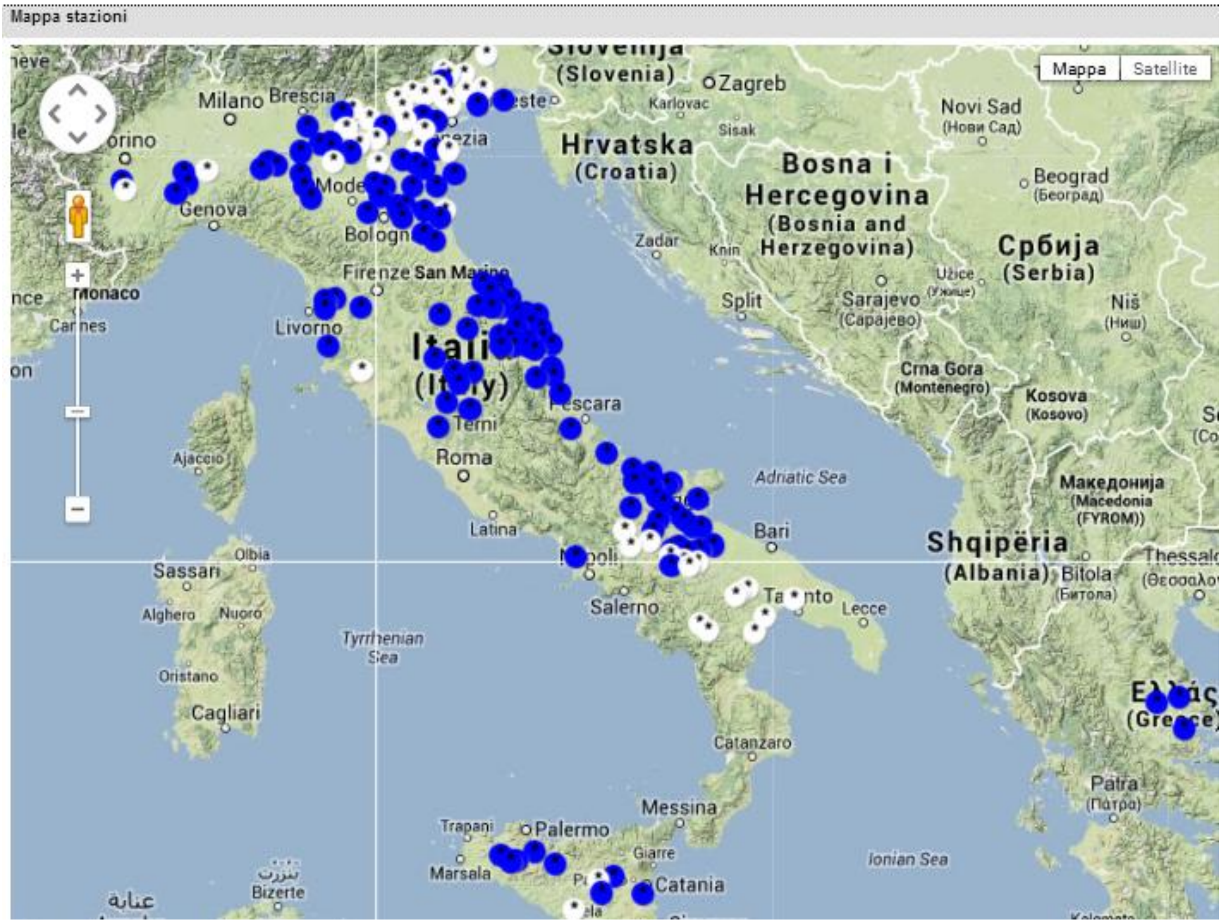
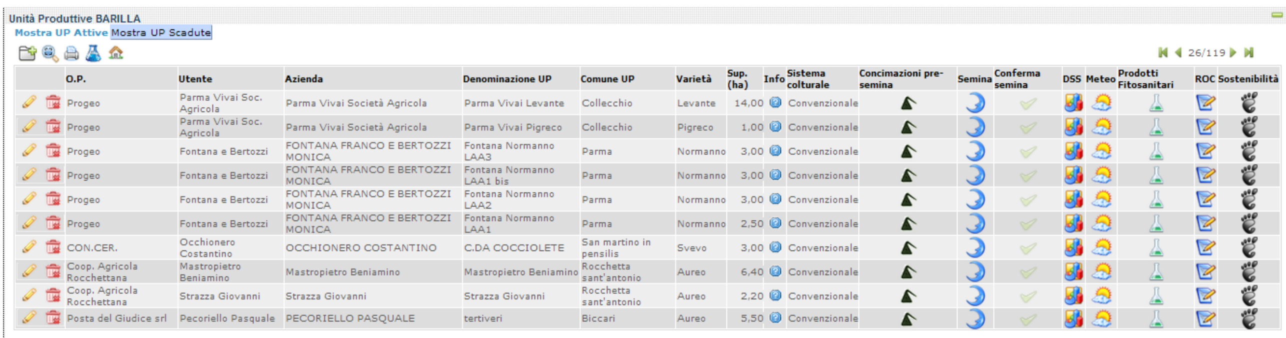


Figure 8: The network of weather stations (blue and white spots of the map) used to monitor weather patterns during the cultivation of durum wheat.

When data are correctly filled in a new "production unit", models start running and all services are available throughout the durum wheat season. In Figure 9 an example of crop list: for each crop unit a sum up data (membership organization, user name, farm name, production unit name, municipality, wheat variety, hectares, weather station, and farm management) and the main services supplied to growers and technicians is shown. Following each service will be described in more details.



Unità Produttive BARILLA

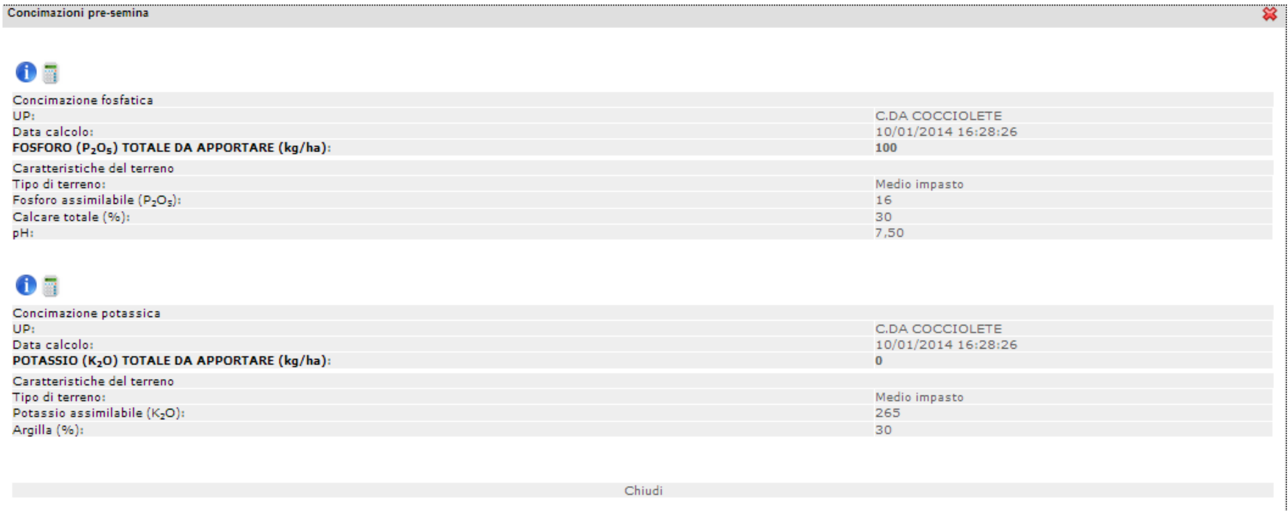
Mostra UP Attive Mostra UP Scadute

26/119

	O.P.	Utente	Azienda	Denominazione UP	Comune UP	Varietà	Sup. (ha)	Info	Sistema colturale	Concimazioni pre-semina	Semina	Conferma semina	DSS	Meteo	Prodotti Fitosanitari	ROC	Sostenibilità
	Progeo	Parma Vivai Soc. Agricola	Parma Vivai Società Agricola	Parma Vivai Levante	Collecchio	Levante	14,00		Convenzionale								
	Progeo	Parma Vivai Soc. Agricola	Parma Vivai Società Agricola	Parma Vivai Pigreco	Collecchio	Pigreco	1,00		Convenzionale								
	Progeo	Fontana e Bertozzi	FONTANA FRANCO E BERTOZZI MONICA	Fontana Normanno LAA3	Parma	Normanno	3,00		Convenzionale								
	Progeo	Fontana e Bertozzi	FONTANA FRANCO E BERTOZZI MONICA	Fontana Normanno LAA1 bis	Parma	Normanno	3,00		Convenzionale								
	Progeo	Fontana e Bertozzi	FONTANA FRANCO E BERTOZZI MONICA	Fontana Normanno LAA2	Parma	Normanno	3,00		Convenzionale								
	Progeo	Fontana e Bertozzi	FONTANA FRANCO E BERTOZZI MONICA	Fontana Normanno LAA1	Parma	Normanno	2,50		Convenzionale								
	CON.CER.	Occhionero Costantino	OCCHIONERO COSTANTINO	C.DA COCCIOLETE	San martino in pensilis	Svevo	3,00		Convenzionale								
	Coop. Agricola Rocchettana	Mastropietro Beniamino	Mastropietro Beniamino	Mastropietro Beniamino	Rocchetta sant'antonio	Aureo	6,40		Convenzionale								
	Coop. Agricola Rocchettana	Strazza Giovanni	Strazza Giovanni	Strazza Giovanni	Rocchetta sant'antonio	Aureo	2,20		Convenzionale								
	Posta del Giudice srl	Pecoriello Pasquale	PECORIELLO PASQUALE	tertiveri	Biccari	Aureo	5,50		Convenzionale								

Figure 9: A snapshot illustrating how granoduro.net® services are displayed to users. Ten crop unit are listed (one horizontal line for each CU). A summary of information collected during "crop unit" characterization is shown and intuitive icons help users find the service wanted.

By clicking on the icon advices on the possible application of phosphorus and potassium before sowing ("before-sowing fertilization") will be shown. The recommendation of fertilizer's application depends on soil texture, physical and chemical soil characteristics (e.g. Ph, limestone, available phosphorus and potassium, etc.), mineral fertilizers endowment, rotation, and expected yield (Figure 10).


Concimazioni pre-semina

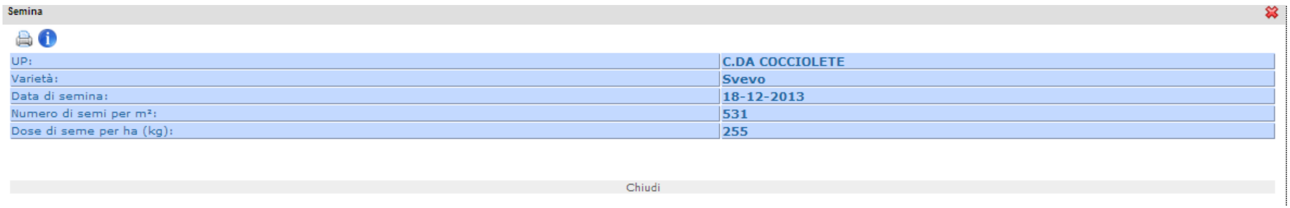
Concimazione fosfatica	
UP:	C.DA COCCIOLETE
Data calcolo:	10/01/2014 16:28:26
FOSFORO (P_2O_5) TOTALE DA APPORTARE (kg/ha):	**100**
Caratteristiche del terreno	
Tipo di terreno:	Medio impasto
Fosforo assimilabile (P_2O_5):	16
Calcare totale (%):	30
pH:	7,50

Concimazione potassica	
UP:	C.DA COCCIOLETE
Data calcolo:	10/01/2014 16:28:26
POTASSIO (K_2O) TOTALE DA APPORTARE (kg/ha):	**0**
Caratteristiche del terreno	
Tipo di terreno:	Medio impasto
Potassio assimilabile (K_2O):	265
Argilla (%):	30

Chiudi

Figure 10: A snapshot illustrating suggestions for before-sowing fertilization with phosphorus and potassium by granoduro.net®.

Recommendations about density of sowing are available through the symbol: ("soil density/hectare advice"). The density of sowing is influenced by variety, date of sowing, bed sowing, depth of sowing, risk of water logging, weight of thousand seeds, climate category, soil texture and presence of gravel (Figure 11). The output indicates the number of seeds per square meter and kilograms of seed per hectare.


Semina

UP:	C.DA COCCIOLETE
Varietà:	Svevo
Data di semina:	18-12-2013
Numero di semi per m²:	531
Dose di seme per ha (kg):	255

Chiudi

Figure 11: A snapshot illustrating suggestions for density of sowing. granoduro.net® shows sowing as number of seeds per square meter and as kilograms per hectare of vital seeds.

By the icon data about temperature, leaf wetness, air humidity and rainfall registered by the closest weather station are provided in real-time (Figure 12). The outputs are given for the last 72 hours (Figure 13), from October 1st of the year of sowing to the day consultation (Figure 14) and as weather forecast of five days later the day of consultation (Figure 15).

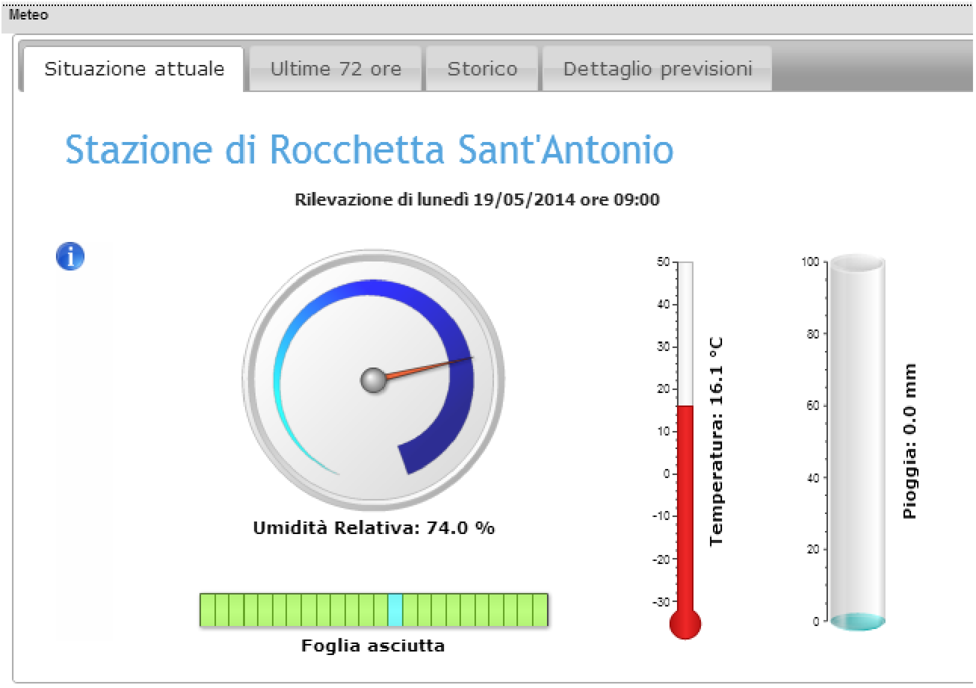


Figure 12: Real-time weather data outputs: last data registered and transmitted by the reference weather station.

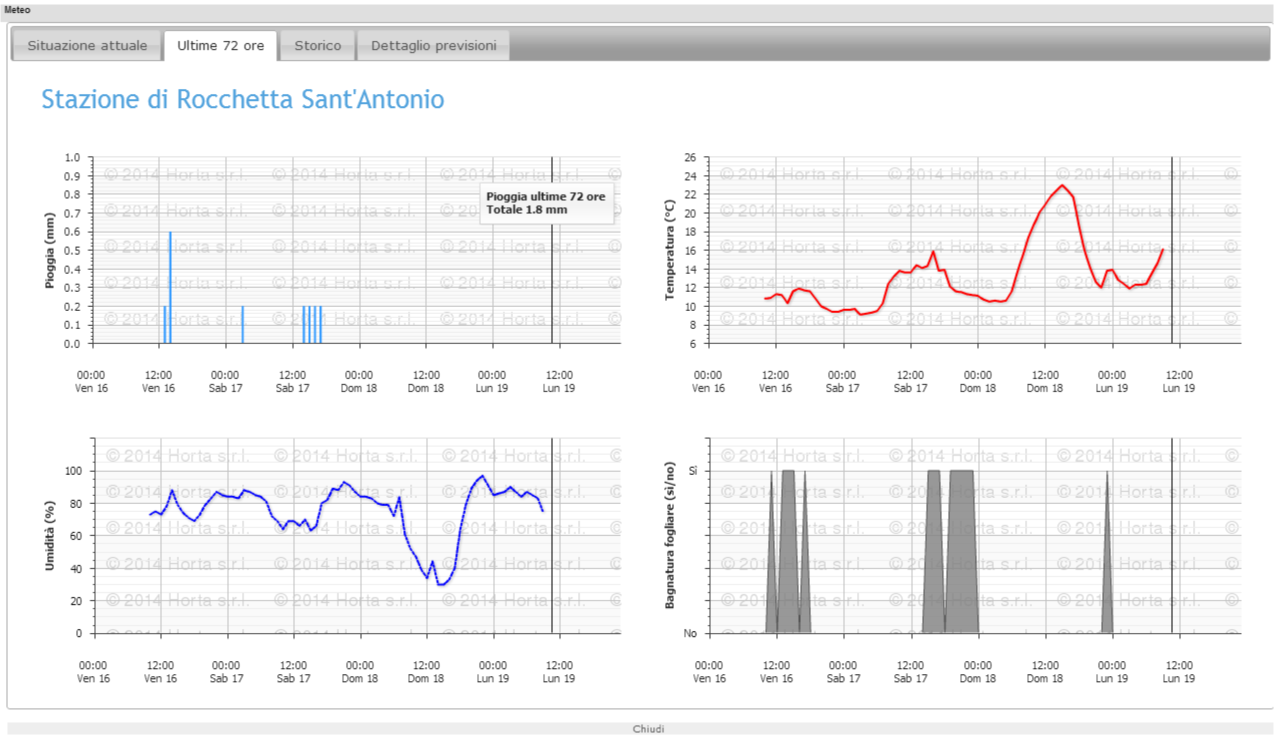


Figure 13: Weather data outputs of last 72 hours.

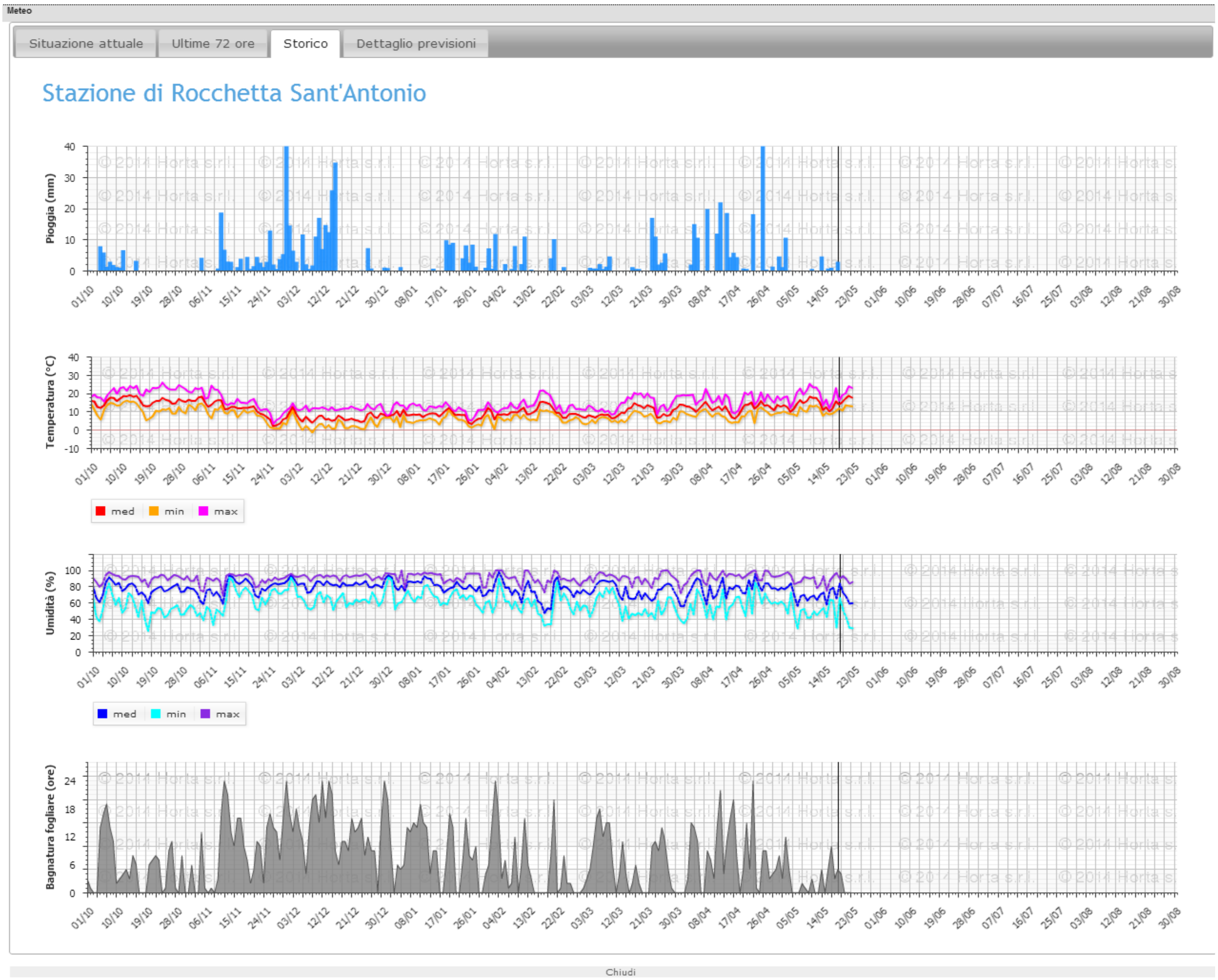


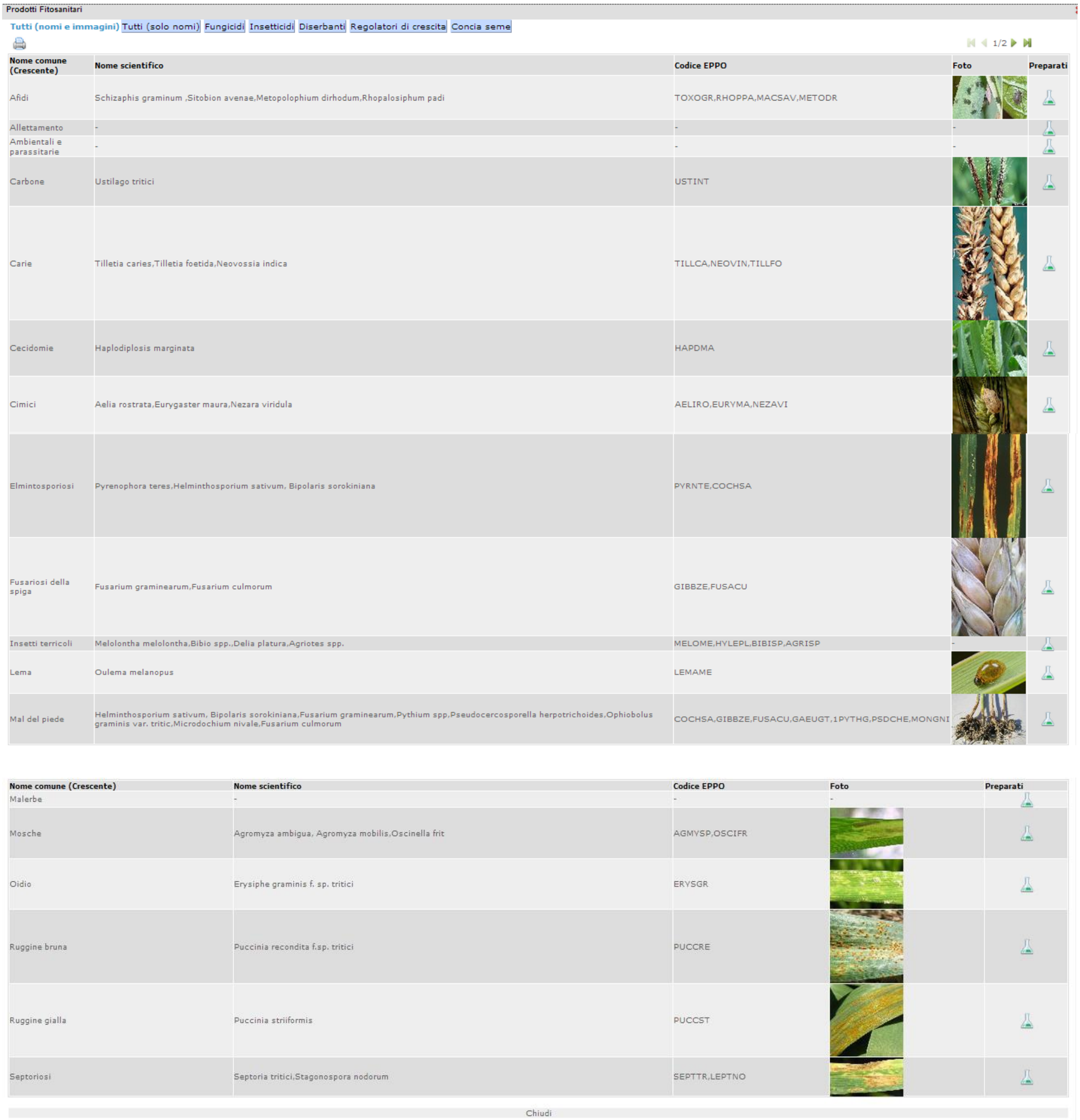
Figure 14: Outputs of historical weather data (temperature, rain, air relative humidity and leaf wetness).

	Tempo	Temperatura		Precipitazioni		Umidità Relativa	Vento a 2m		
		Minima °C	Massima °C	Probabilita %	Quantità mm	%	Descr.	dir_vento	Velocità Km/h
lunedì 19	pioggia debole	9.0	16.2	51	0.8	66	moderata	E-SE	10.45
martedì 20	poco nuvoloso	8.9	20.2	22	0.4	59	debole	N	6.85
mercoledì 21	sereno	10.2	22.3	10	0.0	57	debole	E-NE	9.37
giovedì 22	sereno	10.8	24.2	10	0.0	48	debole	NE	5.05
venerdì 23	nubi sparse	13.1	26.4	10	0.1	43	debole	O	7.57
sabato 24	sereno	16.1	25.7	10	0.3	46	moderata	O	12.25
domenica 25	pioggia e schiarite	16.0	23.3	78	3.2	67	debole	E-SE	5.77

Le previsioni sul punto stazione sono state sviluppate da Horta in collaborazione con ilMeteo.it

Figure 15: Outputs of the weather forecast for the following five days.

Thanks to *granoduro.net*® users can consult a complete and up to date database of pesticides approved for durum wheat cultivation in Italy. The goal of this DSS is to encourage a more conscious use of pesticides and not to promote some pesticides rather than other ones. For this reason, none pesticides manufacturer is recommended, promoted or inadvisable. By clicking on (Figure 16) insecticide, fungicide, herbicides, plant growth regulator, avoiding lodging, and seeds dressing fungicides available for durum wheat are listed for the main adversity. For each plant protection product the following information are given: physical and chemical properties, human and environmental risk of toxicity, the label, rules of usage, risk of resistance development, controlled pests, as well as the field applicability according to weather forecast and pesticides properties (Figure 17).



Prodotti Fitosanitari

Tutti (nomi e immagini) Tutti (solo nomi) Fungicidi Insetticidi Diserbanti Regolatori di crescita Concia seme

1/2

Nome comune (Crescente)	Nome scientifico	Codice EPPO	Foto	Preparati
Afidi	Schizaphis graminum ,Sitobion avenae,Metopolophium dirhodum,Rhopalosiphum padi	TOXOGR,RHOPPA,MACSAV,METODR		
Allettamento	-	-	-	
Ambientali e parassitarie	-	-	-	
Carbone	Ustilago tritici	USTINT		
Carie	Tilletia caries,Tilletia foetida,Neovossia indica	TILLCA,NEOVIN,TILLFO		
Cecidomie	Haplodiplosis marginata	HAPDMA		
Cimici	Aelia rostrata,Eurygaster maura,Nezara viridula	AELIRO,EURYMA,NEZAVI		
Elmintosporiosi	Pyrenophora teres,Helminthosporium sativum, Bipolaris sorokiniana	PYRNTE,COCHSA		
Fusariosi della spiga	Fusarium graminearum,Fusarium culmorum	GIBBZE,FUSACU		
Insetti terricoli	Melolontha melolontha,Bibio spp.,Delia platura,Agriotes spp.	MELOME,HYLEPL,BIBISP,AGRISP	-	
Lema	Oulema melanopus	LEMAME		
Mal del piede	Helminthosporium sativum, Bipolaris sorokiniana,Fusarium graminearum,Pythium spp,Pseudocercosporella herpotrichoides,Ophiobolus graminis var. tritic,Microdochium nivale,Fusarium culmorum	COCHSA,GIBBZE,FUSACU,GAEUGT,1PYTHG,PSDCHE,MONGNI		

Nome comune (Crescente)	Nome scientifico	Codice EPPO	Foto	Preparati
Malerbe	-	-	-	
Mosche	Agromyza ambigua, Agromyza mobilis,Oscinella frit	AGMYSP,OSCIFR		
Oidio	Erysiphe graminis f. sp. tritici	ERYSGR		
Ruggine bruna	Puccinia recondita f.sp. tritici	PUCCRE		
Ruggine gialla	Puccinia striiformis	PUCCST		
Septoriosi	Septoria tritici,Stagonospora nodorum	SEPTTR,LEPTNO		

Chiudi

Figure 16: Adversities considered by the pesticide database of granoduro.net® . Clicking on on the right of each horizontal line, users can find pesticides for insects (aphis, flies, Oulema melanopus, soil insects, bugs, and midge), avoiding lodging, plant growth regulators, several fungi (septoria leaf blotch complex, fusarium heat blight, powdery mildew, yellow and brown rust, Elimintosporium spp., Tilletia spp., Ustilago tritici and foot rot complex) and herbicide.

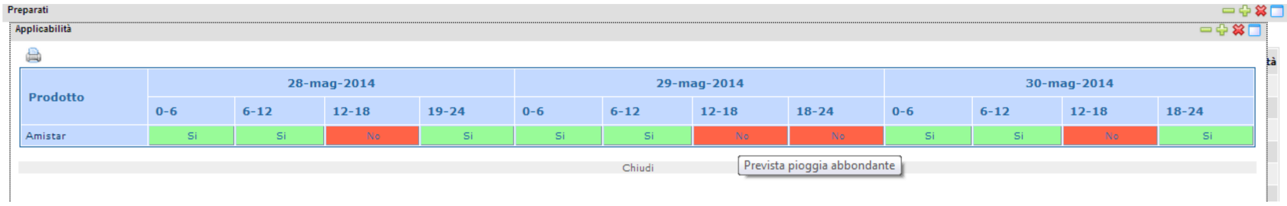


Figure 17: An example of applicability of pesticide Amistar according to weather pattern in the day of consultation and in the following two days. Forecast of wind, rain, too low or too high temperature, extreme relative humidity not recommend treatment (red warning), whereas if meteorological parameters are suitable to physical and chemical properties of pesticide, the treatment is recommended (green warning).

The core of *granoduro.net*® is represented by the disease control functionality (icon). Epidemiological models are driven by weather data and simulate i) the development of the different pathogens and ii) the risk of mycotoxins Deoxynivalenol (DON) and Zearalenone (ZEA) production (DON is produced by some *Fusarium* species that infect wheat caryopsis during ripening, while ZEA is produced by both *Fusarium* and *Gibberella* species). The use of epidemiological models allows to schedule treatments against a particular pathogen only if really necessary. In such a way repeated treatments over time can be replaced by treatments only when disease pressure is high (i.e. high inoculums, high spreading by wind and/or rain and high risk of infection). The diseases considered to date are: septoria leaf blotch (*Septoria tritici* and *Stagonospora nodorum*), fusarium heat blight (*Fusarium culmorum* and *F. graminearum*), powdery mildew (*Blumeria graminis f. sp. Tritici*), yellow and brown leaf rust (*Puccinia striiformis f.sp. tritici* and *Puccinia triticina* (*recondita*). For each disease and risk, two output's levels are provided by the system: i) a synthetized output represented by a dashboard giving the general risk and ii) , provided by clicking on the dashboards, detailed outputs of the specific epidemiological models (Figure 18-19).

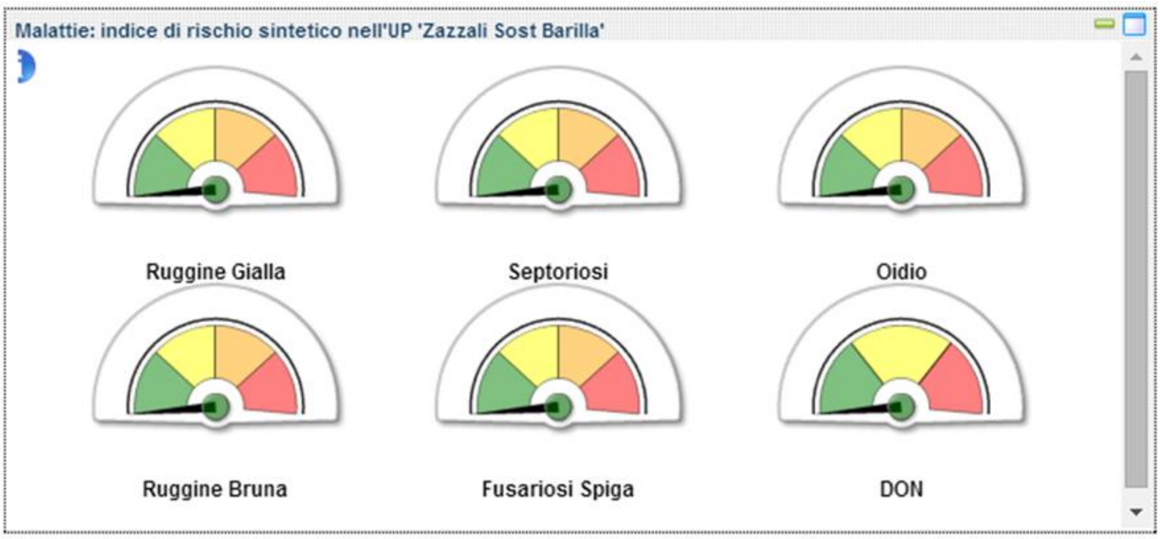


Figure 18: First level output: dashboards for risk of yellow rust occurrence (i.e. "Ruggine Gialla"), septoria leaf blotch complex (i.e. "Septoriosi"), powdery mildew (i.e. "Oidio"), brown rust (i.e. "Ruggine bruna"), fusarium head blight (i.e. "Fusariosi Spiga") and DON. Green means low risk, while red very high risk of infections onset.

Figure 19 shows as example the detailed outputs of the model for septoria infections: spring infection pressure, inoculum dose, disease spreading, and autumn and winter infection pressure. While Figure 20 shows the second level of outputs of the model for DON production: probability of DON production and its variation depending on strategy adopted by growers to control mycotoxigenic fungi.

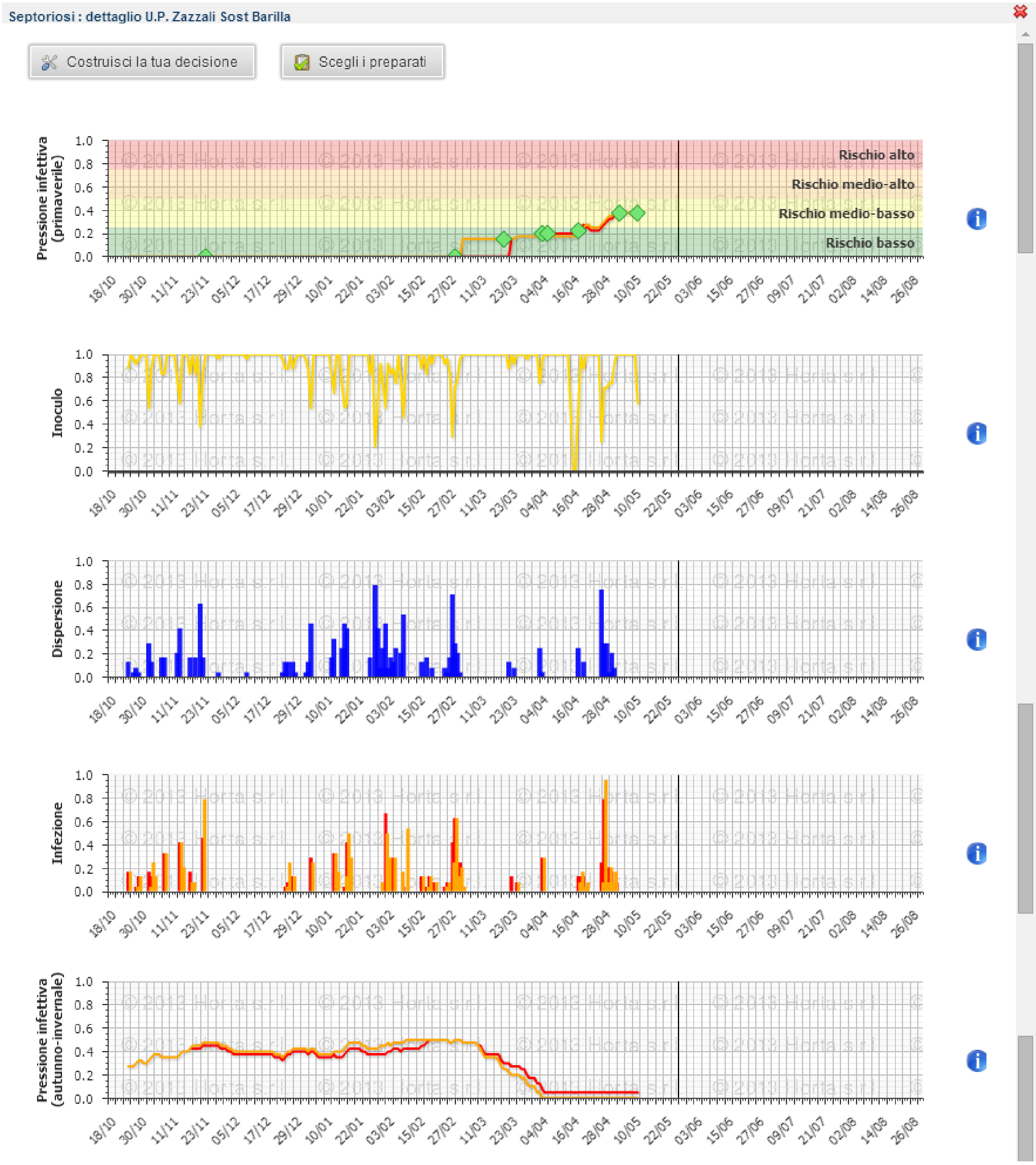


Figure 19: An example of graphs shown to users if the dashboards of septoria leaf blotch complex (i.e. "Septoriosi") is clicked. Graph about spring infection pressure, field inoculums amount, disease spreading, and autumn and winter infection pressure are shown from the October, 1st to five days later the day of consulting.

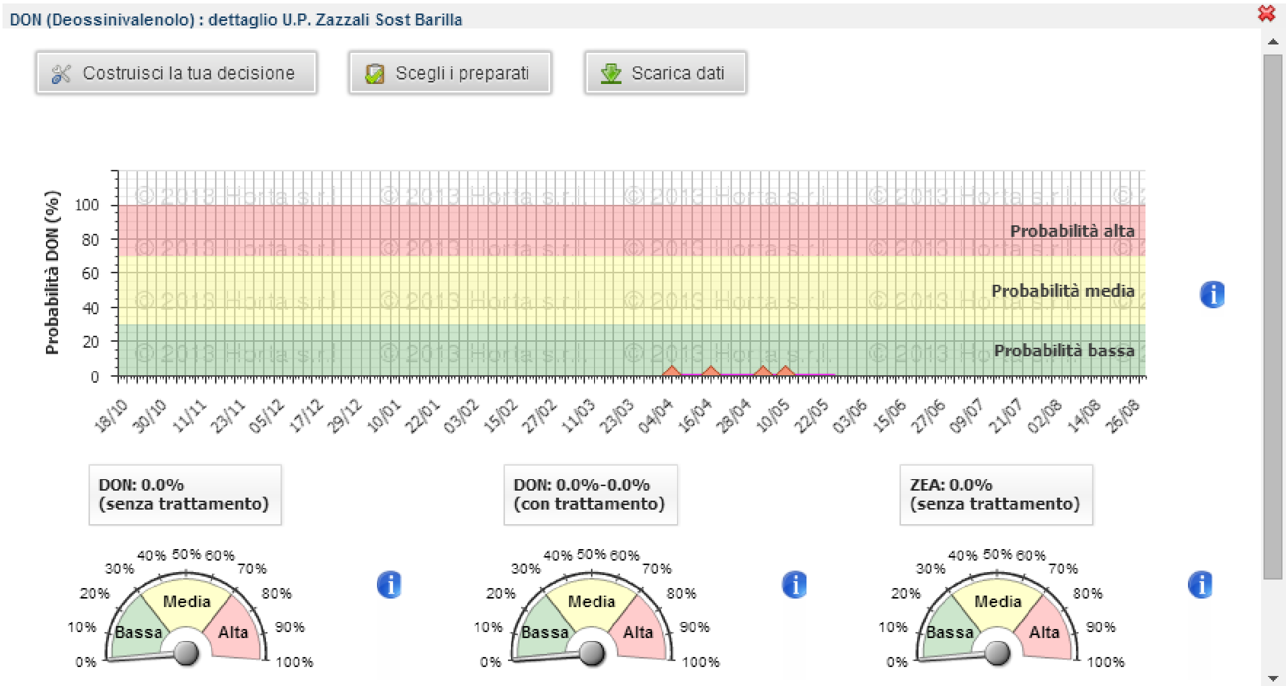


Figure 20: An example of graph shown to users if the dashboards of DON is clicked. Graph about the probability of DON developing is shown from the first expected day of heading (April, 7th) to the end of ripening. Other threes dashboards explain the risk of DON if none fungicide treatment is performed (on the left), if a treatment is done (in the centre) and the risk of ZEA occurrence if none fungicide treatment is done by growers.

Complementary to the disease models a model for winter wheat development was integrated into the DSS (Rossi et al., 1997). Dynamics of wheat phenological phase, flowering behaviour, and total and green area of each leaf are calculated from the time of their appearance until complete senescence based on date of sowing, wheat variety and weather variables (Figure 21) (Salinari and Meriggi, 2011).

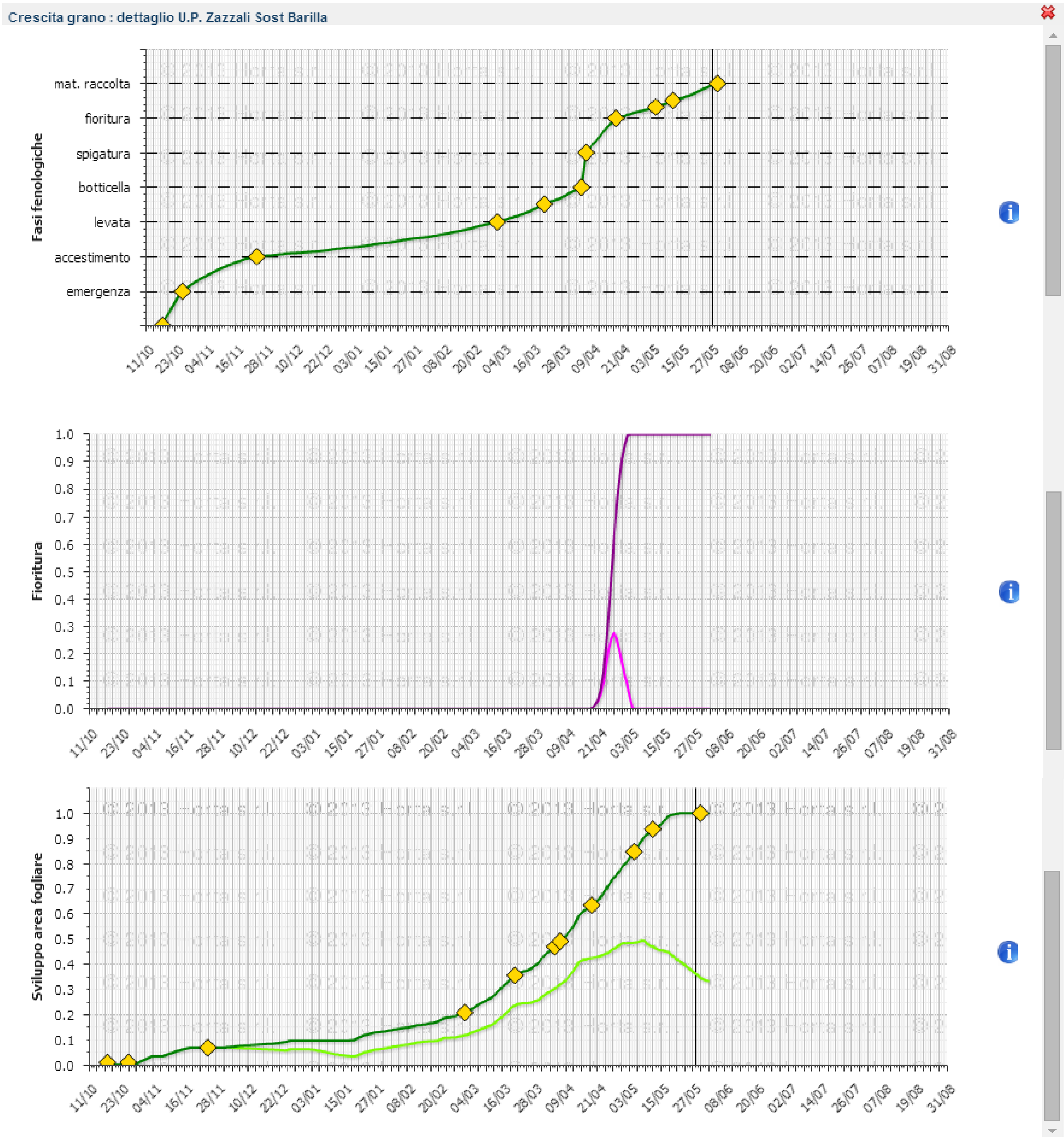


Figure 21: The first graphs shows the simulation of winter wheat crop canopy development during season, from sowing to five days later the day of consulting; all key phenological stages are pointed by yellow rhombus. In the second graph a focus on flowering is displayed to monitor the relationship between rainfalls, flowering and risk of Fusarium head blight developing. The last graph describes the development of leaf biomass; light green line means green leaf biomass at the date indicated by x axis, while the dark green line describes the total developed leaf biomass (green and dry) at the date indicated by x axis.

Another functionality of *granoduro.net*® is dedicated to weed control: for each weed species a descriptive fact sheet (pictures, EPPO, scientific and local name) was prepared to help farmers identify what they see in the field (Figure 22 and 23). Once selected one or more weeds observed, the system indicates with a ranking frame (from the most effective to the less ones) which commercial product can be used for the control depending on predicted wheat phonological stage, weed sensitivity to the active ingredients of pesticides, weather conditions, chemical and physical properties of pesticides.

Growers choice products (one or two) according to effectiveness and farm storage availability, if pesticides are compatible (chemical miscibility) a sum up of chemicals choices is displayed (Figure 24), otherwise users are encouraged to choice other products. As for pesticide also for herbicides, field applicability of the day of consulting and for the two days later is available (Figure 25).

Erbe Infestanti [Selezione valore Infestante 1]

Solo Nomi | Nomi e Immagini

Codice EPPO	Nome Scientifico	Nome Comune	Tipologia	Scheda
ADOAE	*Adonis aestivalis*	Adonide	Dicotiledone	pdf
ALOMY	*Alopecurus myosuroides*	Coda di volpe	Monocotiledone	pdf
AMIMA	*Ammi majus*	Visnaga maggiore	Dicotiledone	pdf
ANGAR	*Anagallis arvensis*	Centocchio dei campi	Dicotiledone	pdf
ANEGR	*Anethum graveolens*	Aneto	Dicotiledone	pdf
ANTAR	*Anthemis arvensis*	Camomilla bastarda	Dicotiledone	pdf
APESV	*Apera spica-venti*	Agrostide annuale	Monocotiledone	pdf
ARTVU	*Artemisia vulgaris*	Assenzio selvatico	Dicotiledone	pdf
AVEFA	*Avena fatua*	Avena selvatica	Monocotiledone	pdf
AVEST	*Avena sterilis*	Avena maggiore	Monocotiledone	pdf
BIFRA	*Bifora radians*	Coriandolo fetido	Dicotiledone	pdf
BROST	*Bromus sterilis*	Forasacco rosso	Monocotiledone	pdf
CAPBP	*Capsella bursa-pastoris*	Borsa del pastore	Dicotiledone	pdf
CARHI	*Cardamine hirsuta*	Billeri	Dicotiledone	pdf
CENCY	*Centaurea cyanus*	Fiordaliso	Dicotiledone	pdf
CERAR	*Cerastium arvense*	Peverina arvense	Dicotiledone	pdf
CHYSE	*Chrysanthemum segetum*	Margherita delle messi	Dicotiledone	pdf
CIRAR	*Cirsium arvense*	Stoppione	Dicotiledone	pdf
CONAR	*Convolvulus arvensis*	Vilucchio comune	Dicotiledone	pdf
CAGSE	*Convolvulus sepium*	Vilucchio maggiore	Dicotiledone	pdf
DIPER	*Diplotaxis erucoides*	Ruchetta selvatica	Dicotiledone	pdf
EQUAR	*Equisetum arvense*	Coda cavallina	Pteridofita	pdf
FUMOF	*Fumaria officinalis*	Fumaria	Dicotiledone	pdf
GAETE	*Galeopsis tetrahit*	Canapa selvatica	Dicotiledone	pdf
GALAP	*Galium aparine*	Attaccamani	Dicotiledone	pdf
GLAIT	*Gladiolus segetum*	Gladiolo selvatico	Monocotiledone	pdf
PICEC	*Helminthia (Picris) echioides*	Aspraggine	Dicotiledone	pdf
LAMAM	*Lamium amplexicaule*	Erba ruota	Dicotiledone	pdf
LAMPU	*Lamium purpureum*	Lamio rosso	Dicotiledone	pdf
LEGSV	*Legousia speculum - veneris*	Specchio di venere	Dicotiledone	pdf
KICSP	*Linaria spuria*	Soldino	Dicotiledone	pdf
LOLMU	*Lolium multiflorum*	Loglietto	Monocotiledone	pdf
MATCH	*Matricaria chamomilla*	Camomilla comune	Dicotiledone	pdf
MATMA	*Matricaria matricarioides*	Camomilla selvatica	Dicotiledone	pdf
MERAN	*Mercurialis annua*	Mercorella annua	Dicotiledone	pdf
MYGPE	*Myagrum perfoliatum*	Miagro liscio	Dicotiledone	pdf
MYOAR	*Myosotis arvensis*	Miosotide dei campi	Dicotiledone	pdf
PAPRH	*Papaver rhoeas*	Papavero	Dicotiledone	pdf
PHABR	*Phalaris brachystachys*	Scagliola cangiante	Monocotiledone	pdf
PHAMI	*Phalaris minor*	Scagliola minore	Monocotiledone	pdf
PHAPA	*Phalaris paradoxa*	Scagliola sterile	Monocotiledone	pdf
POAAN	*Poa annua*	Fienarola annua	Monocotiledone	pdf
POAPR	*Poa pratensis*	Fienarola dei prati	Monocotiledone	pdf
POATR	*Poa trivialis*	Fienarola comune	Monocotiledone	pdf
POLAV	*Polygonum aviculare*	Correggiola	Dicotiledone	pdf
POLCO	*Polygonum convolvulus*	Convolvolo nero	Dicotiledone	pdf
POLLA	*Polygonum lapathifolium*	Persicaria maggiore	Dicotiledone	pdf
POLPE	*Polygonum persicaria*	Persicaria	Dicotiledone	pdf
RANAR	*Ranunculus arvensis*	Ranuncolo dei campi	Dicotiledone	pdf
RAPRA	*Raphanus raphanistrum*	Ravanello selvatico	Dicotiledone	pdf
RAPRU	*Rapistrum rugosum*	Ravanello rugoso	Dicotiledone	pdf
RUMAC	*Rumex acetosella*	Romice acetosella	Dicotiledone	pdf
RUMOB	*Rumex obtusifolius*	Romice comune	Dicotiledone	pdf
SCAPV	*Scandix pecten-veneris*	Pettine di venere	Dicotiledone	pdf
SENVU	*Senecio vulgaris*	Erba calderina	Dicotiledone	pdf
SLYMA	*Silybum marianum*	Cardo di S. Maria	Dicotiledone	pdf
SINAL	*Sinapis alba*	Senape bianca	Dicotiledone	pdf
SINAR	*Sinapis arvensis*	Senape selvatica	Dicotiledone	pdf
SONAR	*Sonchus arvensis*	Grespino dei campi	Dicotiledone	pdf
SONOL	*Sonchus oleraceus*	Cicerbita	Dicotiledone	pdf
SPRAR	*Spergula arvensis*	Renaiola	Dicotiledone	pdf
STEME	*Stellaria media*	Centocchio comune	Dicotiledone	pdf
THLAR	*Thlaspi arvense*	Erba storna	Dicotiledone	pdf
TORAR	*Torilis arvensis*	Lappolina	Dicotiledone	pdf
VERHE	*Veronica hederaefolia*	Morso di gallina	Dicotiledone	pdf
VERPE	*Veronica persica*	Veronica querciola	Dicotiledone	pdf
VICSA	*Vicia sativa*	Veccia comune	Dicotiledone	pdf
VICVI	*Vicia villosa*	Veccia villosa	Dicotiledone	pdf
VIOTR	*Viola tricolor*	Viola del pensiero	Dicotiledone	pdf
GERDI	*Geranium dissectum*	Geranio sbrindellato	Dicotiledone	pdf

Chiudi

Figure 22: The list of seventy more important weeds of Italy that can be chosen by users during weed tool query. EPPO, scientific and local name are displayed as well as pictures and fact sheets to simplify recognizing.

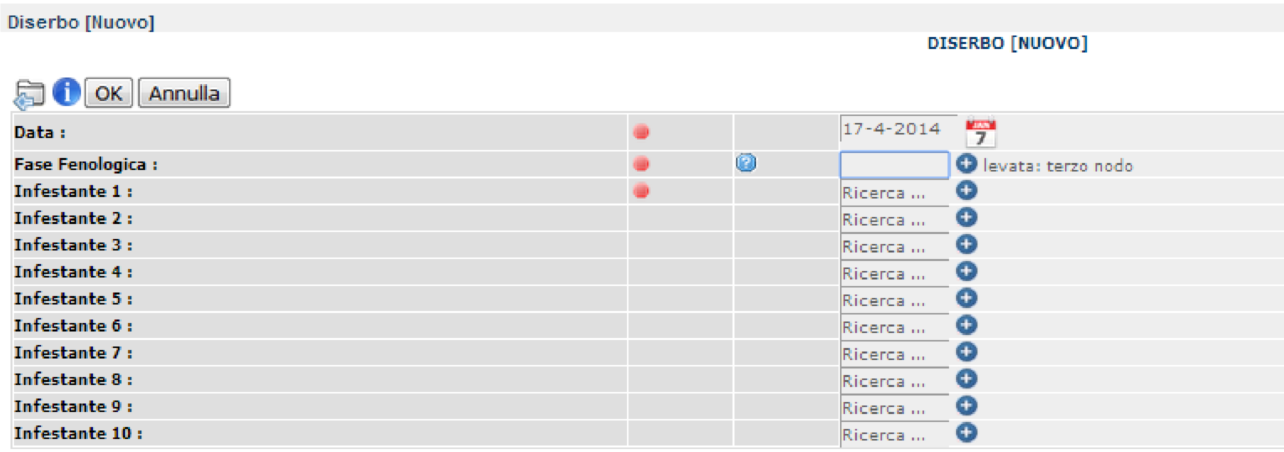


Figure 23: A snapshot of user input screen. User, according to experience or field scouting, can input up to ten weeds, change the crop phonological stage and the date of hypothetical treatment.

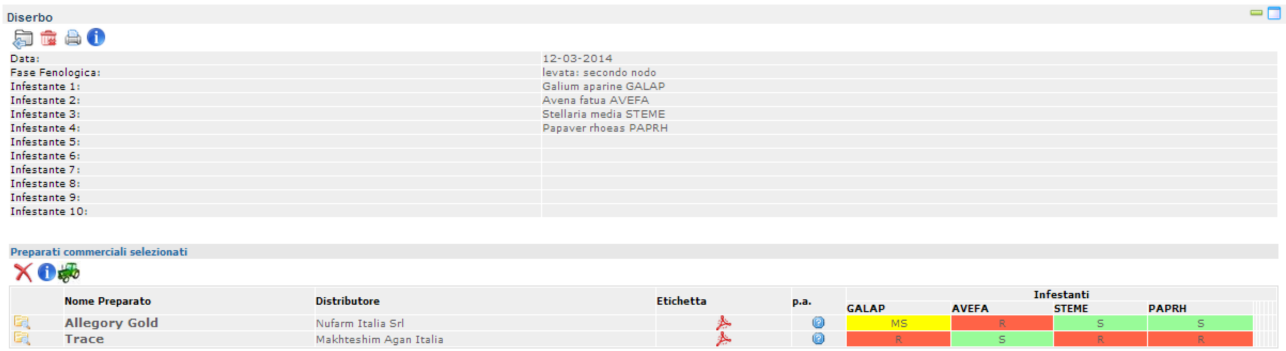


Figure 24: An example of treatment of March 12th during durum wheat stem elongation against four weeds (GALAP, AVEFA, STEME, PAPRH) with two herbicides (Allegory Gold and Trace). A recap of pesticides effectiveness toward the four weeds is described by means of colours: red (weed resistant), yellow (weed partially susceptible), and green (weed susceptible).

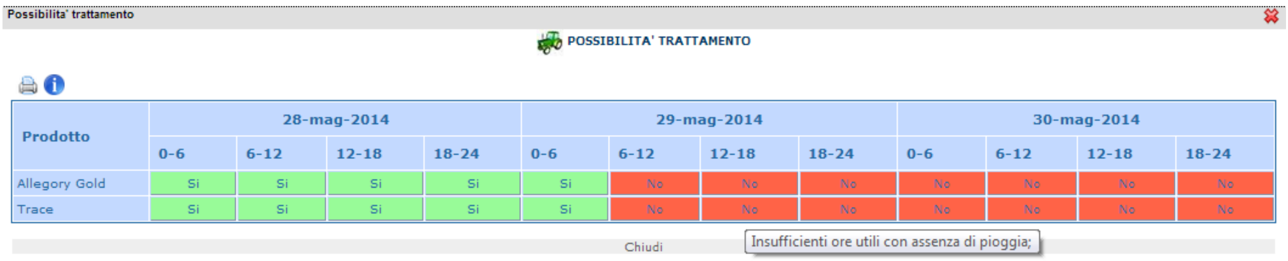


Figure 25: An example of applicability of herbicide Allegory Gold and Trace according to weather pattern in the day of consultation and the following two days. Forecast of wind, rain, too low or too high temperature, extreme relative humidity are weather patterns where granoduro.net® not recommend treatment (red warning), whereas if meteorological pattern are suitable to physical and chemical pesticide properties the treatment is recommended (green warning).

A functionality for crop fertilization is also present in the DSS: at the beginning of crop season potassium and phosphorus fertilization are considered, while during spring, advices are provided on the amount of nitrogen fertilizers and the best timing to spread them into the field (Figure 26). The advice of fertilization is based on a balancing approach between inputs and removals, usually two or three spreading out are recommended. The calculation of fertilization dose takes into account: fall and winter rainfall (from October to February), fall and winter temperature, nitrogen by rain, endowment of nitrogen by soil fertility, nitrogen by mineralization of organic matter and previous crop, organic fertilizers contribution, crop's requirements (depending on variety and expected yield), fall and winter leaching and fixation of nitrogen compounds in the crop residues and soil clay.

Figure 26: An example of nitrogen fertilization profile suggested by granoduro.net®. The 212 kg of nitrogen recommended per hectare should be split into three shares. 60 kg/ha during tillering, 112 kg/ha at the beginning of stem elongation, and the last 40 kg/ha at the booting stage.

To conclude, *granoduro.net®* is not only a decision support system to help farmers during durum wheat cultivation, but also a calculator of environmental impacts. To account environmental impacts and calculate indicators of sustainability, a register of farming operations (Figure 27) is submitted to users through the icon . Each crop activity (cropping activities and technical tools) contributes to the overall impact of wheat cultivation and in this register users can record data about soil tillage, sowing, fertilizations, treatments, irrigation, harvesting and delivering to storage facility (Figure 28).The environmental impact is summed up into three indicators: carbon, water and ecological footprint. Other agronomic indicators as Agronomic Nitrogen Use Efficiency (Agronomic NUE), yield, protein, test weight, and DON contamination are listed in the summary table (Figure 29). The indices of impact are available by the icon .

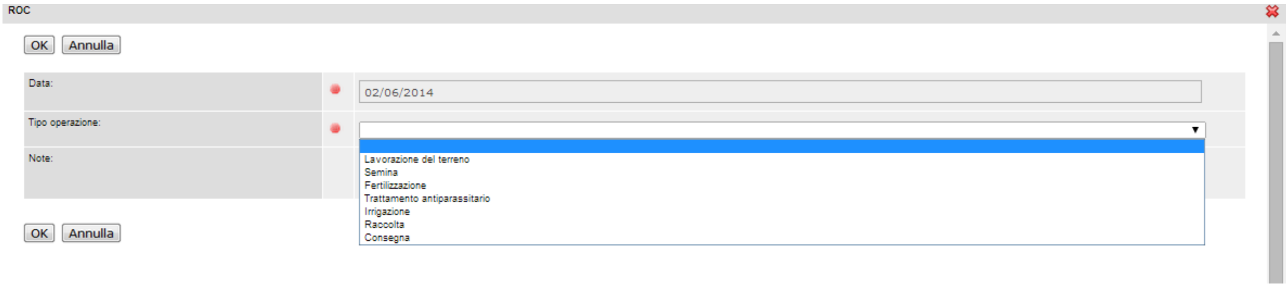


Figure 27: A snapshot of the register of farming operations used to account environmental impacts. Some data about soil tillage ("Lavorazione del terreno"), sowing ("Semina"), fertilization ("Fertilizzazione"), treatments (Trattamento antiparassitario"), irrigation ("Irrigazione"), harvesting ("Raccolta") and delivering to storage facilities ("Consegna") are collected by users with this frame.

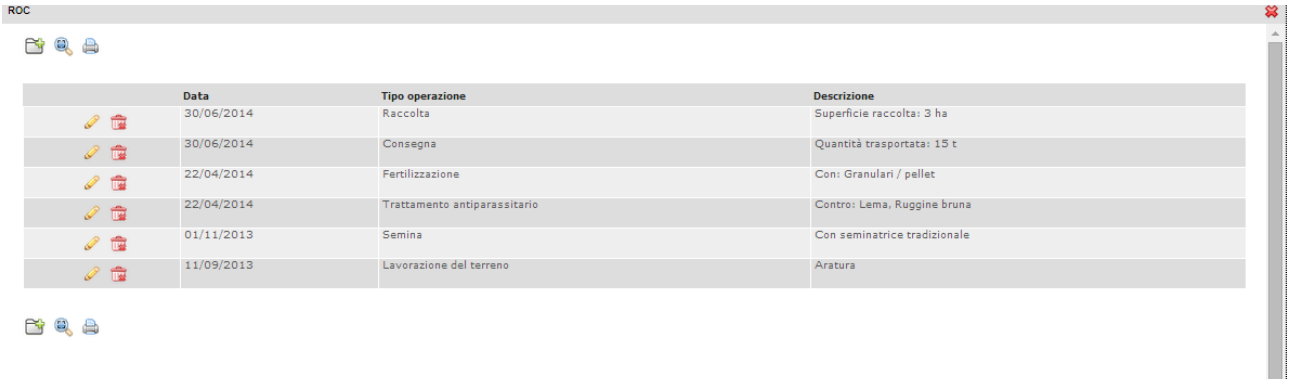
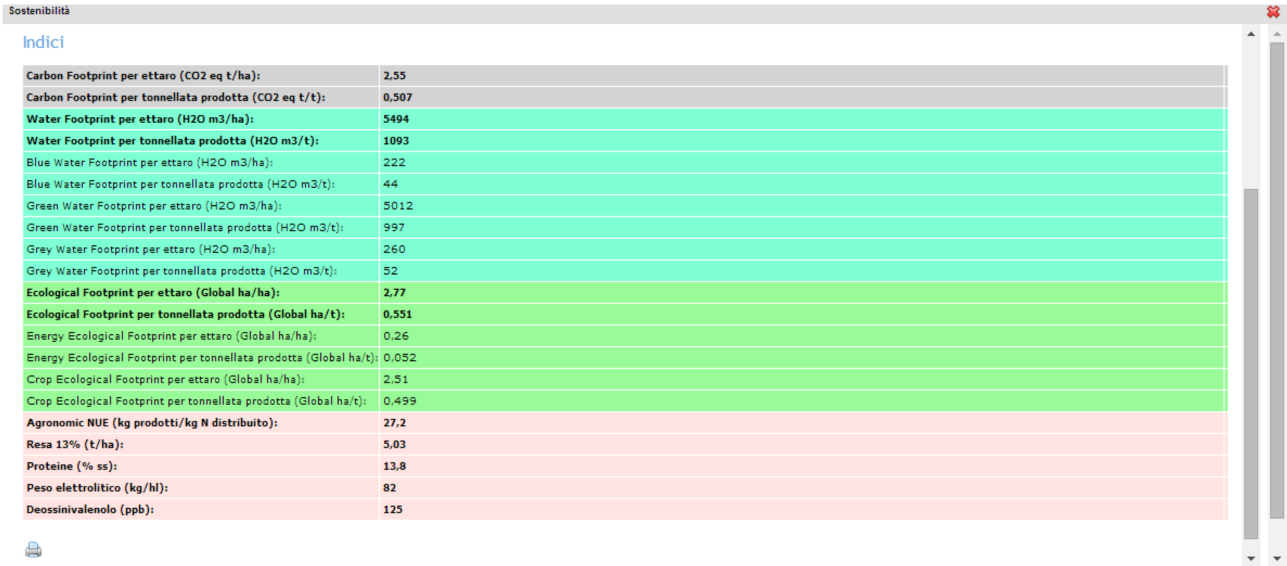


Figure 28: A snapshot of the register of farming operations used to account environmental impacts. Some growers activities are recorded.



Carbon Footprint per ettaro (CO2 eq t/ha):	2,55
Carbon Footprint per tonnellata prodotta (CO2 eq t/t):	0,507
Water Footprint per ettaro (H2O m3/ha):	5494
Water Footprint per tonnellata prodotta (H2O m3/t):	1093
Blue Water Footprint per ettaro (H2O m3/ha):	222
Blue Water Footprint per tonnellata prodotta (H2O m3/t):	44
Green Water Footprint per ettaro (H2O m3/ha):	5012
Green Water Footprint per tonnellata prodotta (H2O m3/t):	997
Grey Water Footprint per ettaro (H2O m3/ha):	260
Grey Water Footprint per tonnellata prodotta (H2O m3/t):	52
Ecological Footprint per ettaro (Global ha/ha):	2,77
Ecological Footprint per tonnellata prodotta (Global ha/t):	0,551
Energy Ecological Footprint per ettaro (Global ha/ha):	0,26
Energy Ecological Footprint per tonnellata prodotta (Global ha/t):	0,052
Crop Ecological Footprint per ettaro (Global ha/ha):	2,51
Crop Ecological Footprint per tonnellata prodotta (Global ha/t):	0,499
Agronomic NUE (kg prodotti/kg N distribuito):	27,2
Resa 13% (t/ha):	5,03
Proteine (% ss):	13,8
Peso elettrolitico (kg/hl):	82
Deossinivalenolo (ppb):	125

Figure 29: An environmental impacts summary table. Indicators as carbon, water and ecological footprint are shown both per hectare and per tons of caryopsis harvested. The impact depends on cropping activities and technical tools recorded by farmers by means of a register of farming operations.

To calculate the impacts, as well as for other DSS functionalities, different databases were implemented. The most important regard:

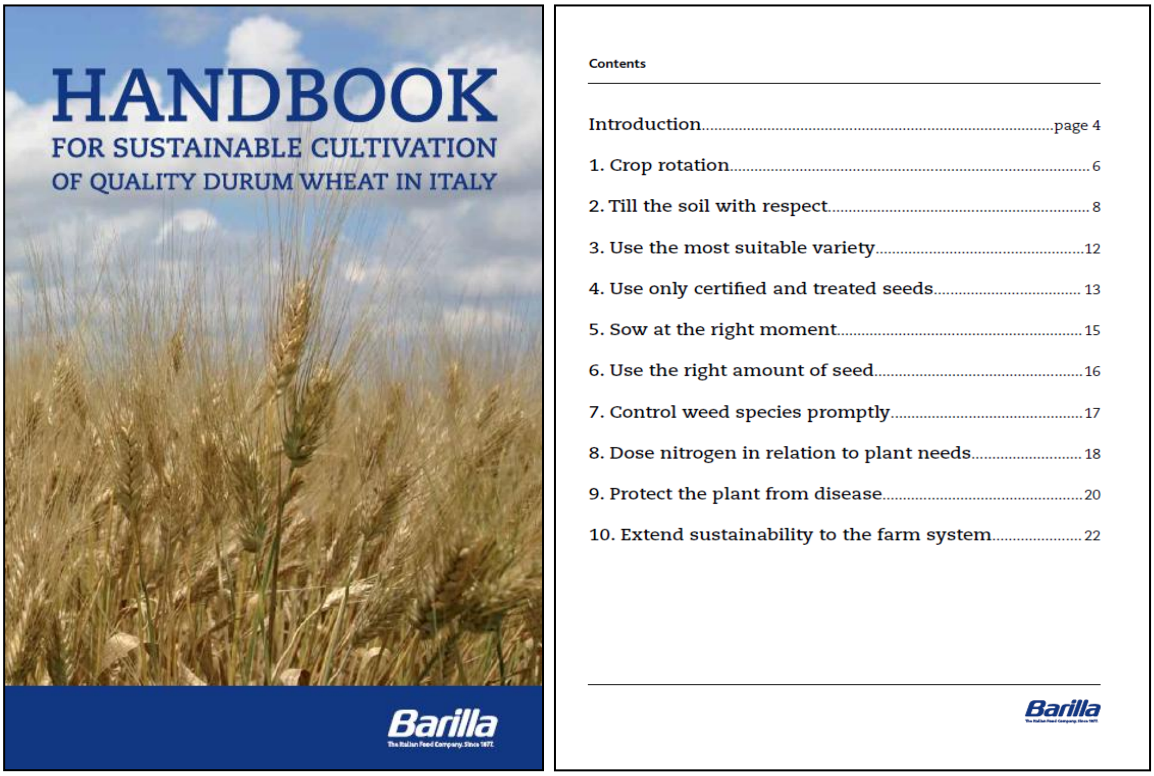
- weeds. Data of miscibility of herbicides, weather thresholds, chemical and physical properties of herbicides, weeds effectiveness, field applicability according to wheat growing stage and weeds characteristics were collected;
- pesticides. Chemical and physical properties, all labels data, method of use, efficacy and toxicity risk data were accounted;
- register of farming operations. Seed companies and storage facilities were inventoried;
- fertilizers. The fertilizers used for durum wheat were categorized and estimated, as well the unit impact according to formulation, nutrients and chemical properties;
- fuel consumption. Any cropping activities was matched with a fuel consumption depending on machine, soil texture and field slope.

To fully understand the potential of this DSS one should consider that the most important weakness of sustainability is the difficulty to demonstrate its advantages. Sustainability hardly proves its benefit for the environment, but *granoduro.net*® through the calculation of cultivation impacts on the environment is able to prove the benefits of sustainability if this is pursued. *granoduro.net*® was chosen and used in the field evaluations for getting durum wheat production more environmentally durable. The matching of advices with the accounting of environmental impacts of cropping activities and technical tools makes this tool what farmers were looking for: a tool for reducing economic and environmental impacts and for proving the benefits of practices carried out into fields.

granoduro.net® is a “working in progress” project where Horta’s staff as a whole has contributed and will concur at the implementation of best and new services.

3.2.2 Handbook for sustainable cultivation of quality durum wheat in Italy

During the PhD a Decalogue for sustainable cultivation of quality durum wheat in Italy was drawn in collaboration with Barilla S.p.A., Horta S.r.l. and LCE S.r.l. (Figure 30). It is a handy booklet to answer needs of increasing durum wheat quality, decreasing of impacts of cropping system and a comeback to basic aspects of agronomy. In this handbook the 10 rules that farmers and technicians must comply for deliver durum wheat to Barilla S.p.A are described.



Contents

Barilla

Figure 30: The cover and contents of the handbook drawn up for Barilla S.p.A. Ten agronomical rules are listed to help farmers to increase sustainability quality durum wheat cultivation in Italy. Processing by Horta S.r.l. and LCE S.r.l..

Sustainability implies the production of goods and food respecting the environment, the economic advantage for farmers and society. Sustainable agriculture contributes for improving the quality of life for both farmers and the community as a whole.

The sustainable farmer gives priority to production systems that help preserve environmental resources, safeguard their wellness and produce an adequate quality and quantity of food, with a connected economic reward. Agricultural sustainability is a priority for the new Common Agricultural Policy (CAP 2014-2020).

This handbook for wheat cultivation is a list of guiding principles for farmers who face the complex challenges of modern agriculture.

The aims of the ten rules that will be described in details in the following pages are:

- DON contamination reduction;

- increase of quality yield;
- reduction of environmental impacts.

Rule 1: Crop rotation

Rotating durum wheat with dicotyledonous crops (e.g. soybean, sunflower, rapeseed, tomato, sugar beets, alfalfa, pulses, grass, etc..):

- **Rotation reduces the environmental impact.** For example, the rotations with dicotyledonous allows a reduction of greenhouse gas by over 30%, due to the possibility of using less fertilizers (Figure 31).

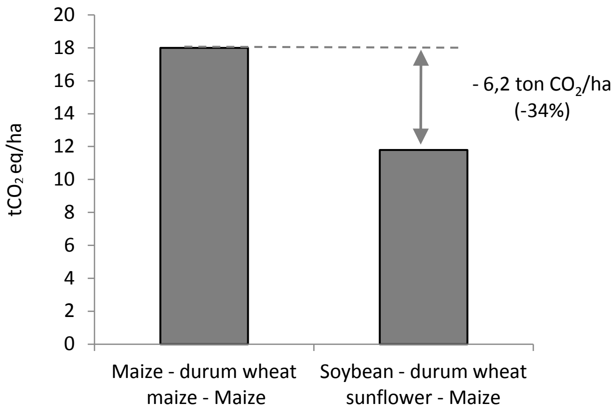


Figure 31: Emission of CO_2 (tCO_2 eq/ha) of two quadrennial crop rotations. Study data "Sustainability of crop systems" coordinated by Barilla, 2010. Processing by LCE S.r.l. and Horta S.r.l..

- **Crop rotation increases the income of the field.** The rotation with dicotyledonous allows approximately a 60% increase of total net income, mainly due to the possibility of obtaining higher yields without decreasing costs (Figure 32).

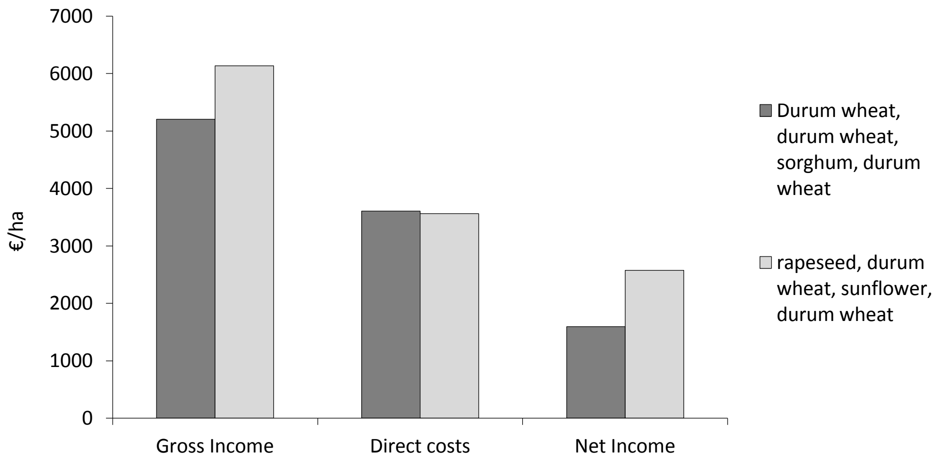


Figure 32: Economic indicators into two different quadrennial rotations in central Italy (€/ha). Study data "Sustainability of crop systems" coordinated by Barilla, 2010. Processing by LCE S.r.l. and Horta S.r.l..

Rule 2: Til soil with respect

Tilling soil in a more conservative manner while taking into account the local area, climate, type of soil and rotation performed, is crucial to preserve its fertility.

- **Conservative tillage allows significant cost savings** (Figure 33). Minimum soil tillage cuts costs of 30-35% (Figure 33) and CO_2 emissions of 30% (Figure 34) compared to traditional methods.

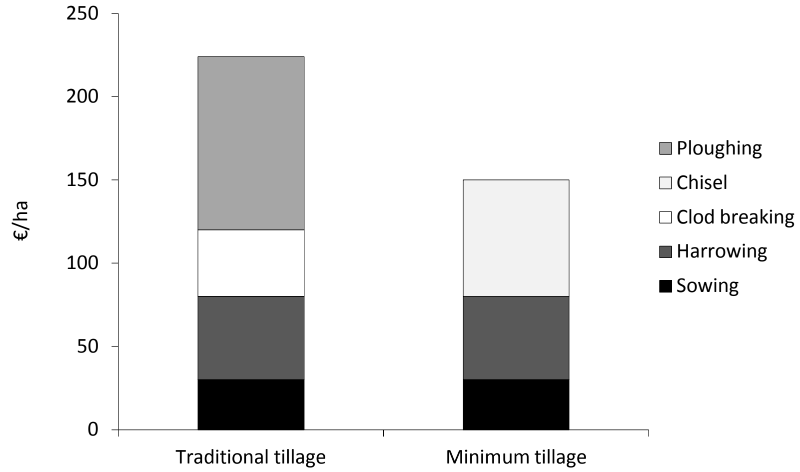


Figure 33: Comparison of sowing costs (€/ha) between traditional and minimum tillage. Study data "Sustainability of crop systems" coordinated by Barilla, 2010. Processing by LCE S.r.l. and Horta S.r.l..

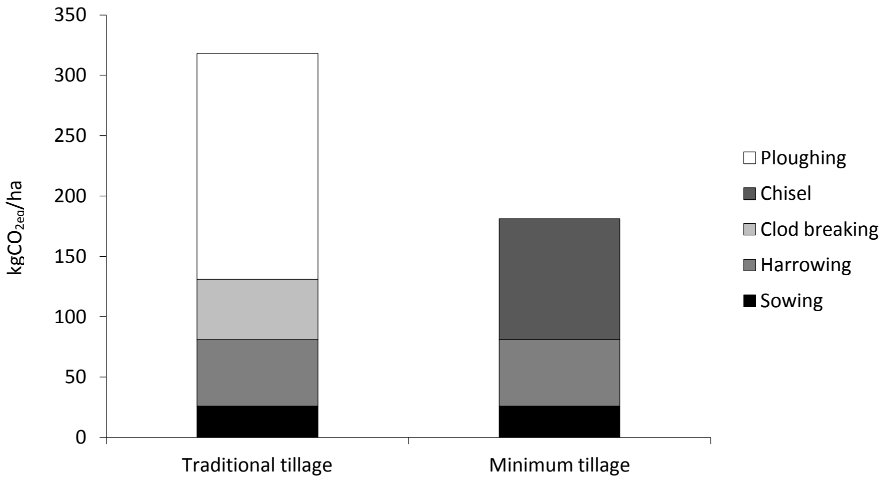


Figure 34: Comparison of sowing emissions ($kgCO_{2eq}/ha$) with a traditional and minimum tillage. Study data "Sustainability of crop systems" coordinated by Barilla, 2010. Processing by LCE S.r.l. and Horta S.r.l..

- **Soil tillage is one of the key elements for reducing mycotoxin risk.** Conditions of high Fusarium head blight risk require land ploughing to reduce inoculums pressure. The risk of DON contamination is higher with minimum or no-tillage, whereas with ploughing the risk of contamination falls down of 79% (Figure 35).

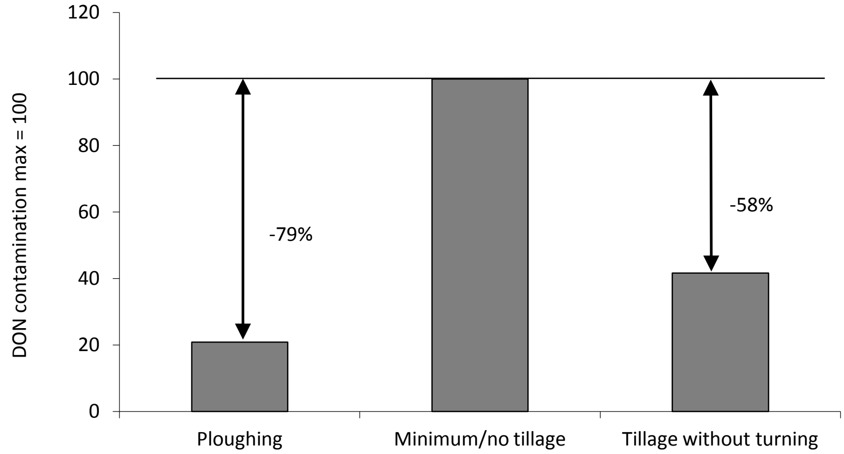


Figure 35: Contribution of ploughing and tillage without turning for decreasing DON contaminations into wheat produced in the 800 plots of Emilia-Romagna region (from 2002 to 2004) with different soil tillage methods. Studies of "Università Cattolica del Sacro Cuore" of Piacenza, Italy, 2004.

Soil tillage is influenced by rotation practiced and the area. In the Table 1 a framework of some recommendations about soil tillage are described for the north, centre and south of Italy with four different type of rotations.

Table 1: Recommendations about ploughing according to area and rotation.

Legend: +++ recommended; ++ advised; + possible; - not advised tillage. Processing by LCE S.r.l. and Horta S.r.l..

Tillage	Northern Italy		Central Italy		Southern Italy	
	Rotation of durum wheat with maize, sorghum and wheat	Rotation of durum wheat with soybean, oilseed rape, tomato, alfalfa and sugar beet	Rotation of durum wheat with maize, sorghum and durum wheat	Rotation of durum wheat with soy, rapeseed, tomato, alfalfa, peas and sugar beet	Monoculture of durum wheat	Rotation of durum wheat with sunflower, oilseed rape and field bean
Deep ploughing (40 – 45 cm)	+++	+	+++	+	+	-
Shallow ploughing (25-30 cm)	+++	++	+++	++	+++	++
Combined/ minimum tillage (25 – 30 cm)	+	++	++	+++	+++	+++
Sod seeding	-	++	-	+++	-	+++

Rule 3: Use the most suitable variety

Choosing the variety in relation to the cropping area and expectations in terms of productivity and technological quality: choose the variety on the basis of production criteria, production stability, resistance to adversities and technological quality.

Rule 4: Use only certified and treated seeds

Only certified seeds guarantee varietal identity (productive potentiality, technological quality and resistance to adversities) and quality of the seeds (purity, germination).

Using certified seeds allows better selection and improved marketed varieties of seeds. Only industrially treated seed allows the best protection against pathogens found on kernels and better active distribution upon each seed.

In Figure 36 dots represent average value of new accessions included into the official trials, while the line represents the growing trend of production over the years thanks to genetic enhancement.

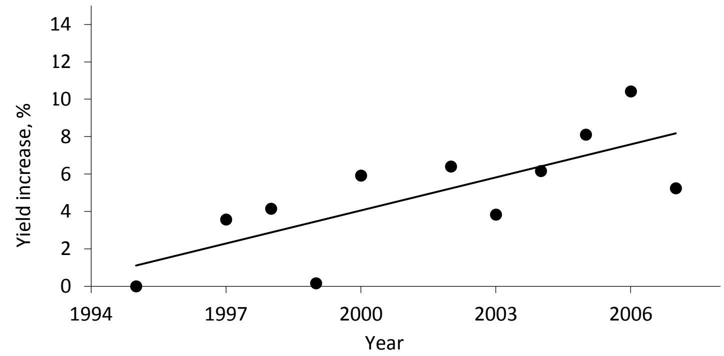


Figure 36: Yields increase (%) of new varieties compared to the Creso and Simeto average (set at 100). National network of variety trials of durum wheat.

Rule 5: Sowing at the right moment

The behaviour of durum wheat variety changes in relation to area and weather conditions. With different time of sowing, the varieties recommended change. The varieties produce differently in relation to sowing period. Some varieties adapt better to late sowing (Figure 37).

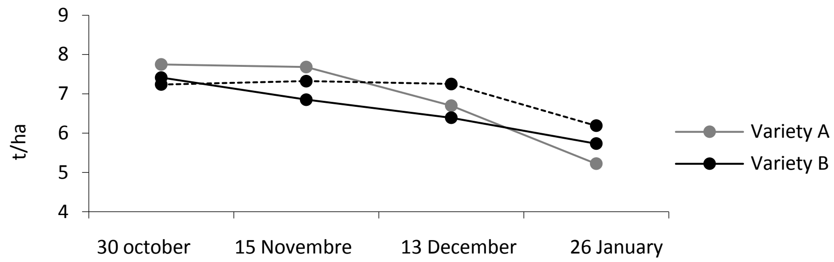


Figure 37: Wheat yield (t/ha) of three varieties sown at four different moments. Processing by LCE S.r.l. and Horta S.r.l..

Rule 6: Use the right amount of seed

Select sowing density in relation to variety, crop area, planting period and soil conditions.

Excessively dense planting prevents crops from the best exploiting of reserves and fosters development of disease (Figure 38). In the figure the variety “A” achieves maximum productivity with balanced sowing rate, whereas variety “B” achieves higher yields with higher investments.

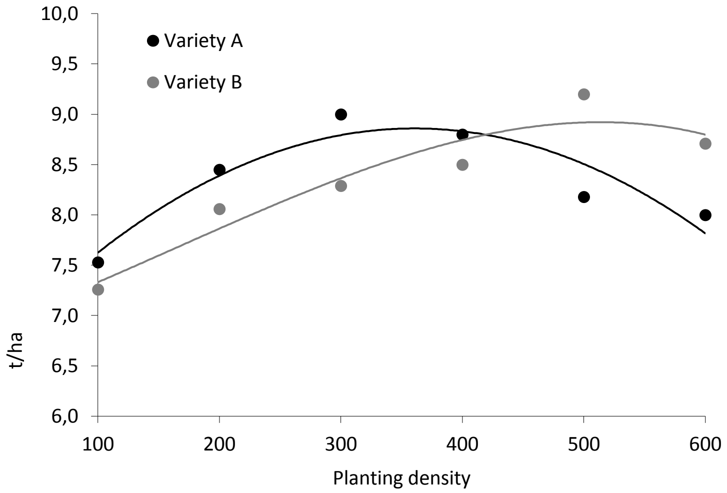


Figure 38: Wheat yield (t/ha) of two varieties with different sowing density in the Emilia Romagna region in 2011.

Rule 7: Weed control

Treatment’s delay leads to consistent production losses due to competition of crop with infesting species. It is crucial to select proper weeding solutions in regard to weed infestation as well as weather and crop conditions. For example, in the southern Italy springtime treatments with herbicides against Avena spp. can lead to production losses of up to 80% compared to winter treatment (Figure 39).

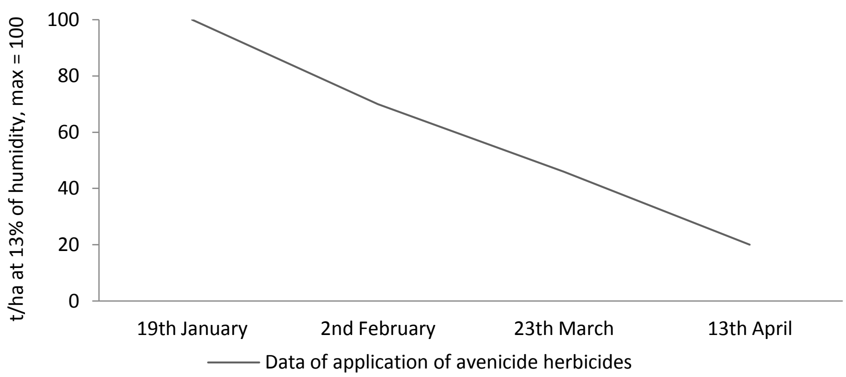


Figure 39: Wheat yield (t/ha at 13% of humidity) in relation to application stage of the two herbicides against wild oats. Tests performed in Foggia (south of Italy). The yield potentiality of the 19th January is set equal to 100. Processing by LCE S.r.l. and Horta S.r.l..

Rule 8: Fertilization in relation to plant needs

Achieving higher yield and protein implies correct dosage of nitrogen by fractionating it in relation to plant needs. High efficiency of nitrogen is obtained considering the required amount of nitrogen supply to wheat according to crop rotation, land endowment, variety cropped and climate pattern. In different year, the highest production was achieved with different doses: differences are caused by climate and crop rotation (Figure 40).

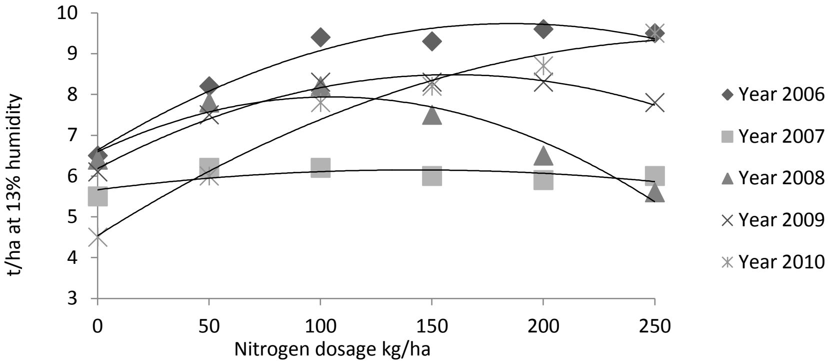


Figure 40: Wheat yield (t/ha at 13% of humidity) under increased dosage of nitrogen fertilizers over five-year period (2006-2010). Tests carried out in Ravenna (north of Italy) by the Terremerse Cooperative in 2006-08 and by Horta in 2009-10. Processing by LCE S.r.l. and Horta S.r.l..

Nitrogen spread out during planting has low efficiency because it is leached by winter precipitation. Nitrogen is more effective when fractionated during cropping season. A fertilization during stages of development is important for the productivity, whereas a fertilization during booting or heading, is crucial to obtain a high protein content (Figure 41).

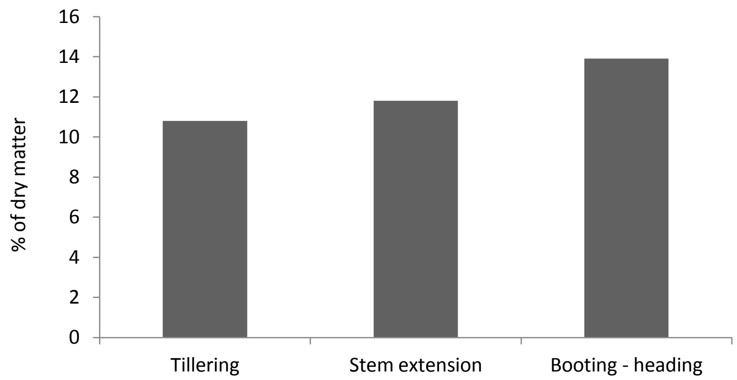


Figure 41: Protein content (% of dry matter) obtained with 3 different times of application of nitrated fertilizers. Tests carried out in Ravenna (north of Italy) in 2011. The same nitrogen dose of 41 units (from ammonium nitrate) was applied during tillering, stem extension and booting-heading. Processing by LCE S.r.l. and Horta S.r.l..

Rule 9: Pests control

Farmers should carry out treatment in relation to real risk. Risk depends mainly on varietal susceptibility, stage of development, agronomic choices, weather conditions, incoculum and infective pressure of pests.

Fusarium head blight is one of the most important disease of durum wheat in Italy also because Fusarium species produce the mycotoxin DON (Deoxynivalenol). Control of Fusarium must be performed through preventive and curative measures. Several factors affect mycotoxin production (Figure 42). The 47% of risk onset is influenced by seasonal trend and cultivation area, varietal species influence for the 33%, crop rotation 8%. The remaining 12% depends on soil tillage choices (Giosué and Meriggi, 2010).

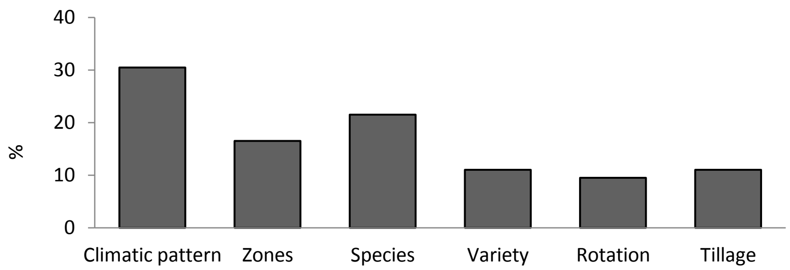
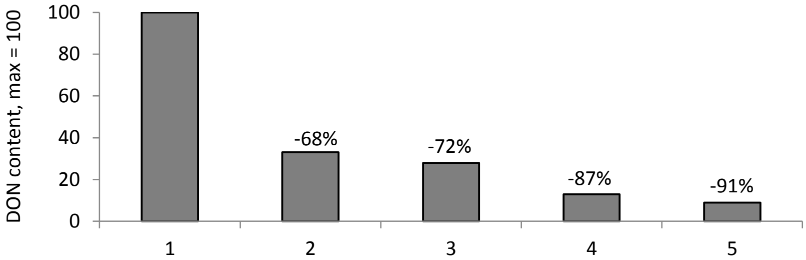


Figure 42: Contribution in % of different DON accumulation factors. Data processed over a three-year study performed in Emilia Romagna by Università Cattolica del Sacro Cuore in 2005.

Different crop strategies can affect toxins production in a different way. Combining the factors described in Figure 42 the risk of contamination will be different. Limiting DON content in cereal can be achieved only through an overall strategy that accounts for all crop aspects (Figure 43).



	1	2	3	4	5
Fungicide treatment	no	no	no	no	yes
Crop rotation	cereals	cereals	other crops	other crops	other crops
Tillage	sod	ploughing	ploughing	ploughing	ploughing
Variety	A	A	A	B	B

Figure 43: Effects of different technical strategies on DON content into kernels. Trials performed in 3 place of the Po valley (Northern Italy) for the research project SINSIAF. The worst situation (situation 1) is set equal to 100. Tests performed by Università Cattolica del Sacro Cuore in 2007. The percentage values express the reduction of risk compared with the highest value (situation 1: no one fungicide treatment, cereal rotation, sod seeding and susceptible variety "A"). Processing by LCE S.r.l. and Horta S.r.l..

Rule 10: Extend sustainability to farm system

Planning the whole rotation and integrating durum wheat cultivations in the schedule allows to reach objective more easily. Moreover, the employment of technical measures in respect of good farm practices and the compliance with guidelines for Integrated Pest Management (IPM) will entail a sustainable use of resources and pesticides. Finally, the adoption of farm hydraulic measures to prevent erosion, runoff and contamination of water bodies and fostering bio-diversity actions (use hedges, cover crops, etc.) will simplify the achievement of purposes.

3.3 Validation of innovative tools for the sustainable durum wheat management and of sustainability indicators

3.3.1 Feasibility study

The first step of the validation project was the identification and comparison (based on historical data) of the different cropping systems practiced by growers during durum wheat cultivation in Italy (country from which about 75% of the durum wheat for Barilla's pasta production comes from). The objective of this first step was to identify the cropping systems and crop rotations able to achieve better economic, quality, safety and environmental performance (Ruini et al. 2010).

The 13 more representative Italian four-year crop rotation systems were analysed taking into consideration also their geographical distribution (Ruini et al. 2011).

In the north the following five scenarios were tested:

1) *Maize rotation*: Maize, Durum wheat, Maize, Maize;
2) *Diversified rotation*: Soybean, Durum wheat, Oilseed rape, Maize.
3) *Cereals rotation*: Maize, Durum wheat, Grain Sorghum, Common wheat;
4) *Industrial rotation*: Soybean, Durum wheat, Maize, Common wheat;
5) *Horticoltural rotation*: Tomato, Durum wheat, Maize, Common wheat.

In the centre the following four scenarios were tested:

6) *Cereals rotation*: Durum wheat, Durum wheat, Grain Sorghum, Durum wheat;
7) *Proteic pea rotation*: Pea, Durum wheat, Pea, Durum wheat;
8) *Alfalfa rotation*: Alfalfa, Alfalfa, Alfalfa, Durum wheat;
9) *Industrial rotation*: Oilseed rape, Durum wheat, Sunflower, Durum wheat.

In the south the following four scenarios were tested:

10) *Durum wheat rotation*: Durum wheat, Durum wheat, Durum wheat, Durum wheat;
11) *Fodder rotation*: Oats and vetch, Durum wheat, Oats and vetch, Durum wheat;

12) *Horticoltural rotation*: Tomato, Durum wheat, Durum wheat, Durum wheat;

13) *Chickpea rotation*: Chickpea, Durum wheat, Chickpea, Durum wheat.

For each cropping system two different management strategies were considered:

- High Input (Hi): characterized by deep soil tillage, wide use of fertilizers and pesticides;
- Low Input (Li): characterized by minimum tillage, limited use of fertilizers and pesticides without the possibility of irrigation (except with tomato).

When possible a third management strategy was also considered:

- Organic farming (Org): which excludes the use of synthetic fertilizers and pesticides.

For the evaluation of impacts of the above mentioned crop rotation systems and management strategies the indicators described in the former section were used. To calculate *carbon*, *water* and *ecological footprint* indices the software SimaPro 7 was used. It is a widely used program for calculating the emission by means of a life cycle assessment (LCA) approach for products and/or production processes of any production sector. The input data were taken from the database Ecoinvent (one of the largest web-based inventory of environmental impacts of goods and processes), collected directly in the farms or estimated with the help of the IPCC (Intergovernmental Panel on Climate Change) manuals. The process for the calculation of the indicators followed ISO 14000 standards, which were used as guidelines to understand environmental impact assessment principles, and the results are shown in Table 2.

Table 2: Main outcomes about the emissions, net income, nitrogen efficiency and DON index of the selected rotations in different areas of Italy. Average of the high and low input management strategies. Processing by Horta S.r.l..

	Region	Cropping system	Yield (t/ha)	Carbon Footprint[1] (tCO_2eq/t)	Water Footprint ($m^3 H_20/t$)	Ecological Footprint (global ha/t)	Net Income (€/t)	Agronomic NUE (kg/kg)	DON Risk (0-9)
Noth	Lombardy, Veneto and Friuli Venezia Giulia	Maize	7	0.51	315	0.38	155.3	33.8	7.9
		Diversified	7.5	0.42	294	0.36	166.9	44	1.7
	Emilia Romagna	Cereals	7.3	0.51	328	0.4	140.7	32.5	7.9
		Industrial	7.5	0.41	315	0.38	156.7	42.2	2.3
		Horticultural	7.5	0.36	315	0.38	151.1	47.1	1.7
Central	Marche, Tuscany	Cereals	3.3	0.67	745	0.73	24.1	28.4	3.9
		Proteic pea	5.3	0.43	502	0.49	138.8	45.3	0
		Alfalfa	4.3	0.3	478	0.47	99.4	66.7	0
		Industrial	5.3	0.34	479	0.47	139.2	58.5	0
South	Apulia, Basilicata, Sicily	Durum wheat	2.5	0.74	1429	1.11	23.3	32.4	1
		Fodder	5	0.45	694	0.54	132.8	44.3	0
		Horticultural	4.2	0.53	874	0.68	111.8	38.7	0
		Chickpea	5	0.45	694	0.54	132.8	44.3	0

[1]The calculation of carbon footprint does not take into account the sequestration of carbon performed by crops during growing season because LCE S.r.l. estimated, in according with IPPC rules, that the carbon fixed as organic matter is for the 90% or more emitted in the air within the next two or three years, if usual practices of tillage are carried out.

Results for the three footprints indices obtained in this analysis are consistent with data available in literature. Usually for the cultivation of one ton of durum wheat between 0.3 – 0.8 tCO_2eq are produced, 300 - 1800 m^3 H_20 are consumed, and 0.3 – 1.3 global ha are required for resource production and waste disposal. These data were esteemed by the Barilla's EPD of pasta drown up in 2009.

In order to estimate the efficiency of each scenario the indicators values were converted into an efficiency index. The value of each indicator was converted into a number from 1 to 5: the higher the value, the higher the positive judgment of the cropping system and the lower its impact. This index was quantified for the thirteen rotations tested and results for the footprints indices are shown in Figure 44 for the north, centre and south of Italy.

The cereals rotation, both following high and low input strategy, is the worst scenario from the emission point of view in all Italian regions. While the best rotations resulted to be the diversified one in Northern Italy, the pea and alfalfa ones in Central Italy and fodder and chickpea ones in Southern Italy. "The restricted use of inputs ("Li") entailed an higher value of efficiency index (and therefore lower impacts) except for the cereals rotation in northern and central Italy and for the durum wheat monoculture in southern Italy. Usually, within unfavourable rotations (i.e. the cereals rotation in the north and centre or the durum wheat monoculture in the south of Italy) the restricted use of chemicals ("Li") entailed an lower value of efficiency index. This happens because the negative effects of cereals monoculture (diseases occurring, soil depletion, decreasing of fertility) are speeded up with negative effects on yield and qualitative parameters.

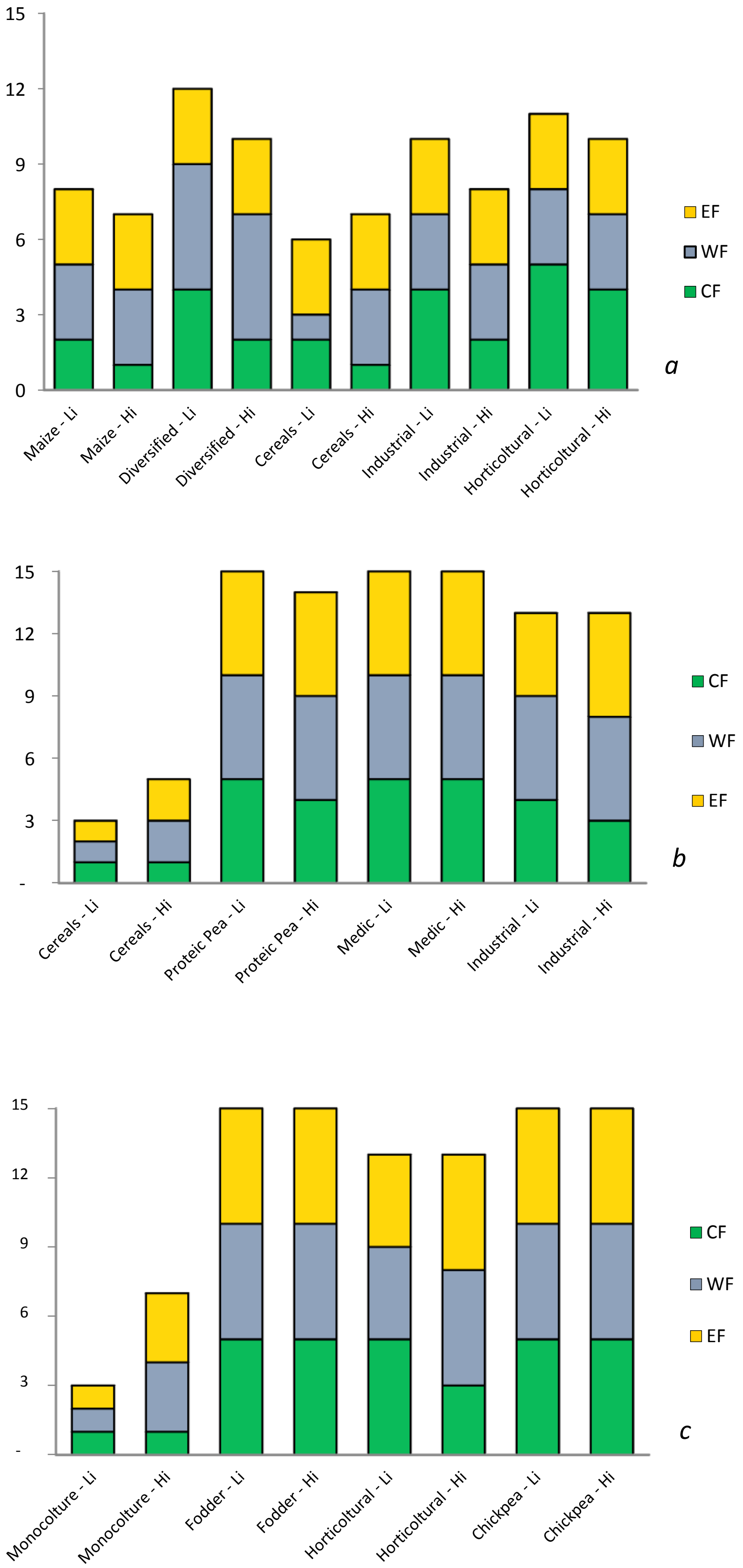


Figure 44: Efficiency index of different scenarios in the north (a), centre (b) and south (c) of Italy. Higher is the efficiency index, lower will is the impact on the environment. "Li": low input, "Hi": high input. EF: Ecological Footprint index, WF: Water Footprint index , CF: Carbon Footprint index. Processing by Horta S.r.l..

The calculation of the efficiency index (values 1-5) was done also for the indicators *Agronomic NUE* and *DON contamination*. Higher is the value of the efficiency index, lower is the nitrogen deficiency (i.e. a good availability of nitrogen by previous crop or a good chemical or organic fertilization plan) and the risk of mycotoxin DON occurrence.

In Northern Italy the rotations of durum wheat with soybean, oilseed rape and tomato increased the efficiency of fertilization and decreased the risk of *Fusarium* species development. For these two reasons, diversified, industrial and horticultural scenarios in the north of Italy have an efficiency index higher than rotations with cereals (maize and wheat), which promote *Fusarium* head blight occurrence. This happens also in the centre and south of Italy (Figure 45), where rotation of durum wheat with leguminous increases the index of nitrogen efficiency and decreases the risk of mycotoxins. Nevertheless in the centre and south of Italy the risk of DON contamination is naturally lower thanks to mainly dryer weather patterns during wheat flowering. The difference between high and low input scenarios are not significant for these two indicators for the majority of circumstances as can be seen in the Figure 45.

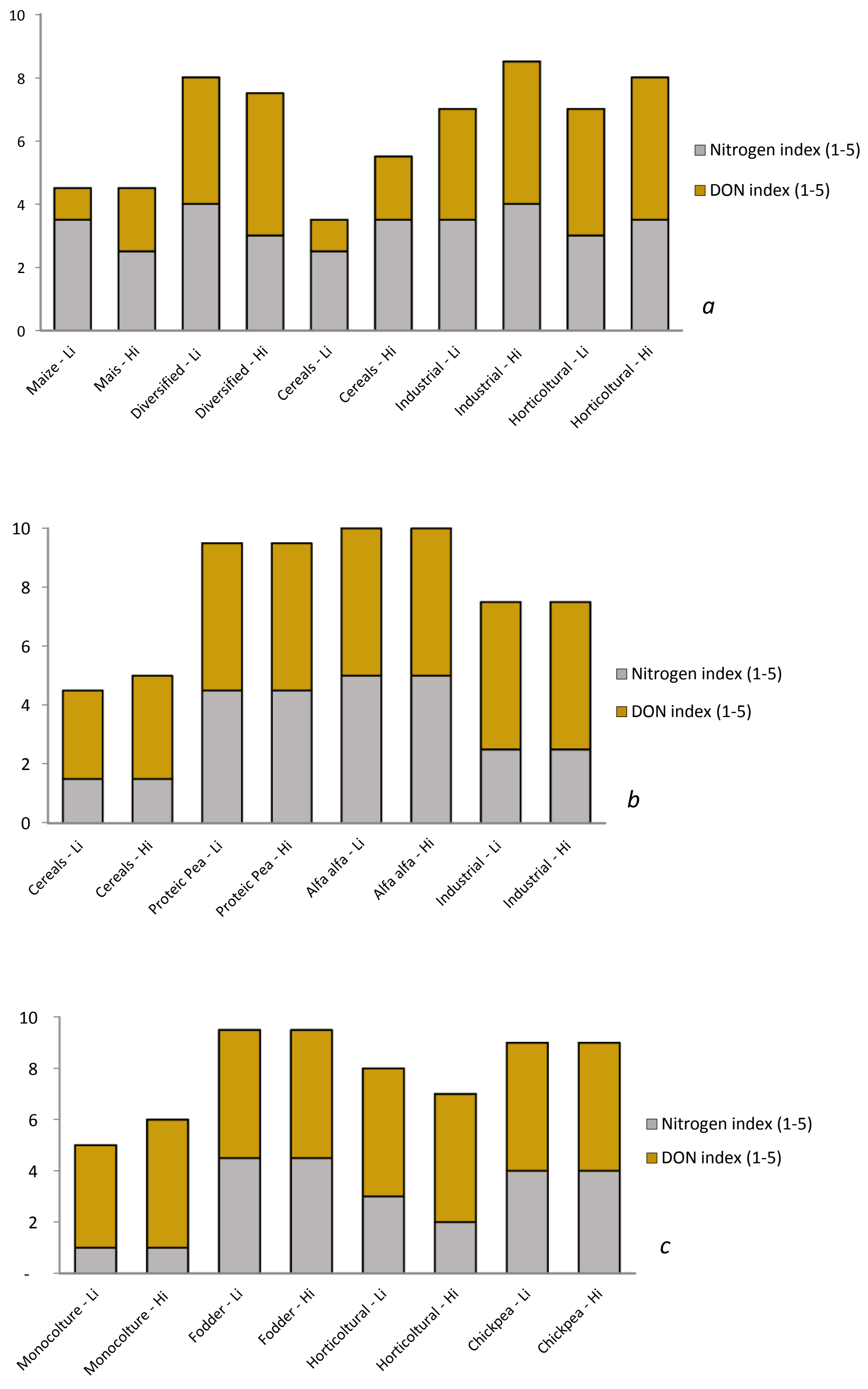


Figure 45: Efficiency index of different scenarios in the north (a), centre (b) and south (c) of Italy. Higher is the efficiency index, lower is the nitrogen deficiency and the risk of DON contamination. "Li": low input, "Hi": high input. EF: Ecological Footprint, WF: Water Footprint, CF: Carbon Footprint. Processing by Horta S.r.l..

The assessment of economic behaviour of the thirteen rotations was done through the indicator *net income*. For this evaluation the direct costs of cultivation operations and technical processes were updated at November 17th, 2009.

The rotation tested in the north are all profitable because yield are sufficiently high, while in the centre and south durum wheat rotated with other cereals or in monoculture makes cultivation inconvenient and only rotations with leguminous and horticultural crops guarantee a satisfactory return. Therefore, as happened with the previous indicators, also *net income* indicator disincentives the monoculture of durum wheat or the rotation of durum wheat with other cereals such as sorghum, common wheat and maize (Figure 46).

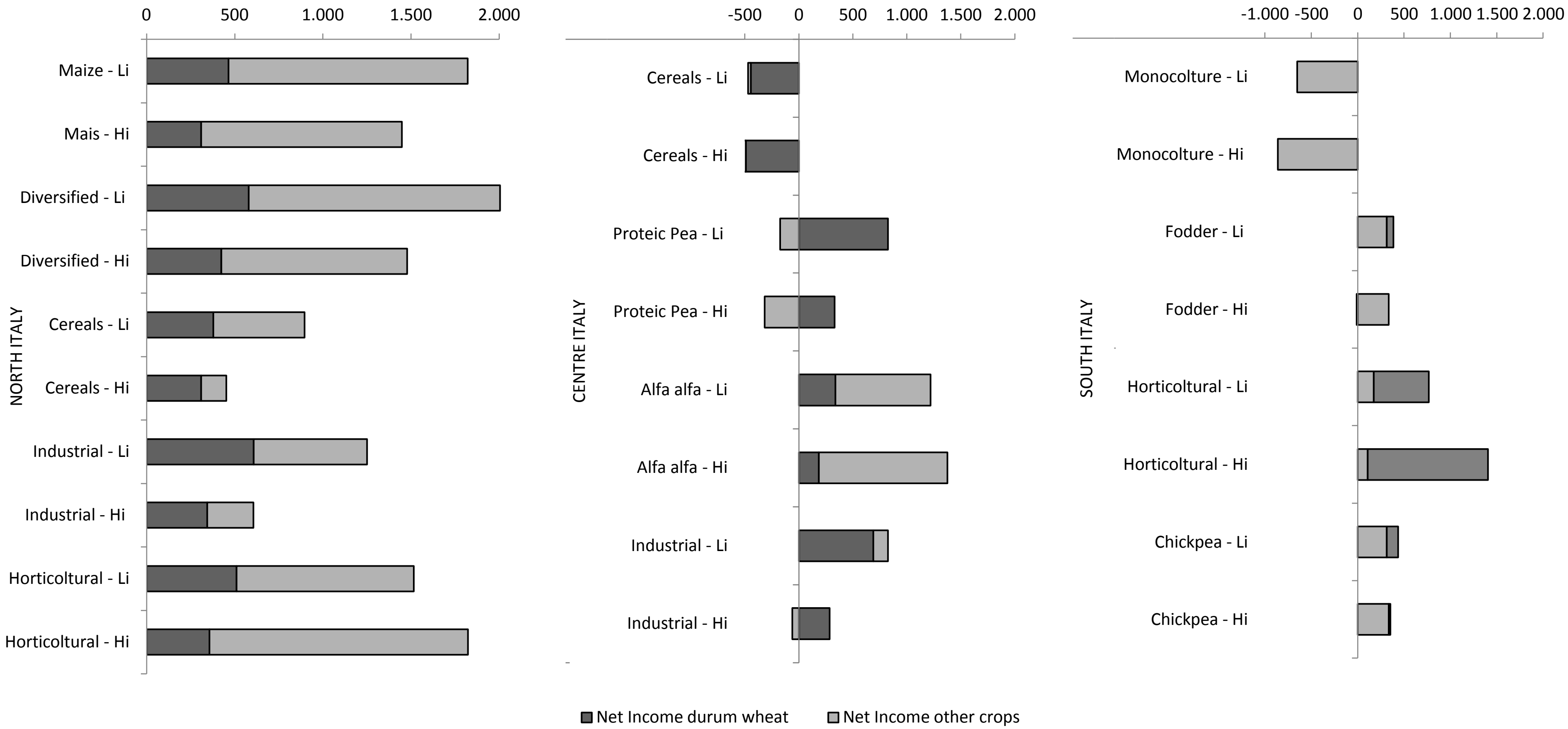
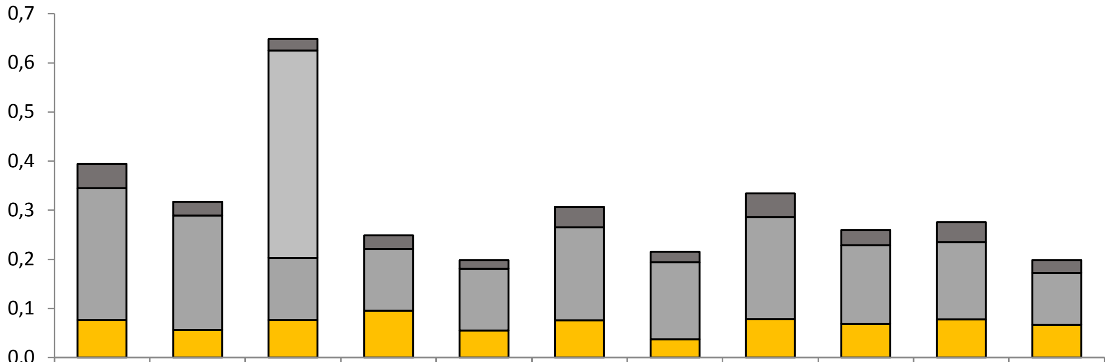


Figure 46: Net income (€/ha) of different scenarios in the north, centre and south of Italy where durum wheat is rotated with some crops. "Li": low input, "Hi": high input. Processing by Horta S.r.l..

To better understand which factor influenced mostly the emission of CO_2 in the atmosphere a sensitivity analysis on all footprint entries was also performed (Figure 47): the greenhouse gases emissions due to NH_4, N_2O and CH_4 produced during the storage and spreading out of organic and synthetic fertilizers were also considered. As already mentioned in Table 2 the CO_2 sequestered by crops was not taken into account because not relevant.

During durum wheat cultivation the most important contribution to Global Warming Potential (GWP) is given by the use of organic and synthetic fertilizers. Second ranked are the agricultural operations that generate greenhouse gases mainly by fuel consumption.



	Horticultural hi	Horticultural li	Horticultural org	Medic hi	Medic li	Proteic pea hi	Proteic pea li	Chickpea hi	Chickpea li	Durum wheat hi	Durum wheat li
	North Italy			Central Italy				South Italy			
Other	0,05	0,03	0,02	0,03	0,02	0,04	0,02	0,05	0,03	0,04	0,03
Organic Fertilizers	-	-	0,42	-	-	-	-	-	-	-	-
Fertilizers	0,27	0,23	0,13	0,13	0,13	0,19	0,16	0,21	0,16	0,16	0,11
Agricultural operations	0,08	0,06	0,08	0,10	0,06	0,08	0,04	0,08	0,07	0,08	0,07

Figure 47: Contribution (tCO_2eq/t agricultural products) of the main entries of carbon footprint indicator to the increase of GWP during durum wheat cultivation. "li": low input, "hi": high input, "org" organic inputs. Processing by Horta S.r.l and LCE S.r.l..

Moreover, to better specify the carbon footprint indicator in Figures 48, 49, 50, 51, 52 and 53 are shown the values of CO_2 emitted by each single crop, for each single rotation, for the north, centre and south of Italy. The bar charts show the carbon footprint both per tons of agricultural production and per hectare. Since in Northern Italy livestock is common, for these scenarios the impacts by organic farming "Org" were also considered. Indeed, it was demonstrated that organic cropping systems that use manure or sewage lead to high impacts (Figures 48 and 49). The emissions of CO_2 are by 20-50% higher compared to the use of synthetic fertilizers. Therefore, from a carbon footprint point of view, organic agriculture is more impacting than conventional patterns.

When the emissions of CO_2 are considered per ton of agricultural production, maize and horticultural rotations are the less impacting ones. Nonetheless, this is mainly due to the fact that maize and tomato cultivations achieve very high yields: when emissions of CO_2 are reported per hectares these same rotations present very high impacts. Emissions of CO_2 per hectare of oilseed rape, sorghum and soy crops are lower compared to other crops. This is justified by the notoriously reduced use of technical tools (pesticides and fertilizers) for their cultivation.

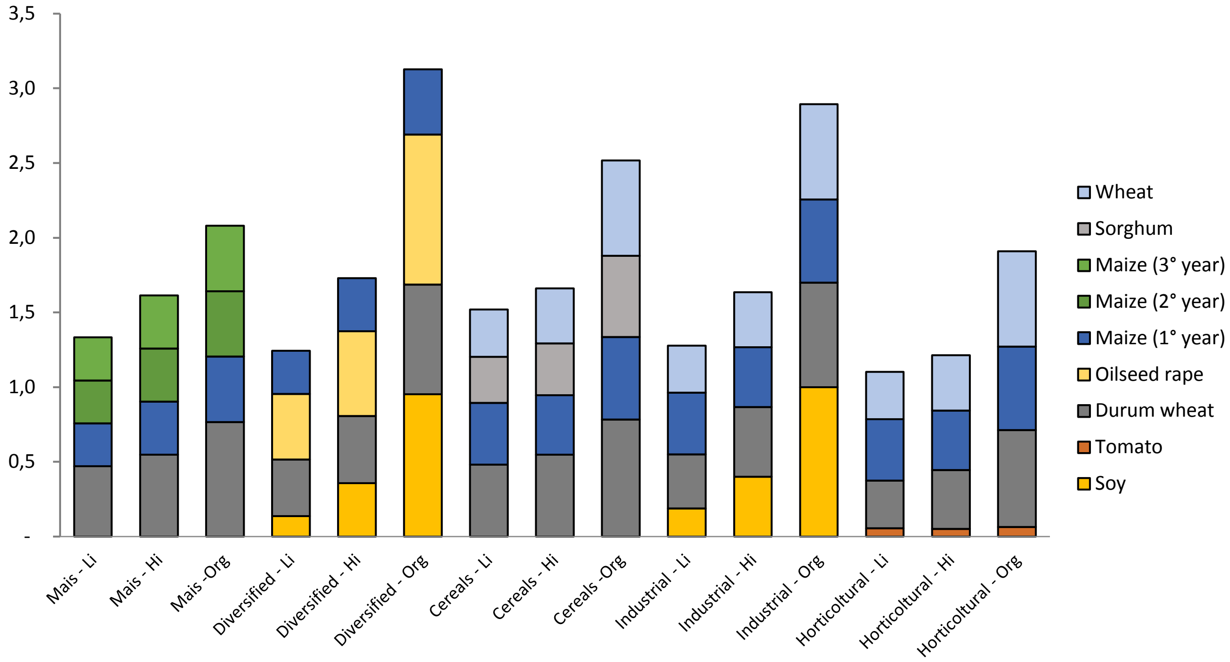


Figure 48: Carbon footprint related to several crop rotations carried out in the north of Italy with high (Hi), low (Li) or organic (Org) inputs. Emission expressed as tCO_2eq/t agricultural product. Processing by Horta S.r.l and LCE S.r.l..

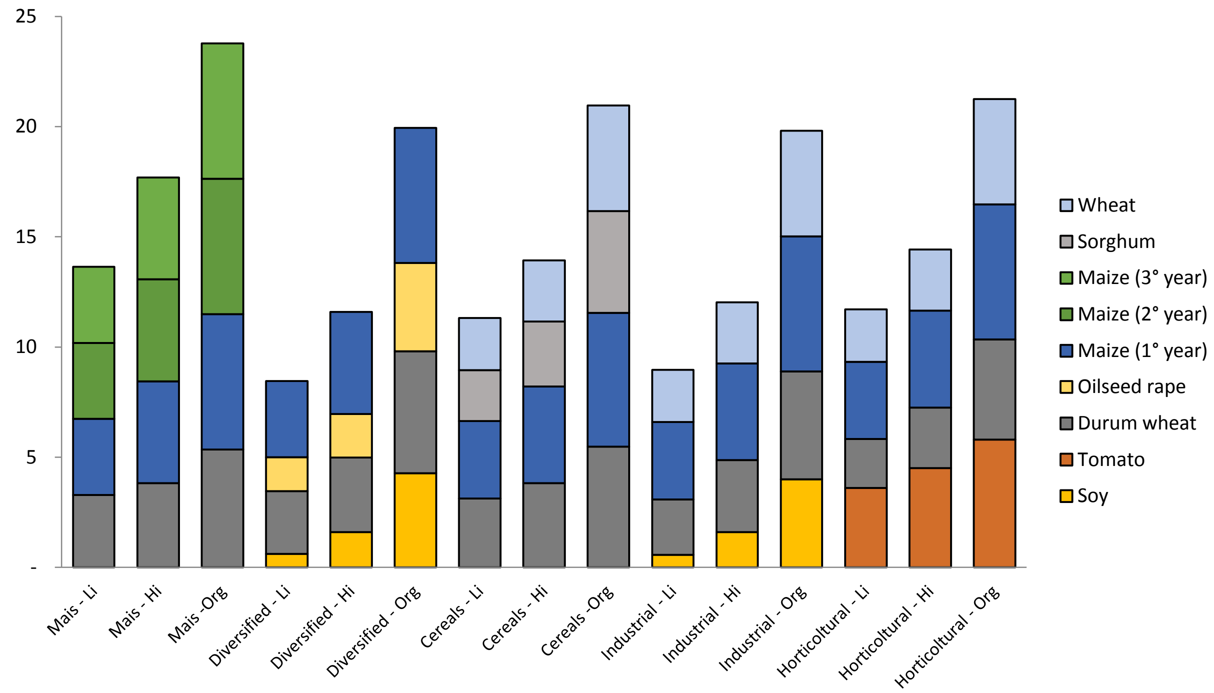


Figure 49: Carbon footprint related to several crop rotations carried out in the north of Italy with high (Hi), low (Li) or organic (Org) inputs. Emission expressed as tCO_2eq/hectare. Processing by Horta S.r.l and LCE S.r.l..

In central Italy (Figures 50 and 51) the results obtained for alfalfa rotation proved the key role played by leguminous fodder to collapse CO_2 emissions: only during the first year the emissions are significant because an arrangement of fields is requirement, but from the second year, the emissions are almost nil. The emissions of durum wheat in the centre of Italy are the highest of all crops judged in the scenarios; if emission are accounted per tons of harvested, only sunflower emission is higher than durum wheat (Figure 50).

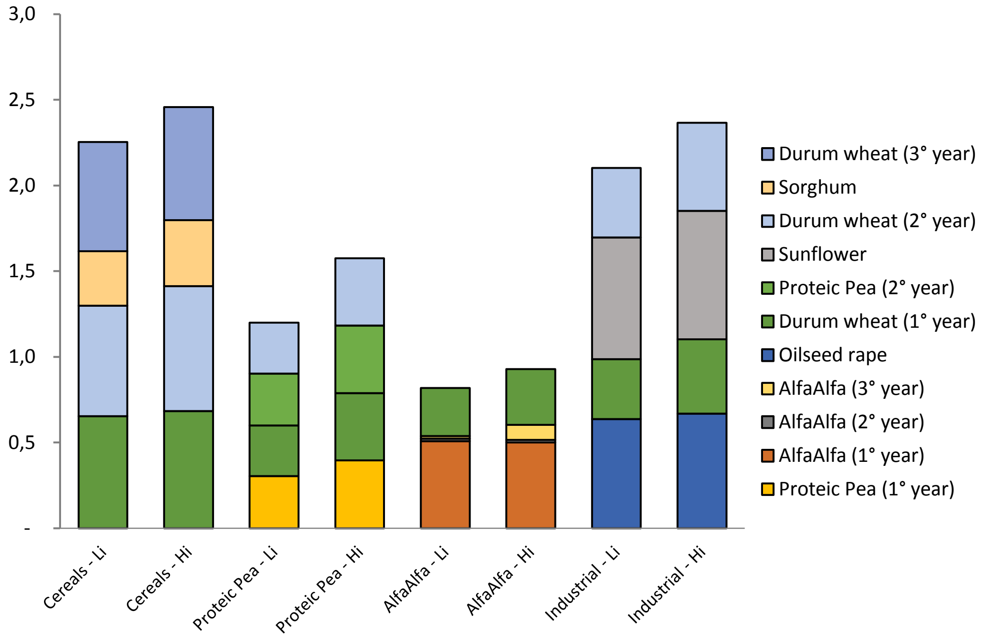


Figure 50: Carbon footprint related to several crop rotations carried out in the centre of Italy with high (Hi) or low (Li) inputs. Emission expressed as tCO_2eq/t agricultural product. Processing by Horta S.r.l and LCE S.r.l..

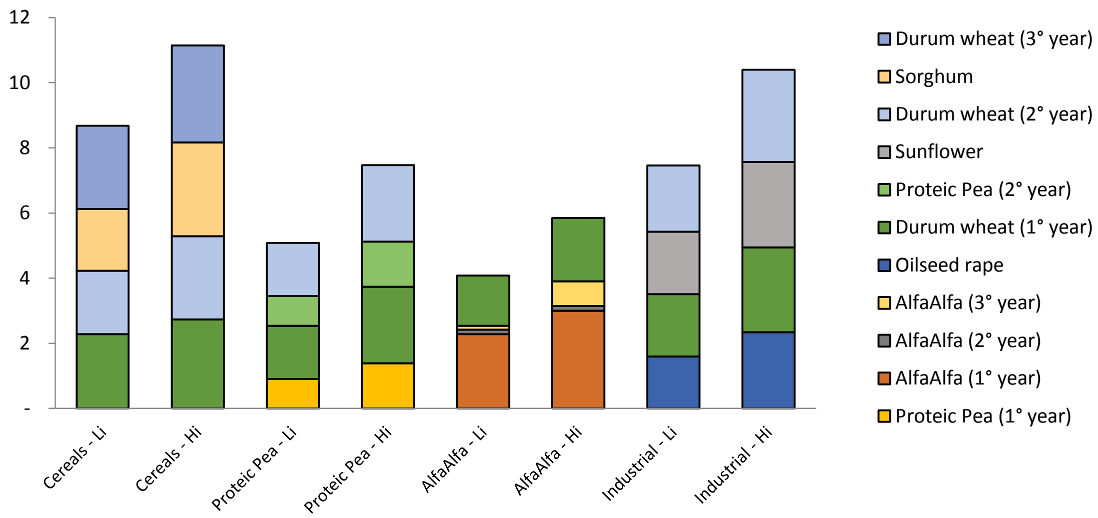


Figure 51: Carbon footprint related to several crop rotations carried out in the centre of Italy with high (Hi) or low (Li) inputs. Emission expressed as tCO_2eq/hectare. Processing by Horta S.r.l and LCE S.r.l..

Figures 52 and 53 provide the results obtained for Southern Italy. For this analysis an additional rotation was considered, being very common in the south of Italy: lentil, durum wheat, lentil and durum wheat. Like in the north and centre, the abundant use of fertilizers, chemicals and soil tillage increases the emission of CO_2 for every scenarios except for the monoculture of durum wheat. This happens because the yields, in a scenario with only durum wheat, are so low that the use of production factors increase the yield, and as a consequence the impact decrease, both per ton and hectare. Fodder rotation account for lowest CO_2 emissions. Lentil rotation determines important emissions per ton (Figure 52) but few emissions per hectare (Figure 53), due to a the very low yield per hectare. An opposite behaviour was registered for horticultural rotation because tomato cultivations achieve very high yields.

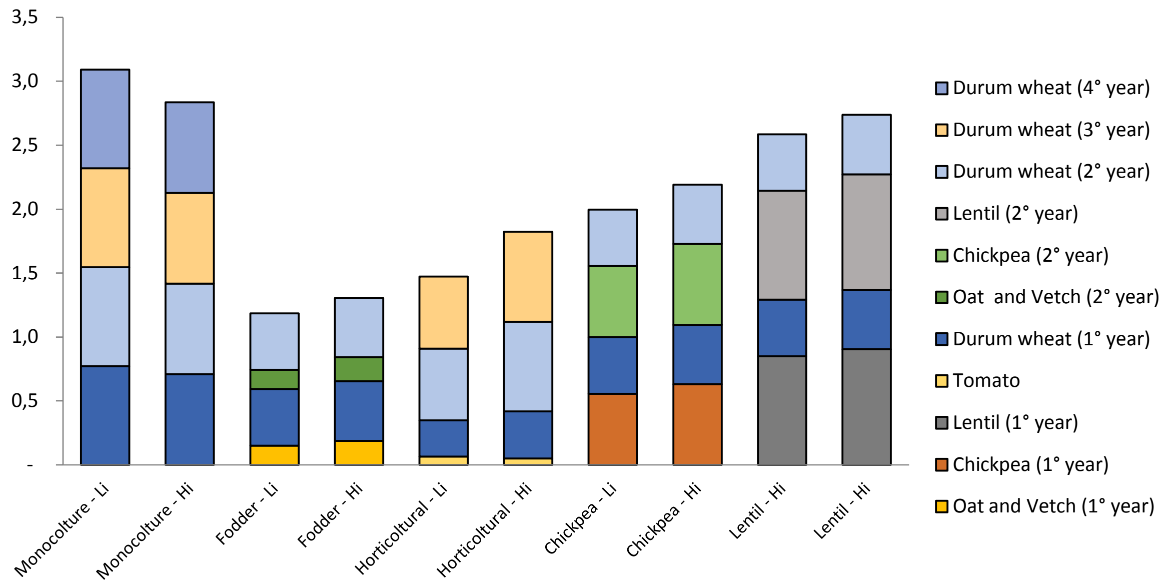


Figure 52: Carbon footprint related to several crop rotations carried out in the south of Italy with high (Hi) or low (Li) inputs. Emission expressed as tCO_2eq/t agricultural product. Processing by Horta S.r.l and LCE S.r.l..

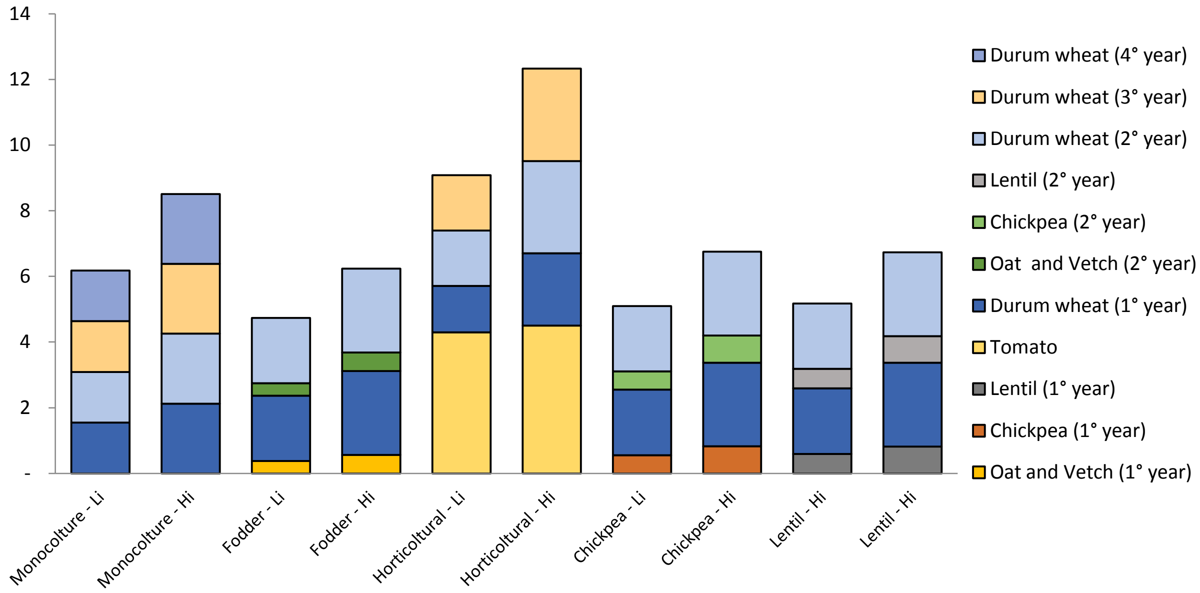


Figure 53: Carbon footprint related to several crop rotations carried out in the south of Italy with high (Hi) or low (Li) inputs. Emission expressed as tCO_2eq/hectare. Processing by Horta S.r.l and LCE S.r.l..

Once again it was demonstrated that, also in regards to emissions, crops do better when rotated with pulses. This occurs because pulses (i.e. peas, lentils, chickpea, alfalfa, clover fodder) decrease the greenhouse gas emissions of a crop rotation, thanks to very limited requirement of N fertilizers, and increase fertility of soil thanks to symbiotic nitrogen fixation, with positive effects on the forthcoming crops. They increase soil microbial diversity, which helps plants in rotation to simplify access to nutrients and consequently the lower need of N decreases the N_2O emissions and the non-renewable energy use.

From pests control standpoint pulses, being a broadleaf crop, help breaking cereals pest cycles, reducing pesticide applications during cereal year. Less pesticides entails also a water footprint 10-20% lower than wheat grown in monoculture. This happens also because pulses increase the availability of water for the next crop thanks to better soil structure by alternating variable deep-rooted plants.

Finally, to understand the potential of each scenario to increase fields sustainability, the environmental, agronomic and economic results were merged into an aggregated indicator, expressing the total efficiency of the different crop systems analysed (Figures 54, 55 and 56). The indicator was built up as a score system: a score from 1 to 5 was assigned progressively to all indicators considered and added up. Only for net income the score ranged from -5 to +5 in order to express also contexts of economic loss. Therefore, the maximum possible value was 30 (score 5 for all indicators), whereas the worst was -5 (score 0 for carbon footprint, water footprint, ecological footprint, nitrogen index, Don index and -5 for net income). The higher the score, the better the crop system evaluation.

In northern Italy (Figure 54) the total score for maize and cereals scenarios, which are considered the baseline scenarios, resulted to be lower than for diversified rotations (industrial and horticultural scenarios). The latter can be therefore identified as alternative and innovative options that should be promoted. Durum wheat monoculture or in rotation with other cereal crops is strongly discouraged since the score of total efficiency index is low (less than 15).

In the centre (Figure 55) best performances were given by durum wheat with pea, whereas the worst scenario was once again the monoculture. Not only pea but also alternative rotations with oilseed rape, sunflower and alfalfa are efficient.

In the south (Figure 56) the net income of monoculture scenario (a traditional scenario) is strongly negative and also other indicators have a poor performance. Instead, any rotations with dicotyledonous (which are considered innovative and alternative scenarios) should be suggested for increasing all pillars of sustainability.

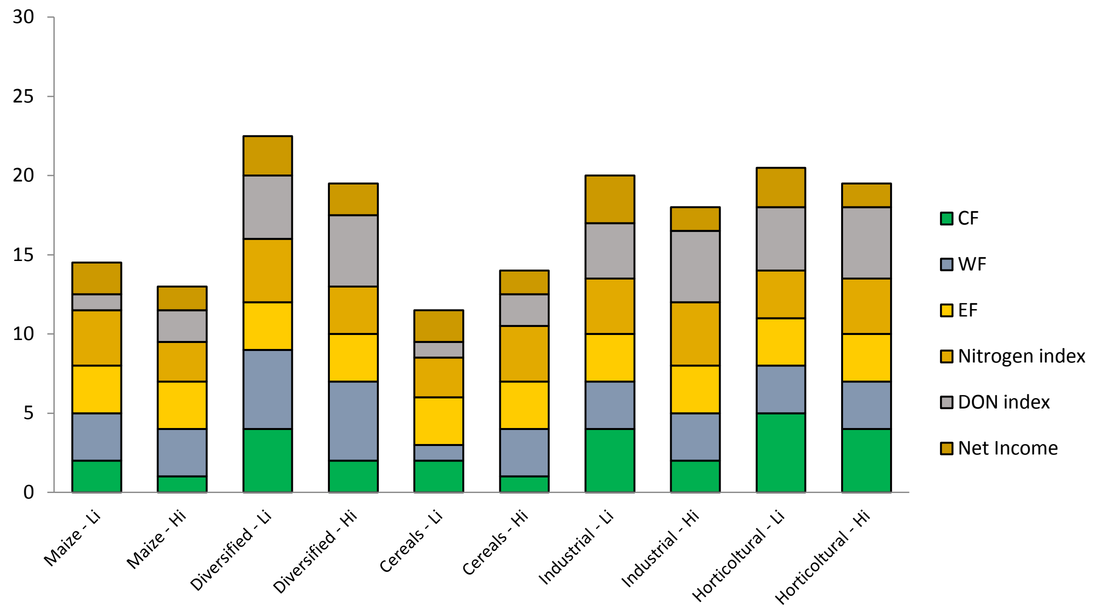


Figure 54: Overall efficiency index of several rotation patterns. CF, WF and EF mean Carbon, Water and Ecological Footprint. Scores of scenarios studied for the north of Italy with high "Hi" and low "Li" use of production factors. Processing by Horta S.r.l and LCE S.r.l..

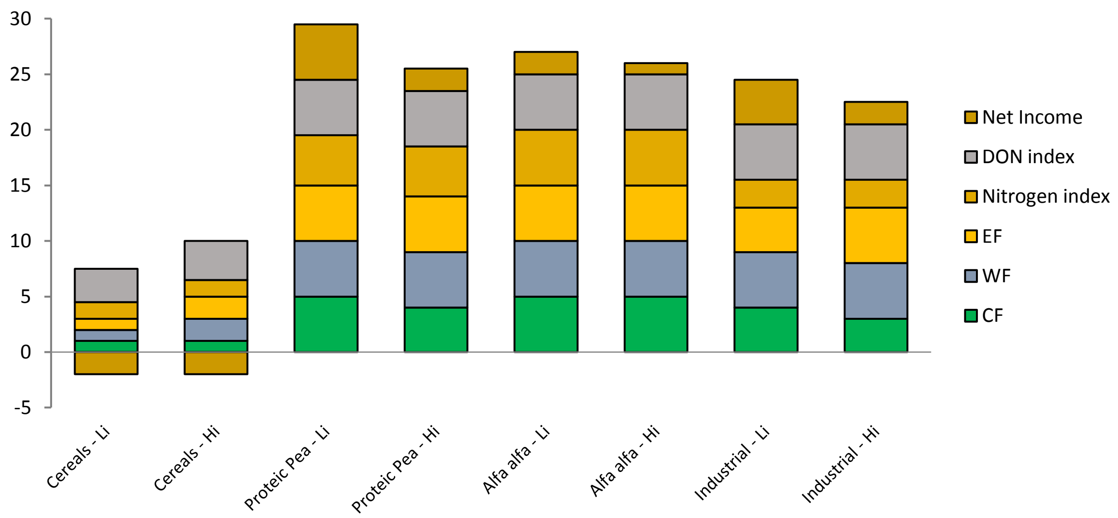


Figure 55: Overall efficiency index of several rotation patterns. CF, WF and EF mean Carbon, Water and Ecological Footprint. Scores of scenarios studied for the centre of Italy with high "Hi" and low "Li" use of production factors. Processing by Horta S.r.l and LCE S.r.l..

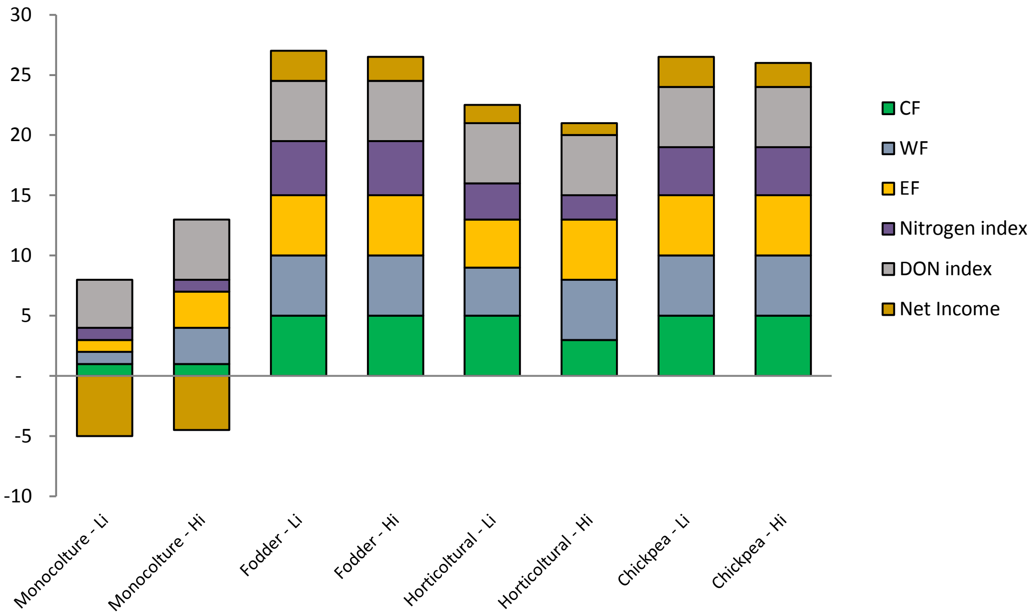


Figure 56: Overall efficiency index of several rotation patterns. CF, WF and EF mean Carbon, Water and Ecological Footprint. Scores of scenarios studied for the south of Italy with high "Hi" and low "Li" use of production factors. Processing by Horta S.r.l and LCE S.r.l..

This first study gave interesting theoretical outputs on how specific crop rotations achieve better environmental and economic performances. As a step forward project partners decided to evaluate impacts of the rotations really carried out by farmers in order to understand how distant are the real conditions to the optimal ones.

3.3.2 Comparison between real and optimised durum wheat management

To collect real data on rotations and crop management a questionnaire (Figure 57) was prepared and sent to 20 farmers selected, in agreement with Barilla, all around Italy.

FARM	
TOTAL HECTARES	
FILLING DATE	

			Year	2011	2010	2009	2008
CULTURAL ACTIVITIES	Description	Cultural activities costs- €/ha	Unit	SOY	DURUM WHEAT	CORN	COMMON WHEAT
Primary soil tillage	Ploughing 45/50 cm		number of transits				
	Ploughing 25/30 cm		number of transits				
	Combined grubber (30-40 cm)		number of transits				
	Ripping		number of transits				
	Other (to specify)		number of transits				
Secondary soil tillage	Harrowing		number of transits				
	Harrowing with revolving harrow		number of transits				
	Harrowing with rigid teeth or with springs		number of transits				
	Between rows weeding		number of transits				
	Between rows milling		number of transits				
	Other (to specify)		number of transits				
Conservation tillage	Direct sowing (combined)		number of transits				
	Sod sowing		number of transits				
Seeding on tillaged soil	Wheat sowing machine		number of transits				
	Precision sowing with localized phosphorus		number of transits				
	Tomato transplant		number of transits				
	Other (to specify)		number of transits				
	Other (to specify)		number of transits				
Fertilization	Granular manure distribution		number of transits				
	Other (to specify)		number of transits				
	Other (to specify)		number of transits				
Herbicides	Pre-seeding / pre-emergence		number of transits				
	Post-emergence		number of transits				
Pest control	Fungicide distribution		number of transits				
	Insecticide distribution		number of transits				
	Insecticide distribution with "stilt"		number of transits				
	Other (to specify)		number of transits				
Irrigation	Irrigation with sprinkling		number of transits				
	Irrigation with hoses (fertirrigation)		number of transits				
	Recovery hoses		number of transits				
	Other (to specify)		number of transits				
Harvesting	Summer crop combined harvesting		number of transits				
	Wheat combined harvesting		number of transits				
	Tomato harvesting		number of transits				
	Crop residues cutting up		number of transits				
	Other (to specify)		number of transits				
	Other (to specify)		number of transits				
TECHNICAL TOOLS	Description	Techincal tools costs- €/ha	Unit	SOY	DURUM WHEAT	CORN	COMMON WHEAT
Seed	Wheat seeds (these might be with fingicide and/or insecticide)		kg/ha				
	Corn seeds		unit/ha				
	Soy seeds		kg/ha				
	Soy rhizobia		kg/ha				
	Tomato transplant		unit/ha				
	Other (to specify)		kg/ha				
Herbicides	To specify product name		kg/ha				
	To specify product name		kg/ha				
	To specify product name		kg/ha				
Pest control	To specify product name		kg/ha				
	To specify product name		kg/ha				
	To specify product name		kg/ha				
Fertilizers	Diammonium phosphate 18-46		kg/ha				
	Triple superphosphate (47% P2O5)		kg/ha				
	Ammonium nitrate (34% N)		kg/ha				
	Urea (46% N)		kg/ha				
	Manure (0,5% N)		kg/ha				
	NPK (8-24-24)		kg/ha				
	Other (to specify)		kg/ha				
	Other (to specify)		kg/ha				
	Other (to specify)		kg/ha				
YIELDS	Description		Unit	SOY	DURUM WHEAT	CORN	COMMON WHEAT
Quantitative and qualitative outputs	Crop yield	-	t/ha (commercial humidity)				
	Proteins (durum and common wheat)	-	% of dry matter				
	Hectolitre weight (durum and common wheat)	-	kg /hl				
	DON (durum and common wheat)	-	ppb				
	Other (to specify)	-	-				
ENVIRONMENT ASPECTS	Description		Unit	SOY	DURUM WHEAT	CORN	COMMON WHEAT
Various	Use of cover crop	-	-				
	Use of hedges, buffer strip, ecc.	-	-				
	Anti-drift nozzles	-	-				
	Mitigation measures of runoff (hilly diches, ecc.)	-	-				
	Subsurface drainage	-	-				

Figure 57: The questionnaire used to collect information by farmers about cropping activities performed and technical tools used into four-year rotations from 2008 to 2011. Processing by Horta S.r.l.

The questionnaire was divided into four sections:

- cropping activities;
- technical tools used;
- yield and qualitative outcomes;
- environmental aspects.

Each section was composed by sub-sections with multiple entries. The questionnaire required information about practices that were implemented during growing season. For example, the “technical tools” section is divided into sub-sections: “Seed”, “Herbicide”, “Pests control”, etc., each one with their entries. The last section concerns environmental friendly actions undertaken by growers to increase the sustainability of crops and these should provide an overview of the attitude and awareness of farmers toward environmental issues.

Twelve out of twenty farmers filled in the questionnaire and the data gathered were compared with target values given by expert knowledge. This means that real scenarios (data from questionnaires) were compared with target scenarios (expert opinions) that describe the best distribution of costs, pesticides and fertilization plans depending on farm location, rotation, weather and other strategic choices undertaken by grower. Target values were estimated for low (reduced tillage, fertilizers, irrigation and limited use of pesticides), high (intensive tillage, irrigation, intensive fertilization and high environment chemical pressure in order to maximize yields, rather than cost reduction) and organic (observance of organic farming principles and postulates) use of inputs. Nonetheless almost all the farmers interviewed demonstrated to be yield-oriented, rather than cost reduction-oriented (low-input scenario), and therefore mainly target values referring to high input strategy were considered (only exception the rotation of durum wheat with sunflower).

Each rotation performed by farms was matched with a specific theoretical scenario, helping the identification of weaknesses of growers’ practices carried out. Price of crops was related to March 2011 quotation (durum wheat was 270-280 €/ton).

Considering the questionnaires filled in by farmers the following rotations were identified:

- Rotation 1: tomato, durum wheat, tomato, common wheat;
- Rotation 2: durum wheat, maize, common wheat, sugar beet;
- Rotation 3: last year with alfalfa, durum wheat, maize, first year with alfalfa;
- Rotation 4: sugar beet, durum wheat, chickpea, durum wheat;
- Rotation 5: sunflower, durum wheat, sunflower, durum wheat (low input, case 1);
- Rotation 6: sunflower, durum wheat, sunflower, durum wheat (low input, case 2);
- Rotation 7: sunflower, durum wheat, clover seed, durum wheat;
- Rotation 8: sunflower, durum wheat, sunflower, durum wheat (high input);

- Rotation 9: field beans, durum wheat, durum wheat, field beans;
- Rotation 10: field beans, durum wheat, durum wheat, sunflower;
- Rotation 11: durum wheat, sunflower, durum wheat, sunflower;
- Rotation 12: durum wheat, oilseed rape, durum wheat, oilseed rape.

Farms tested were located in three Italian regions: Emilia Romagna (in the northern Italy for the rotations 1 and 2), Marche (in the central Italy for the rotations 3,4,5,6,7,8,9, and 10) and Apulia (in the southern Italy for the rotations 11 and 12). The interviewed person were chosen between farmers cropping durum wheat as the main crop of the rotation. They were opinion leader in their area, so that data collected were representative of a more advanced and scientific agriculture. For the twelve interviewed, historical data were collected about soil tillage, drilling, chemicals treatments, fertilizations, harvesting, qualitative parameters, irrigation and environmental measures.

Each rotation has a detailed cost structure, due to different strategies of fertilization, cultivation and technical tools used and their comparison with target values allowed the identification of weak and strengths points of farming processes and choices undertaken during the crop growing cycle.

For all twelve rotations, costs and emissions indicators were calculated and compared with target values. Indicators like the contamination of mycotoxin, the yield of crop and the carrying out of the eco-conditionality measures were not subjected to elaboration since these are simple and “ready to use” numerical values. For the other composite indicators (such as carbon, ecological and water footprint) the same method described previously was used for calculation.

Table 3 *a,b,c* and *d* list the indicators values obtained for the different rotations and for the different scenarios (real vs. target).

Table 3 a: Real and target values of variables and indicators monitored in the second project step.

			Carbon Footprint (tCO_2eq/t)		Carbon Footprint (tCO_2eq/ha)		Water Footprint (tH_2O/t)		Water Footprint (tH_2O/ha)		Ecological Footprint (global m^2/t)		Ecological Footprint (global m^2/ha)	
Rotation	Year	Crops	Real	Target	Real	Target	Real	Target	Real	Target	Real	Target	Real	Target
Rotation 1	2011	Tomato Scarpariello	0.09	0.06	6.75	4.20	89.8	84.3	6735.0	5901.0	482.9	384.1	36214.5	26888.4
	2010	Durum Wheat	0.51	0.41	3.21	2.87	997.4	998.5	6283.5	6989.5	4602.4	4221.0	28995.2	29547.2
	2009	Tomato Scarpariello	0.09	0.06	6.75	4.20	89.8	84.3	6735.0	5901.0	482.9	384.1	36214.5	26888.4
	2008	Common Wheat	0.36	0.33	2.34	2.31	997.3	997.4	6482.3	6981.6	4355.8	3870.9	28312.6	27096.1
Rotation 2	2011	Durum Wheat	0.31	0.41	2.02	2.87	613.8	451.3	3989.8	3159.4	4687.8	4419.2	30470.5	30934.5
	2010	Maize	0.12	0.20	1.38	2.20	624.4	680.4	7180.3	7484.6	2465.4	2586.2	28351.6	28448.2
	2009	Common Wheat	0.25	0.22	1.80	1.65	589.2	542.3	4242.0	4067.2	4125.7	4189.6	29704.7	31422.0
	2008	Sugar beet	0.03	0.04	2.14	2.28	90.9	122.6	6482.6	6988.8	405.9	527.7	28940.7	30080.6
Rotation 3	2011	Alfalfa	0.69	0.42	5.54	2.54	694.3	119.1	5554.5	714.8	3425.6	4826.5	27404.4	28959.1
	2010	Durum Wheat	0.42	0.38	1.89	1.89	1157.4	1157.3	5208.1	5786.6	6326.7	5694.0	28470.2	28470.2
	2009	Maize	0.92	0.61	5.95	4.26	581.3	583.7	3778.4	4086.1	4297.1	4386.4	27931.2	30704.6
	2008	Alfalfa	0.08	0.08	0.76	0.71	694.3	694.3	6942.5	5901.1	2693.8	3171.7	26938.1	26959.1
Rotation 4	2011	Sugar beet	0.07	0.07	2.28	3.33	554.1	554.2	18838.2	24937.7	882.8	716.3	30014.0	32233.1
	2010	Durum Wheat	0.54	0.38	2.58	2.28	1175.4	1177.3	5641.8	7064.0	5939.0	4858.2	28507.4	29149.4
	2009	Chickpea	0.43	0.35	0.47	0.63	1830.6	1833.0	2013.6	3299.5	24844.2	15437.0	27328.6	27786.7
	2008	Durum Wheat	0.65	0.46	2.58	2.28	1175.4	942.8	4701.8	4714.1	7126.8	5827.1	28507.4	29135.5
Rotation 5	2011	Sunflower	0.28	0.69	0.84	2.42	1819.4	1818.5	5458.1	6364.6	9224.1	8437.2	27672.3	29530.3
	2010	Durum Wheat	0.69	0.48	3.24	2.64	1177.6	1176.4	5534.8	6470.1	6208.6	5337.5	29180.5	29356.3
	2009	Sunflower	0.28	0.68	0.84	2.38	1819.4	1818.5	5458.1	6364.7	9224.1	8461.0	27672.3	29613.6
	2008	Durum Wheat	0.68	0.48	3.26	2.64	1177.7	1176.4	5652.8	6470.1	6340.7	5337.5	30435.4	29356.3
Rotation 6	2011	Sunflower	0.86	0.68	2.06	2.38	1815.6	1818.5	4357.5	6364.6	11829.7	8437.2	28391.3	29530.3
	2010	Durum Wheat	0.69	0.49	3.59	2.70	1175.5	1176.4	6112.5	6470.1	5734.4	5337.5	29818.8	29356.3
	2009	Sunflower	0.85	0.69	2.04	2.42	1815.7	1818.5	4357.6	6364.7	11884.2	8461.0	28522.1	29613.6
	2008	Durum Wheat	0.80	0.48	3.60	2.64	1175.6	1176.4	5290.0	6470.1	6626.4	5537.5	29818.8	30456.3

Table 3 b: Real and target values of variables and indicators monitored in the second project step.

			Carbon Footprint (tCO_2eq/t)		Carbon Footprint (tCO_2eq/ha)		Water Footprint (tH_2O/t)		Water Footprint (tH_2O/ha)		Ecological Footprint (global m^2/t)		Ecological Footprint (global m^2/ha)	
Rotation	Year	Crops	Real	Target	Real	Target	Real	Target	Real	Target	Real	Target	Real	Target
Rotation 7	2011	Sunflower	1.18	0.81	2.60	2.84	1817.8	1820.2	3999.1	6370.5	13624.9	8784.8	29974.8	30746.9
	2010	Durum Wheat	0.92	0.37	3.50	2.22	1520.1	1373.2	5776.2	8239.4	7866.1	4846.4	29891.1	29078.5
	2009	Clover seeds	1.17	0.28	0.41	0.22	2093.7	1830.7	732.8	1464.5	78209.7	33584.7	27373.4	26867.7
	2008	Durum Wheat	0.83	0.54	3.49	2.70	1375.3	1373.5	5776.2	6867.7	7116.9	5851.9	29891.0	29259.5
Rotation 8	2011	Sunflower	0.46	0.71	1.39	2.49	1815.3	1820.7	5445.9	6372.5	9288.0	8420.3	27863.9	29470.9
	2010	Durum Wheat	0.74	0.61	3.72	3.36	1157.5	1161.3	5787.5	6386.9	5914.2	5434.8	29571.1	29891.5
	2009	Sunflower	0.43	0.71	1.39	2.49	1815.3	1820.7	5808.9	6372.5	8707.5	8420.3	27863.9	29470.9
	2008	Durum Wheat	0.78	0.61	3.72	3.36	1157.5	1161.3	5556.1	6386.9	6160.6	5434.8	29571.1	29891.5
Rotation 9	2011	Field bean	0.17	0.22	0.56	0.77	1329.2	1329.2	4386.5	4652.3	8361.8	8045.6	27593.8	28159.7
	2010	Durum Wheat	0.55	0.45	3.14	2.24	1178.2	1411.5	6715.9	7057.5	5276.4	5847.0	30075.2	29235.0
	2009	Durum Wheat	0.39	0.39	2.42	2.34	2196.5	2197.0	13618.2	13182.2	4663.9	4913.3	28916.1	29479.9
	2008	Field bean	0.15	0.16	0.50	0.56	1329.2	1253.8	4386.4	4388.3	8339.0	7901.5	27518.8	27655.2
Rotation 10	2011	Field bean	0.13	0.19	0.41	0.67	1197.3	1198.6	3831.2	4195.0	8518.5	7972.2	27259.2	27902.6
	2010	Durum Wheat	0.51	0.62	3.16	3.09	1160.0	1160.6	7226.9	5803.2	4824.7	5954.5	30057.7	29772.5
	2009	Durum Wheat	0.48	0.40	2.82	2.20	1159.6	1158.3	6818.4	6370.7	4963.4	5295.0	29184.6	29122.2
	2008	Sunflower	0.75	0.53	2.10	1.86	1820.0	1816.7	5096.1	6358.5	10260.9	8167.0	28730.4	28584.3
Rotation 11	2011	Durum Wheat	0.73	0.60	2.77	2.70	1373.9	1373.7	5220.9	6181.7	7560.3	6520.9	28729.1	29344.1
	2010	Sunflower	0.64	0.63	1.15	1.76	1853.7	1856.4	3336.7	5197.9	15745.4	10402.5	28341.7	29127.1
	2009	Durum Wheat	0.73	0.60	2.77	2.70	1373.9	1373.7	5220.9	6181.7	7560.3	6520.9	28729.1	29344.1
	2008	Sunflower	0.64	0.63	1.15	1.76	1853.7	1856.4	3336.7	5197.9	15745.4	10402.5	28341.7	29127.1
Rotation 12	2011	Durum Wheat	0.73	0.60	2.77	2.70	1373.9	1373.7	5220.9	6181.7	7560.3	6520.9	28729.1	29344.1
	2010	Oilseed rape	0.36	0.41	0.86	1.23	3952.3	3954.1	9485.5	11862.2	11481.3	9384.5	27555.0	28153.6
	2009	Durum Wheat	0.73	0.60	2.77	2.70	1373.9	1373.7	5220.9	6181.7	7560.3	6520.9	28729.1	29344.1
	2008	Oilseed rape	0.36	0.41	0.86	1.23	3952.3	3954.1	9485.5	11862.2	11481.3	9384.5	27555.0	28153.6

Table 3 c: Real and target values of variables and indicators monitored in the second project step.

			Yield (t/ha)		Agr. NUE (kg/kg)		Net Income (€/t)		Net Income (€/ha)		DON		
Rotation	Year	Crops	Real	Target	Real	Target	Real	Target	Real	Target	Real (µg/kg)	Target DON (1-9)	Target (µg/kg)
Rotation 1	2011	Tomato Scarpariello(1)	75.0	70.0	19.0	36.9	46.7	42.0	3502.5	2940.0	/	/	/
	2010	Durum Wheat	6.3	7.0	36.8	53.0	133.8	128.3	842.9	898.1	213.0	1.1	≤1750
	2009	Tomato Scarpariello(2)	75.0	70.0	19.0	36.9	46.7	42.0	3502.5	2940.0	/	/	/
	2008	Common Wheat	6.5	7.0	63.7	53.8	126.7	113.2	823.6	792.4	176.0	5.0	≤1250
Rotation 2	2011	Durum Wheat	6.5	7.0	41.8	35.5	112.6	120.7	731.9	844.9	1500.0	6.6	≤1750
	2010	Maize	11.5	11.0	46.9	37.7	100.6	98.3	1156.9	1081.3	/	/	/
	2009	Common Wheat	7.2	7.5	46.3	58.8	136.6	128.3	983.5	962.3	850.0	5.0	≤1250
	2008	Sugar beet	71.3	57.0	84.5	79.3	23.2	16.0	1654.2	912.0	/	/	/
Rotation 3	2011	Alfalfa(1)	8.0	6.0	32.0	58.8	59.2	6.6	473.6	39.6	/	/	/
	2010	Durum Wheat	4.5	5.0	49.3	33.6	68.4	71.9	307.8	359.5	Near 0	0.0	≤1750
	2009	Maize	6.5	7.0	26.0	35.7	32.1	47.0	208.7	329.0	/	/	/
	2008	Alfalfa(2)	10.0	8.5	0.0	0.0	162.4	133.4	1624.0	1133.9	/	/	/
Rotation 4	2011	Sugar beet	34.0	45.0	51.2	56.6	-2.5	7.8	-85.0	351.0	/	/	/
	2010	Durum Wheat (1)	4.8	6.0	29.9	59.4	97.2	129.6	466.6	777.6	Near 0	0.0	≤1750
	2009	Chickpea	1.1	1.8	0.0	0.0	225.0	347.0	247.5	624.6	/	/	/
	2008	Durum Wheat (2)	4.0	5.0	27.8	41.0	77.7	101.5	310.8	507.5	Near 0	0.0	≤1750
Rotation 5	2011	Sunflower(1)	3.0	3.5	83.3	28.5	215.0	136.8	645.0	478.8	/	/	/
	2010	Durum Wheat(1)	4.7	5.5	29.3	41.0	75.3	107.4	353.9	590.7	Near 0	0.0	≤1750
	2009	Sunflower(2)	3.0	3.5	83.3	28.5	215.0	136.8	645.0	478.8	/	/	/
	2008	Durum Wheat(2)	4.8	5.5	28.7	41.0	71.2	107.4	341.8	590.7	Near 0	0.0	≤1750
Rotation 6	2011	Sunflower(1)	2.4	3.5	28.2	28.5	84.0	137.3	201.6	480.6	/	/	/
	2010	Durum Wheat(1)	5.2	5.5	22.1	41.0	61.0	105.7	317.2	581.4	Near 0	0.0	≤1750
	2009	Sunflower(2)	2.4	3.5	28.2	28.5	84.0	137.3	201.6	480.6	/	/	/
	2008	Durum Wheat(2)	4.5	5.5	25.5	41.0	28.5	105.7	128.3	581.4	Near 0	0.0	≤1750

Table 3 d: Real and target values of variables and indicators monitored in the second project step.

			Yield (t/ha)		Agr. NUE (kg/kg)		Net Income (€/t)		Net Income (€/ha)		DON		
Rotation	Year	Crops	Real	Target	Real	Target	Real	Target	Real	Target	Real (µg/kg)	Target DON (1-9)	Target (µg/kg)
Rotation 7	2011	Sunflower	2.2	3.5	25.9	35.1	73.6	157.3	161.9	550.6	/	/	/
	2010	Durum Wheat(1)	3.8	6.0	20.7	59.4	20.6	124.7	78.3	748.2	0.0	0.0	≤1750
	2009	Clover seeds	0.4	0.8	0.0	0.0	-850.0	159.4	-297.5	127.5	/	/	/
	2008	Durum Wheat(2)	4.2	5.0	22.9	38.0	43.4	92.3	182.3	461.5	0.0	0.0	≤1750
Rotation 8	2011	Sunflower(1)	3.0	3.5	35.3	28.5	189.2	177.3	567.6	620.6	/	/	/
	2010	Durum Wheat(1)	5.0	5.5	22.6	41.0	57.0	113.3	285.0	623.2	0.0	0.0	≤1750
	2009	Sunflower(2)	3.2	3.5	37.6	28.5	202.3	177.3	647.4	620.6	/	/	/
	2008	Durum Wheat(2)	4.8	5.5	21.7	41.0	48.6	113.3	233.3	623.2	0.0	0.0	≤1750
Rotation 9	2011	Field bean(1)	3.3	3.5	0.0	0.0	37.5	39.9	123.8	139.7	/	/	/
	2010	Durum Wheat(1)	5.7	5.0	30.1	38.0	76.5	72.5	436.1	362.5	0.0	0.0	≤1750
	2009	Durum Wheat(2)	6.2	6.0	43.5	59.5	105.5	105.4	654.1	632.4	0.0	0.0	≤1750
	2008	Field bean(2)	3.3	3.5	0.0	0.0	37.5	39.9	123.8	139.7	/	/	/
Rotation 10	2011	Field bean	3.2	3.5	0.0	0.0	50.5	31.1	161.6	108.9	/	/	/
	2010	Durum Wheat(1)	6.2	5.0	33.0	38.0	90.8	88.4	565.7	442.0	0.0	0.0	≤1750
	2009	Durum Wheat(2)	5.9	5.5	32.7	41.0	95.5	104.9	561.5	577.0	0.0	0.0	≤1750
	2008	Sunflower	2.8	3.5	21.9	28.5	136.0	33.7	380.8	118.0	/	/	/
Rotation 11	2011	Durum Wheat(1)	3.8	4.5	26.5	33.6	80.9	98.1	307.4	441.5	0.0	0.0	≤1750
	2010	Sunflower(1)	1.8	2.8	39.1	28.5	118.3	125.9	212.9	352.5	/	/	/
	2009	Durum Wheat(2)	3.8	4.5	26.5	33.6	80.9	98.1	307.4	441.5	0.0	0.0	≤1750
	2008	Sunflower(1)	1.8	2.8	39.1	28.5	118.3	125.9	212.9	352.5	/	/	/
Rotation 12	2011	Durum Wheat(1)	3.8	4.5	26.5	33.6	67.8	89.4	257.6	402.3	0.0	0.0	≤1750
	2010	Oilseed rape(1)	2.4	3.0	31.6	31.3	214.1	169.9	513.8	509.7	/	/	/
	2009	Durum Wheat(2)	3.8	4.5	26.5	33.6	67.8	89.4	257.6	402.3	0.0	0.0	≤1750
	2008	Oilseed rape(2)	2.4	3.0	31.6	31.3	214.1	169.9	513.8	509.7	/	/	/

In the following paragraphs the results obtained for the different indicators are discussed considering mainly durum wheat cultivation within each rotation, only in some cases considering the rotation as a whole.

Carbon Footprint

Figure 58 shows real vs. target data for the indicator Carbon Footprint expressed as tCO_2eq/t durum wheat: real durum wheat emissions were higher than target ones (90% of the values are located on the right of the bisector, area b). Only Durum Wheat-Rot.2 and Rot.10 have real values lower than target ones (left of the bisector, area a) and only Durum Wheat-Ration 9(2) has equivalent real and target values. Also when the rotations are considered as a whole the majority of emissions calculated on real data are higher than the one for target data (Figure 59).

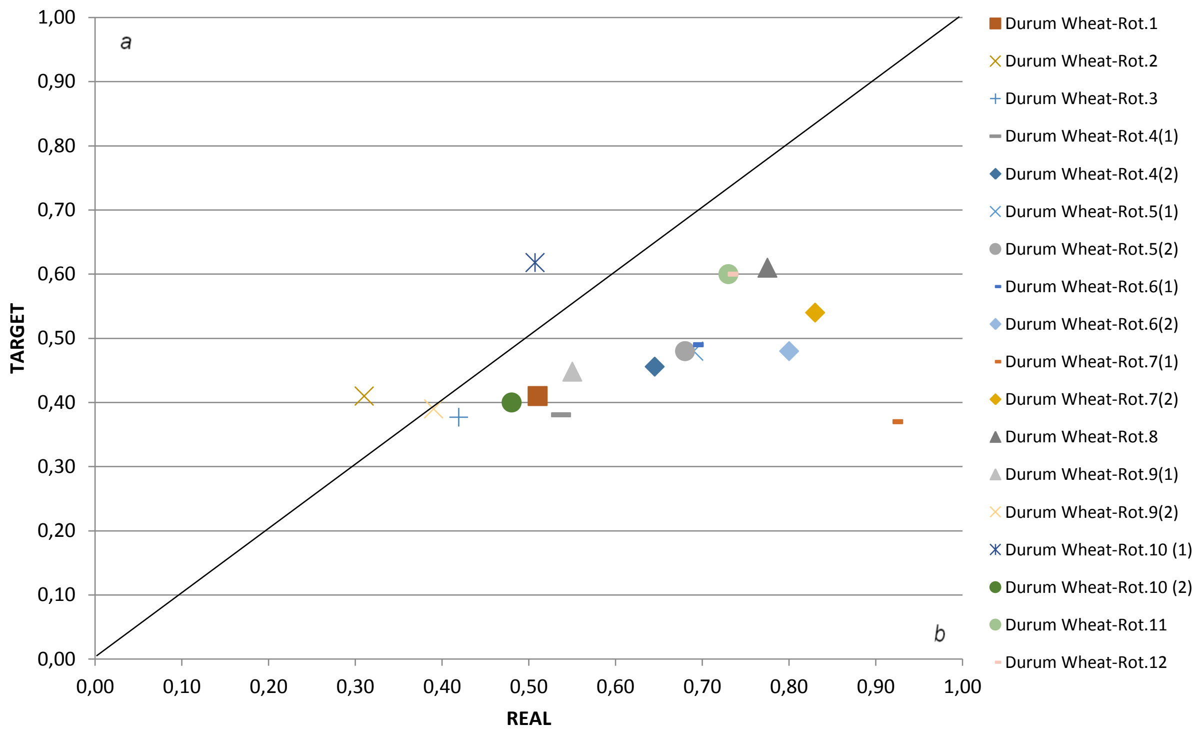


Figure 58: Real and target values of carbon footprint of durum wheat of the 12 rotations (tCO_2eq/t durum wheat). The "(1)" is the first durum wheat of the rotation, whereas "(2)" is the second one.

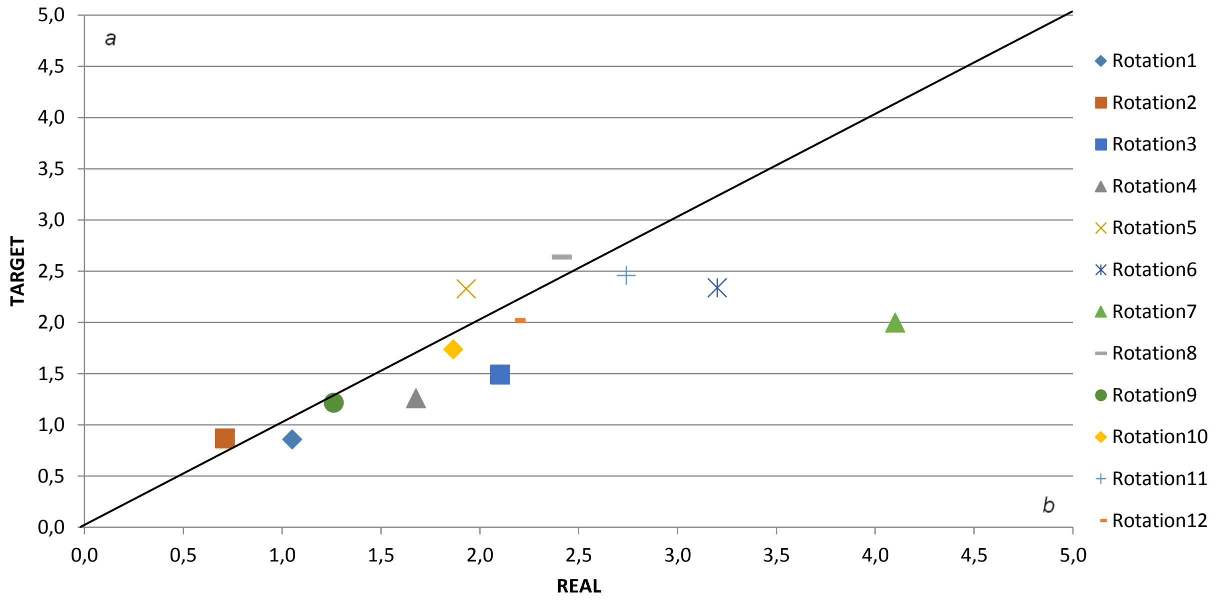


Figure 59: Real and target values of carbon footprint of the 12 rotations (tCO_2eq/t crops).

If emissions of CO_2 are calculated per hectare (Figure 60) their values increase because of the relative low yield per hectare of durum wheat cultivation.

The values calculated on farmers data are, with the exception of few situations, 5-25% higher than target ones.

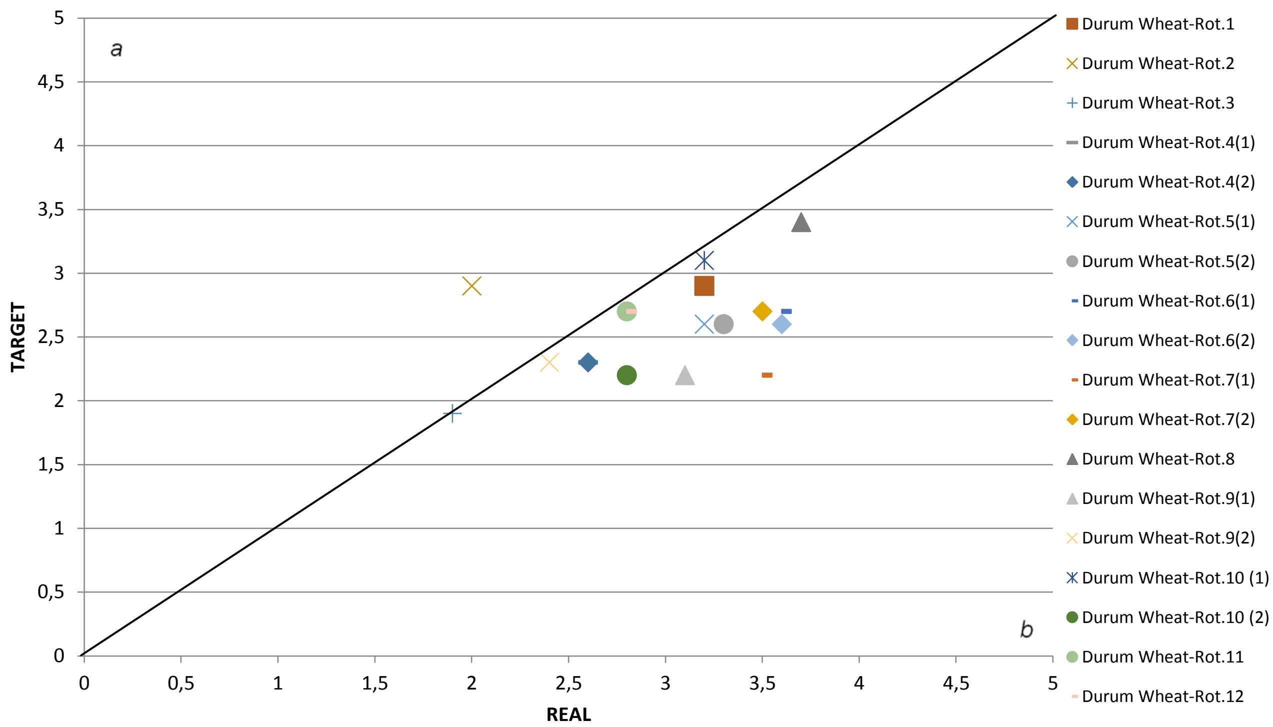


Figure 60: Real and target values of carbon footprint of durum wheat of the 12 rotations (tCO_2eq/ha durum wheat). The "(1)" is the first durum wheat of the rotation, whereas "(2)" is the second one.

Regarding the whole rotations, the higher emissions for wheat and lower emissions for the other crops lead toward an equilibrium between real and target values. The years with cereals cultivation are the most environmental impacting compared with other crops within the rotations.

Only Rotation 1 and 3 have very high real values (Figure 61) due to high Tomato Scarpariello and Maize growing emissions. While, in the Rotation 2 the low CO_2 emission could be connected with the choice to plan a rotation with four different crops.

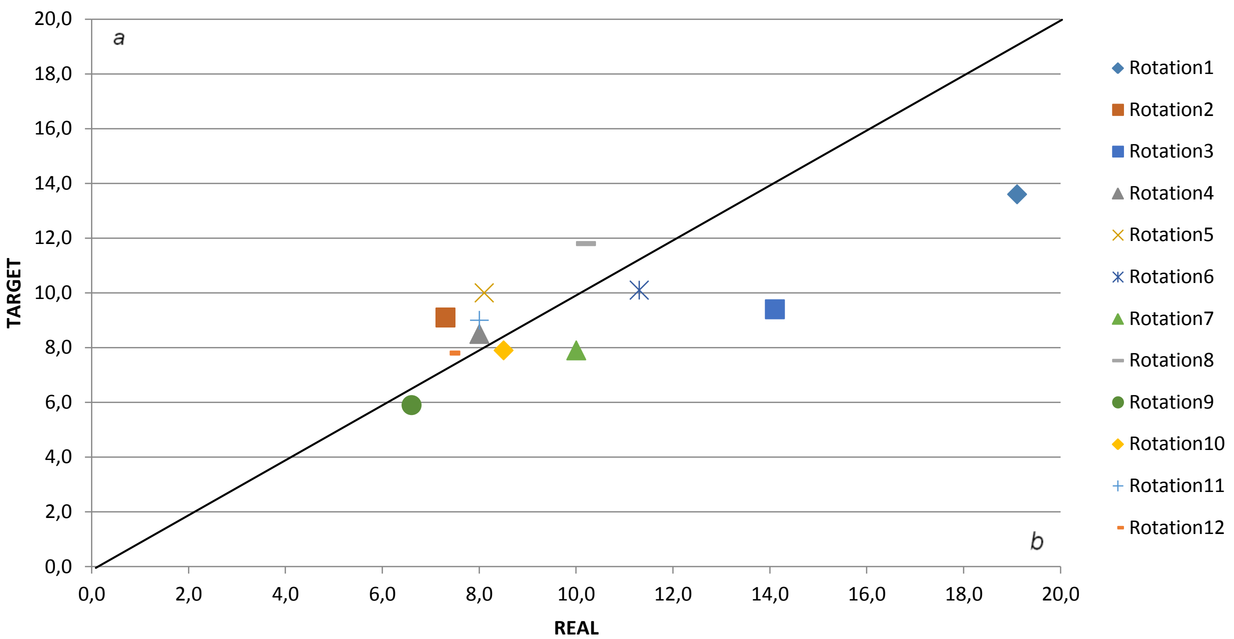


Figure 61: Real and target values of carbon footprint of the 12 rotations (tCO_2eq/ha crops).

It is known that carbon footprint values are affected by fertilizers by 80% and soil tillage by 10%; pesticides (2%), seeds (3%), fuel used during harvesting (2%) and other items (3%) such as the transport to warehouse, influence the impact by a lower percentage *(LCE, personal communication).* The completed questionnaires demonstrated that abundant fertilization and deep tillage are still a common practices performed even after cultivation of crops like sunflower and field beans. Especially in northern Italy deep tillage is used to reduce the risk of mycotoxins (i.e. *Fusarium* inoculum is forced underground). Also in central Italy, mainly hilly area, every year ploughing is a common practice and this entails the increase of risk of erosion and higher fuel consumption. Also, the number of steps for the preparation of the seedbed are often too high. A reduction of fields interventions through combined machine and the use of them with optimal timing could be a way to reduce emissions. Some dicotyledonous crops, such as sunflower, don't leave upon soil a lot of crop residues and sod seeding alternative is feasible. At least with broadleaves crops no tillage or minimum tillage should be promoted as good alternative strategy to decrease emissions and costs without compromise the success of crop.

Water Footprint

Durum wheat in Italy is usually not irrigated: water consumption depends mainly on the evapotranspiration of the crop (called green water) and marginally by water polluted by pesticides and fertilizers used during cropping season (called grey water). The evapotranspiration increases with yield, while grey water is considered nearly the same for real and target crop value. The resulted variability therefore depends on crop biomass and farm location (in the south of Italy usually evapotranspiration is higher than in the north).

Generally, there are not substantial differences between durum wheat and other crops within the rotations due to the scarce influence of farm activities on this indicator. A restricted number of real values are higher than target ones when both the use of inputs and yields are high.

Ecological Footprint

The relationship between yield of crop and use of resources is the main variable influencing the ecological footprint. Indeed, this indicator depends on the use of soil for the cultivation, called “crop land” (91%), the fertilization (4%), the tillage of soil (3%) and other variables (2%) (*LCE, personal communication)*.

Therefore, the low yield of durum wheat and the high use of resources have negative effect on ecological footprint that is inversely proportional to yield.

Only durum wheat cultivation within rotations 9 and 10 achieved real yields higher than target ones and therefore real values for ecological footprint are lower than target ones, meaning that production factors were used in an efficient way (Figure 62).

For all the other rotations real ecological footprints resulted to be higher than target ones mainly due to lower yields achieved (area *b* of Figure 62).

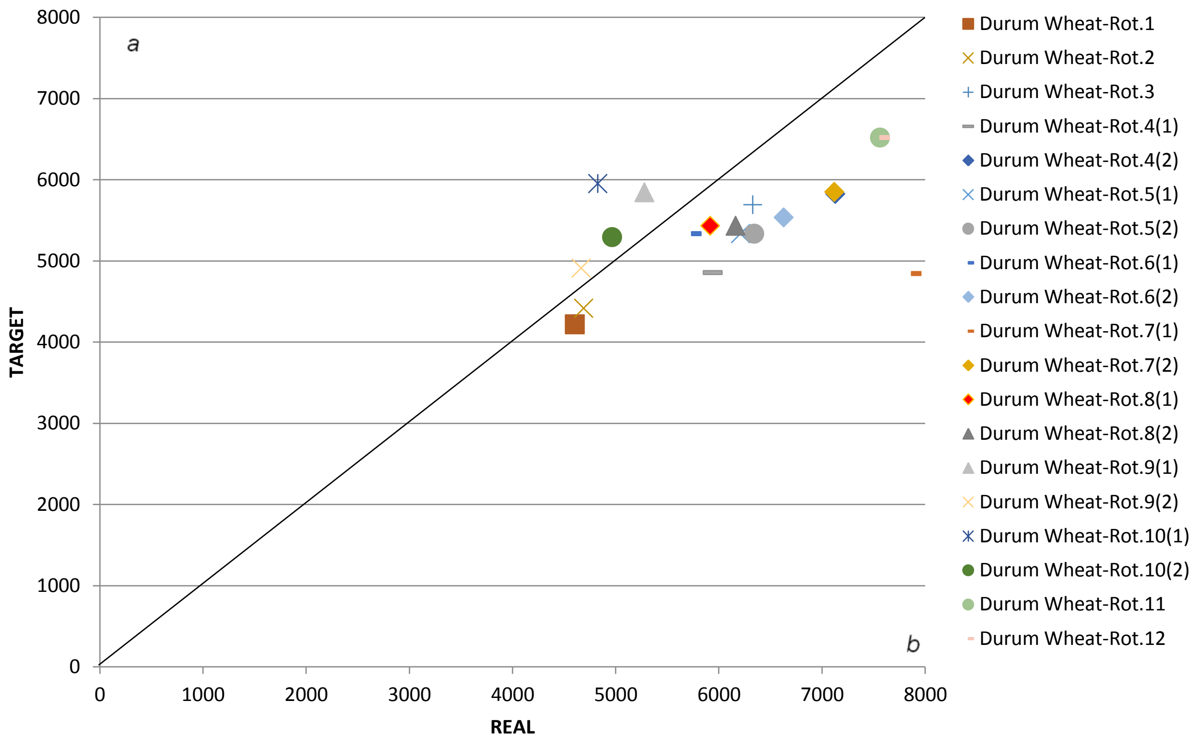


Figure 62: Real and target values of ecological footprint of durum wheat of the 12 rotations (global m^2/t durum wheat). The "(1)" is the first durum wheat of the rotation, whereas "(2)" is the second one.

Agronomic NUE

The indicator Agronomic NUE allows the monitor crop nitrogen efficiency. For its calculation data about yield (kg of kernels per hectare) and the amount of nitrogen spread out on crop (kilograms of nitrogen per hectare) are necessary and were taken from the questionnaires. For a specific amount of nitrogen applied, higher is the amount assimilated by crop, higher will be this indicator.

The Agronomic NUE was calculated only for those crops fertilized by grower. The usual practice in southern Italy is to fertilize with pre-sowing interventions in autumn or winter. This choice is partly justified by the mild winter which allows the growth of cereals also during December and January. But it is also true that the growth in these months, being slow and with a limited foliar apparatus, requires low amounts of nitrogen (less than 20kg/ha between sowing and tillering, Masoni and Pampana, 2004), often available in the soil from previous crop residual nitrogen and crop residues. Therefore, pre-sowing nitrogen fertilization is not sufficiently justified, since it is far from the months (March, April and May) in which plants needs a lot of nitrogen for stems elongation, booting, ear emergence, flowering and ripening of kernels.

In Figure 63 the red dotted lines (value of Agronomic NUE equal to 30) represent the threshold defined by experts for an acceptable use of nitrogen supplied, therefore only crops that fall into area *c* are considered efficient from a nitrogen point of view, while crops that fall into area *a* present a very low nitrogen efficiency. Figure 63 also shows that the majority of real Agronomic NUE values of durum wheat are far from target values (values on the right or on the left of the bisector). In particular, 80% of real values are lower than target ones, meaning a poor efficiency of fertilization. This is often caused by fertilization during growing season with a higher amount of nitrogen in respect to the one effectively needed by plants or a too low final yield for the fertilization plan adopted. Only Durum Wheat-Rot.2 and Durum Wheat-Rot.3 have real nitrogen efficiency higher than target one because, despite yields were similar, the nitrogen inputted on field was lower.

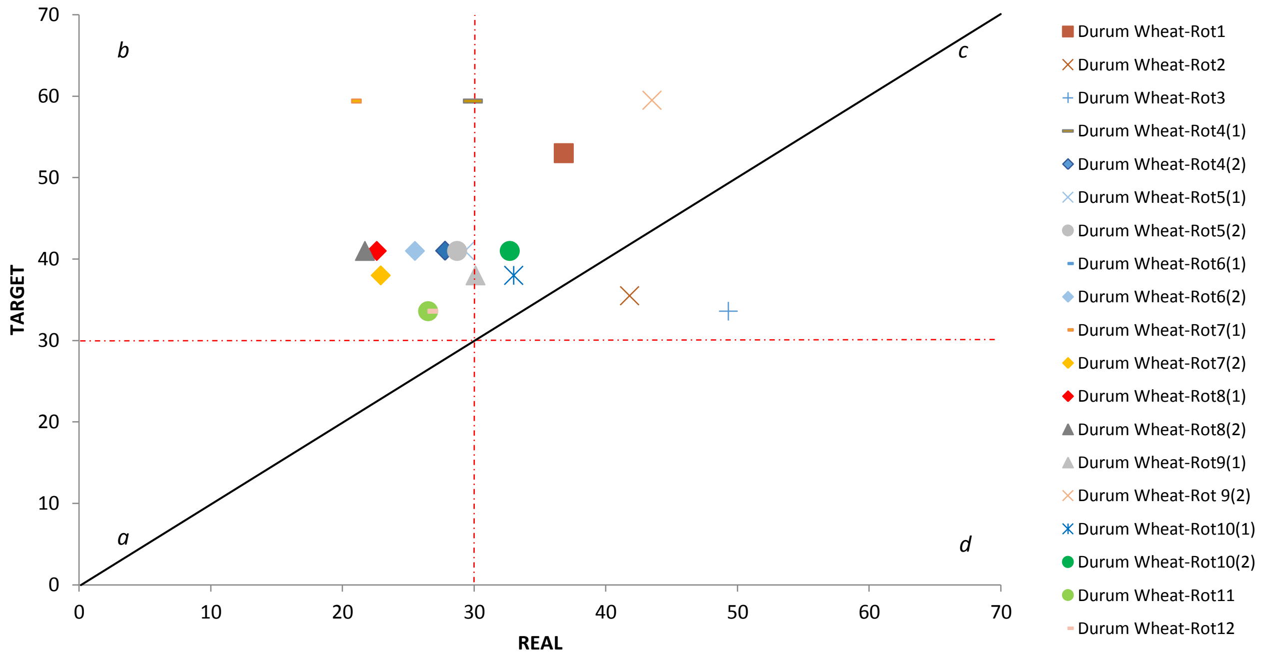


Figure 63: The Agronomic Nitrogen Use efficiency (NUE) index (kg yield/kg N applied) for durum wheat of the 12 rotations. The "(1)" is the first durum wheat of the rotation, whereas "(2)" is the second one.

Regarding the complete rotations, the questionnaires revealed a general low use of fertilization plans and better performances of other crops in respect to durum wheat.

This analysis showed that the low efficacy use of nitrogen fertilization is the most important weak point that requires improvements and is the key issue to work on to increase farm sustainability both economically and environmentally. For this reason, evaluators established that the efficiency of fertilization, estimated by the indicator Agronomic NUE, is an innovative metric to study this critical issue, not well investigated by Italian agronomists yet.

The timing of nitrogen applications is crucial to increase the efficiency of the fertilization, the use of technical assistance can help to optimize it because the best moment of fertilization depends on the stage of crop, variety needs and weather trend. To help farmers to improve fertilization choices was promoted, since the copping season 2011/2012, the use of a decision support system: *granoduro.net®*.

Net income

The prices considered for the calculation of the net income were the following: durum wheat 270 €/t (price taken from *"Bologna Borsa Merci"*, an Italian broad of trade of commodities, at the time of writing this note), tomato Scarpariello 65 €/t, soybean 380 €/t, fodder of alfalfa 180 €/t, common wheat 250 €/t, maize 230 €/t, sunflower 400 €/t, sugar beet 45 €/t, oilseed rape 420 €/t, sorghum 230 €/t, proteic pea 300 €/t, chickpea 700 €/t, lentil 1000 €/t, clover seed 500 €/t and field bean 220 €/t. Since the prices considered are the same for real and target scenario, the differences in net income values are influenced by yield, field activities and technical tools costs, as well as by the spreading over time of costs in the four-year rotations. The comparison revealed that the target durum wheat net income is higher than the real one (Figure 64, almost all values are in area *a*), both considering net income per ton or per hectare (Figure 65). The same happened when the rotations were considered as a whole (Figure 66).

Nevertheless, Durum wheat of Rotation 9 (durum wheat (1) and (2)) and 10 (durum wheat (1) (2)) have good performance both per ton and hectare. This happens because the yields were higher than target ones. The rotation yields per hectare were respectively 5.7, 6.2, 6.2 and 5.9 tons/ha, while the target ones were respectively 5, 6, 5 and 5.5 tons/ha. On the other hand, real costs were only slightly higher than target scenarios. As a consequence, their values are on the right or close to bisector (Figure 64 and 65). For the Durum Wheat-Rot.11 and Durum Wheat-Rot.12 the low real net income was only influenced by the low yield and not by the costs of growing, since, in this last examples, the real costs are lower than target ones.

Per hectare, the best performance of Durum Wheat-Rot.9(1) and Durum Wheat-Rot.10(1) were conditioned also by the favourable rotation (Figure 64); indeed the rotation with legume crops, such as field bean, improves chemical and physical properties of soil with positive effects on wheat yield (and net income).

In Durum Wheat-Rot.7(1) the high cost of cultivation and the low yield (real yield of 3.8 t/ha, while target yield is 6 t/ha) caused the worst performance, as highlighted also in the Figures 64 and 65.

The best situations showed up in northern Italy: Durum Wheat-Rot.1 and Durum Wheat-Rot.2, despite the costs are similar, around 1000 €/ha, the yields of the real scenario were higher, resulting to satisfy net income. Instead, cereal crops of central and southern Italy, are at the limit of the economic convenience.

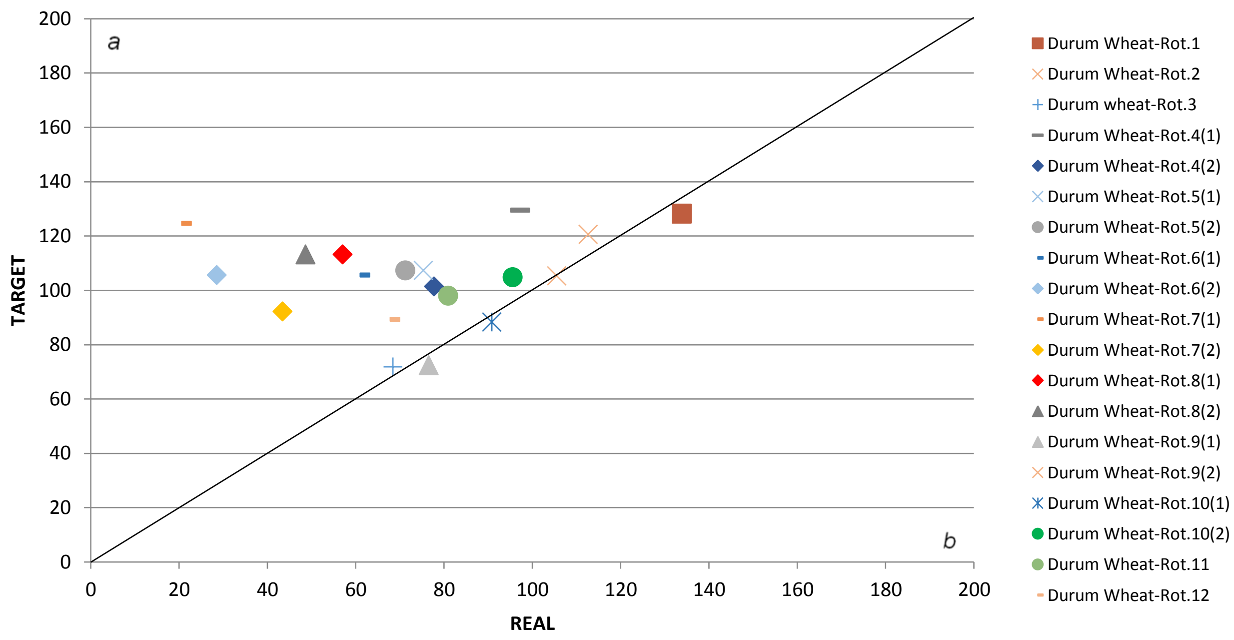


Figure 64: Net income of durum wheat of the 12 rotations (€/t). The "(1)" is the first durum wheat of the rotation, whereas "(2)" is the second time.

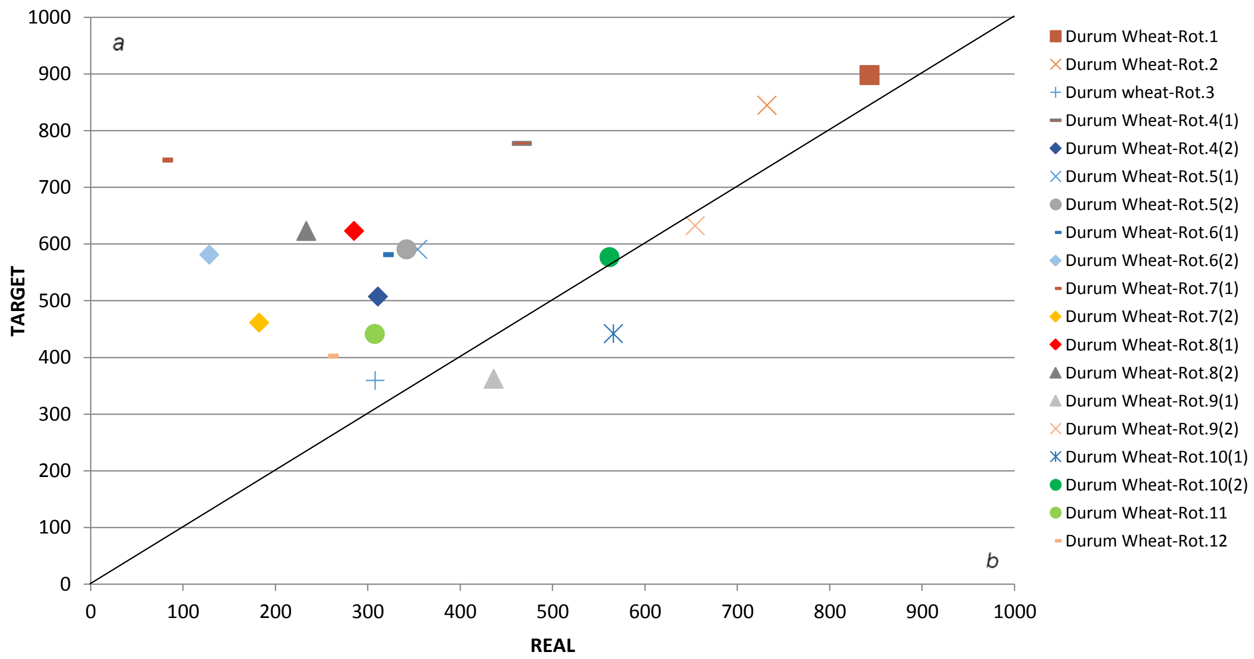


Figure 65: Net income of durum wheat of the 12 rotations (€/ha). The "(1)" is the first durum wheat of the rotation, whereas "(2)" is the second time.

Comparing the net incomes of the whole rotations the worst performances were reached by the rotations of central Italy: 4,6,7. In these cases the distance between real and target scenarios was over 10% in rotation 4, 30-35% in the rotation 6, up to 90% in the rotation 7 (Figure 66). The Rotation 7 has a low real net income because the year with clover seeds crop has a marked negative performance, with a negative impact on the mean of the four-years rotation as a whole. This happened also with sugar beet for the rotation 4. Other bad performances are the rotations 8 and 11 where real net income is lower than target ones because profitability of years with durum wheat is significantly low.

For rotations 1 and 2 the good performance of net income is a contribution of all crops of the rotation (tomato Scarpariello, durum wheat and common wheat for the first one, while sugar beet and maize for the second one).

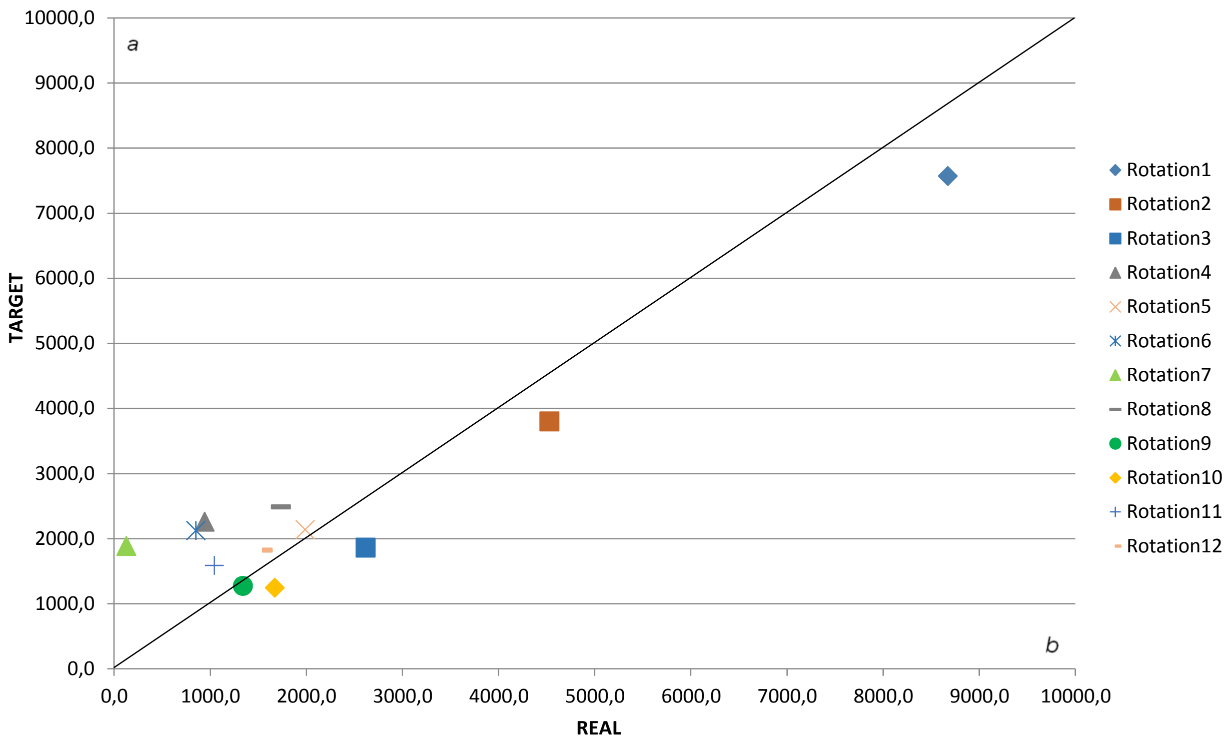


Figure 66: Net income of the 12 rotations (€/ha). The "(1)" is the first time of the crop in the rotation, whereas "(2)" is the second.

DON

The main factors that influence the development of mycotoxigenic fungi and their production of mycotoxins are the weather conditions, the inoculum presence and the host susceptibility. Northern Italy usually presents rainy springs and therefore the risk of contamination is usually high, while in the rest of the country only in particularly rainy springs the fungi can develop. Moreover, the risk is greater in the farming systems where wheat is rotated with maize or other cereals and, since straw is the matter where the pathogen overwinters, minimum or no tillage increase the inoculum upon soil surface. Finally, the mycotoxins production depends on the susceptibility of varieties of wheat toward DON toxin-producing fungi: *Fusarium graminearum and F.culmorum*.

The DON index is a laboratory quantification of the presence of the fungal toxin deoxynivalenol into kernels of common and durum wheat.

DON values were gathered by farmers through the questionnaire and results were compared with legal threshold (1750 µg/kg for durum wheat and 1250 µg/kg for common wheat) and target values (best situation, 0 µg/kg). Data for common and durum wheat are displayed in Table 3 (*c* and *d*).

The risk of contamination of kernels was considered relevant only in the Rotation 2, since it is close to the maximum legal. The other rotations presented values far from legal limit and were freely marketable.

Mitigation measures

In the last part of the questionnaire information on actions adopted by farmer to mitigate negative effects of practices performed during crop cultivation were gathered. The main mitigation measures considered were the use of cover crops, the use of buffer strips and hedge, the use of anti-drift nozzles, the performance of mitigation measures against runoff and the adoption of subsurface drainage. Table 4 reports the obtained answers.

Table 4: List of the rotations which adopted one or more mitigation measures decreasing the exposure of environment. "X" means practice undertaken, while "-" means practice does not carried out.

Rotation	Year	Crops	*Use of cover crop*	*Use of buffer strips and hedges*	*Use of anti-drift nozzles*	*Mitigation measures of runoff*	*Subsurface drainage*
Rotation 1	2011	Tomato Scarpariello	-	X	X	-	-
	2010	Durum Wheat	-	X	X	X	-
	2009	Tomato Scarpariello	-	X	X	-	-
	2008	Common Wheat	-	X	X	X	-
Rotation 2	2011	Durum Wheat	-	-	X	-	-
	2010	Maize	-	-	X	-	-
	2009	Common Wheat	-	-	X	-	-
	2008	Sugar beet	-	-	X	-	-
Rotation 9	2011	Field bean	-	-	-	X	-
	2010	Durum Wheat	-	-	-	X	-
	2009	Durum wheat	-	-	-	X	-
	2008	Fiedl bean	-	-	-	X	-
Rotation 11	2011	Durum Wheat	-	-	X	-	-
	2010	Sunflower	-	-	-	-	-
	2009	Durum Wheat	-	-	X	-	-
	2008	Sunflower	-	-	-	-	-
Rotation 12	2011	Durum wheat	-	-	X	-	-
	2010	Oilseed rape	-	-	-	-	-
	2009	Durum wheat	-	-	X	-	-
	2008	Oilseed rape	-	-	-	-	-

Only in 5 out of 12 situations at least one mitigation measure was performed, demonstrating the still rare attitude of farmers to adopt these practices. The most used mitigation measure was the use of anti-drift nozzles. This can be explained by the fact that a small investment is needed to adopt this mitigation practice and that usually authorities recommend it.

Other mitigation measures are not widely recommended because they are more linked to the characteristics of the area, for example, in flat areas (like in the Po Valley) the use of runoff reduction measures are less important than in hilly areas (such as in the Marche region), and on the other hand, the subsurface drainage is more important in plots with compacted and flat soil than in the hilly setting where the ground slope already allows the elimination of excess rainwater.

As a step foreward, for the most interesting (from a sutainability point of view) and rapresentative crop rotations of Northern, Central and Southern Italy a comparison of real values with target one was performed with more detail. Only Carbon footprint, Agronomic NUE and net income indicators (Table 3 a, b, c, d) were used in this comparison and for the following selected rotations:

- Rotation 1: tomato, durum wheat, tomato, common wheat;
- Rotation 2: durum wheat, maize, common wheat, sugar beet;
- Rotation 5: sunflower, durum wheat, sunflower, durum wheat (low input, case 1);
- Rotation 6: sunflower, durum wheat, sunflower, durum wheat (low input, case 2);
- Rotation 9: field beans, durum wheat, durum wheat, field beans;
- Rotation 11: durum wheat, sunflower, durum wheat, sunflower;
- Rotation 12: durum wheat, oilseed rape, durum wheat, oilseed rape.

About carbon footprint, also a comparison with standard values achieved during the editing of the Environmental Product Declaration of pasta performed by Barilla S.p.A. and LCE S.r.l. in 2009, was done.

Using the data in Table 3, the carbon footprint of durum wheat calculated through real scenarios is higher than target one. This occurs for all rotations except the durum wheat of rotation 2. In addition, the real values are always lower than EPD one, as can be noted in the Figures 67, 68, and 69, except for the durum wheat of rotation 6. Hence, a comparison between real and EDP scenario highlights that, although real values are usually higher than target they are lower than the preliminary EDP study.

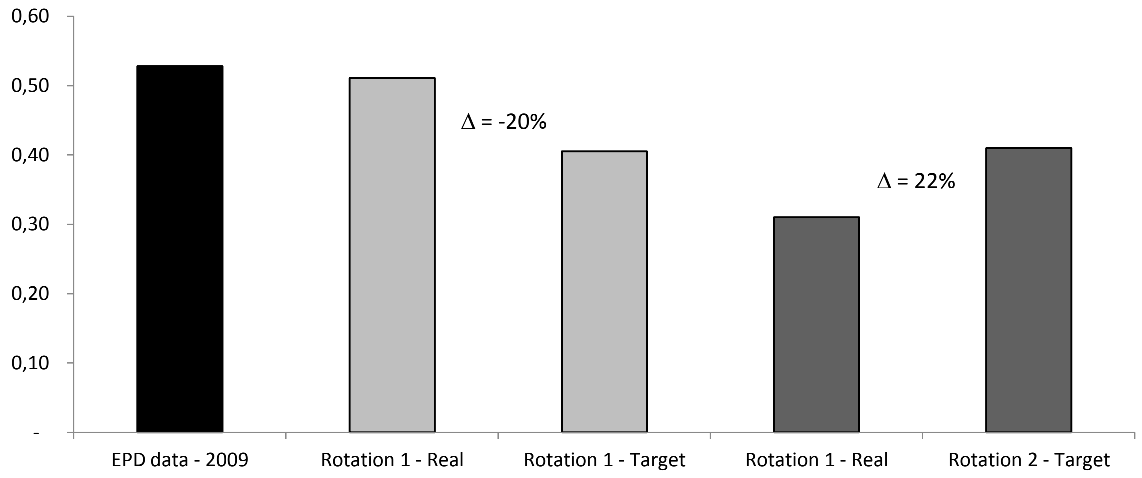


Figure 67: Real and target emission of durum wheat of two rotations in the north of Italy, tCO_2eq/t durum wheat. Data compared with a reference value from literature (EPD data, 2009).

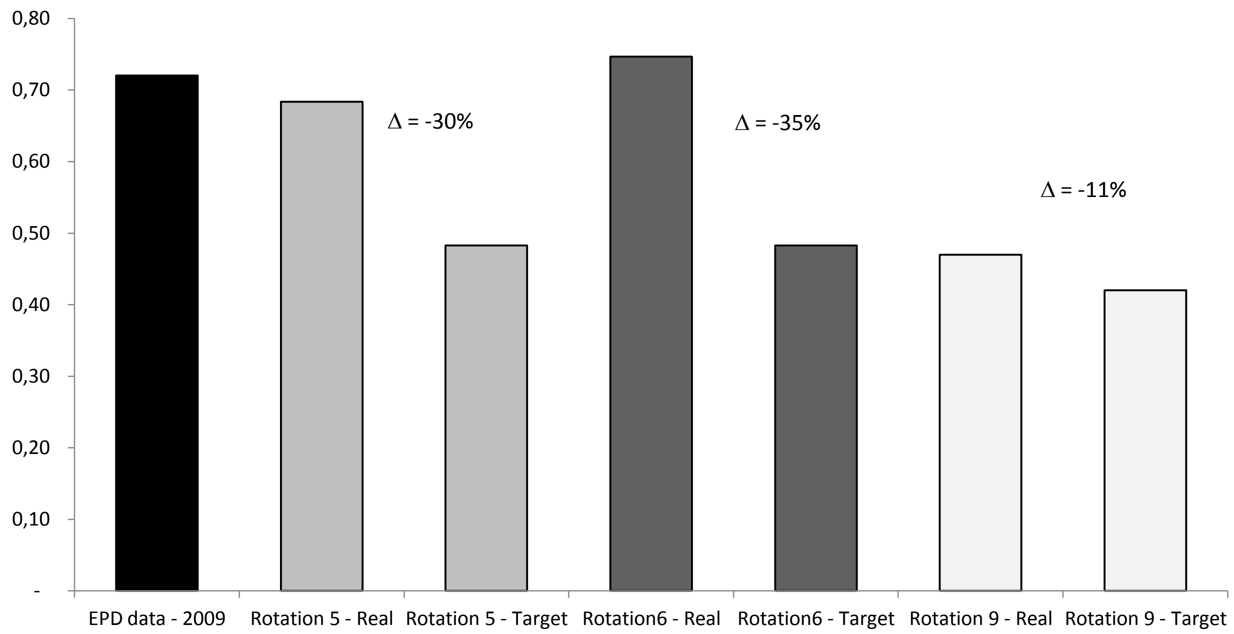


Figure 68: Real and target emission of durum wheat of three rotations in the centre of Italy, tCO_2eq/t durum wheat. Data compared with a reference value from literature (EPD data, 2009).

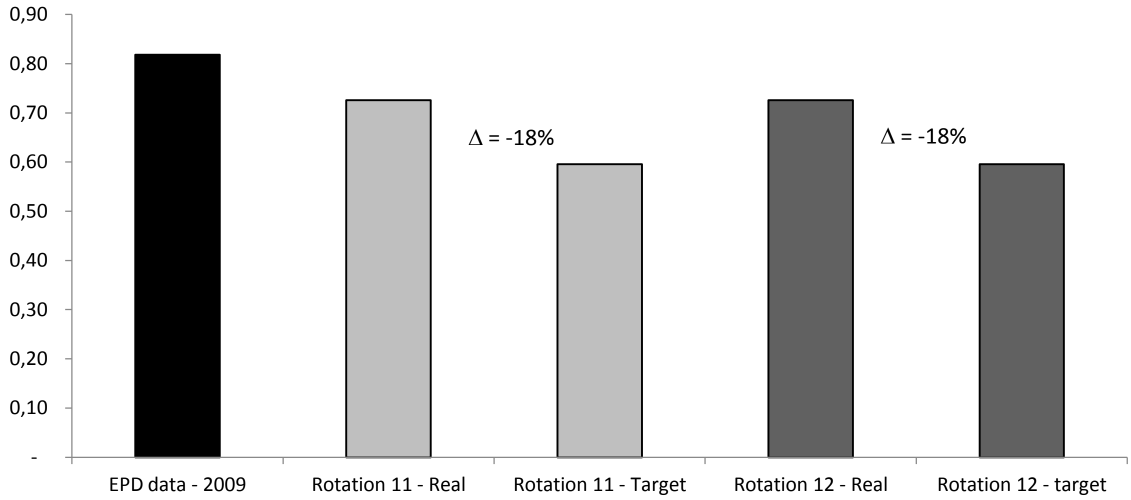


Figure 69: Real and target emission of durum wheat of two rotations in the south of Italy, tCO_2eq/t durum wheat. Data compared with a reference value from literature (EPD data, 2009).

Due to the high input of fertilizers or their not efficient optimization in timing and amount, the emission of carbon dioxide increased. To prove the strong connection between carbon footprint and the efficiency of fertilization it is useful to compare the previous three figures with Figure 70 that shows nitrogen use efficiency (Agronomic NUE). In the Figure 70 the target values are higher than real ones except for rotation 2. Therefore, when the nitrogen fertilization efficiency is lower than target one, the carbon footprint is higher and vice versa.

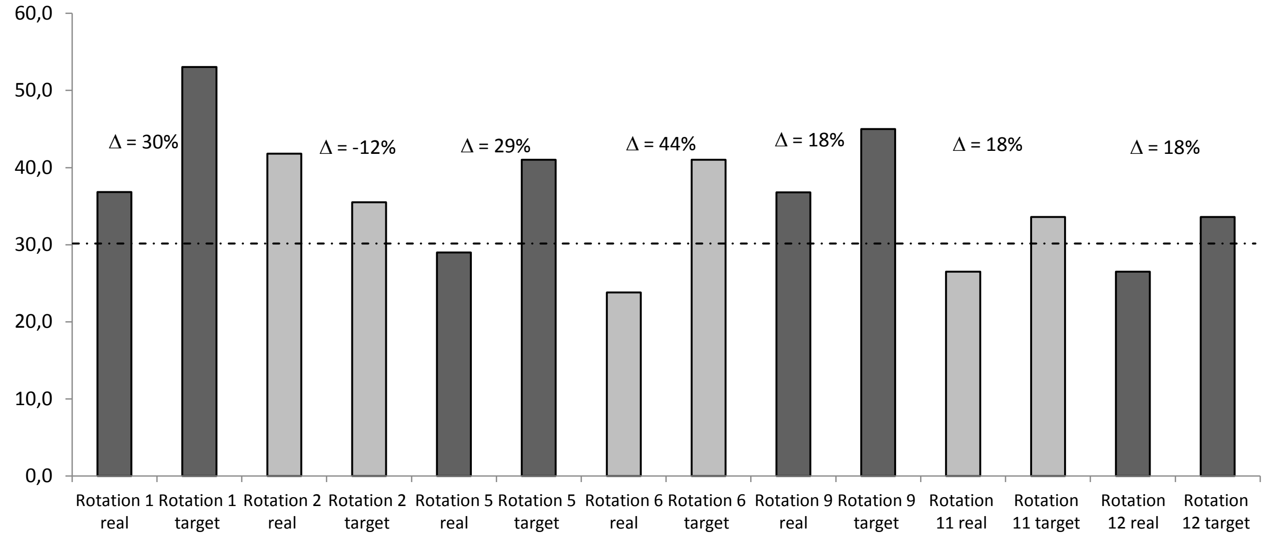


Figure 70: Real and Target Agronomic NUE (kg/kg) of durum wheat of the seven rotations under evaluation. The dotted line is the threshold for an acceptable value of nitrogen use efficiency.

The reasons for a low efficiency of fertilizations can be understood focusing on two issues: firstly, farmers decided the amount of nitrogen to use independently from previous crop, soil analysis and weather conditions; secondly, the timing was not matched with the real needs of stems. As before argued, nitrogen applications are often performed too early respect to effective plant needs and the fertilizer is usually lost by volatilization or leaching into groundwater during spring rainfalls.

To check weak points of the seven rotations it is worth to perform an economic evaluation: a comparison between costs was made to estimate net income values. A discrimination between field operations and technical tools costs allowed to find weaknesses of choices made during cropping season. In Figure 71 real and target costs are compared.

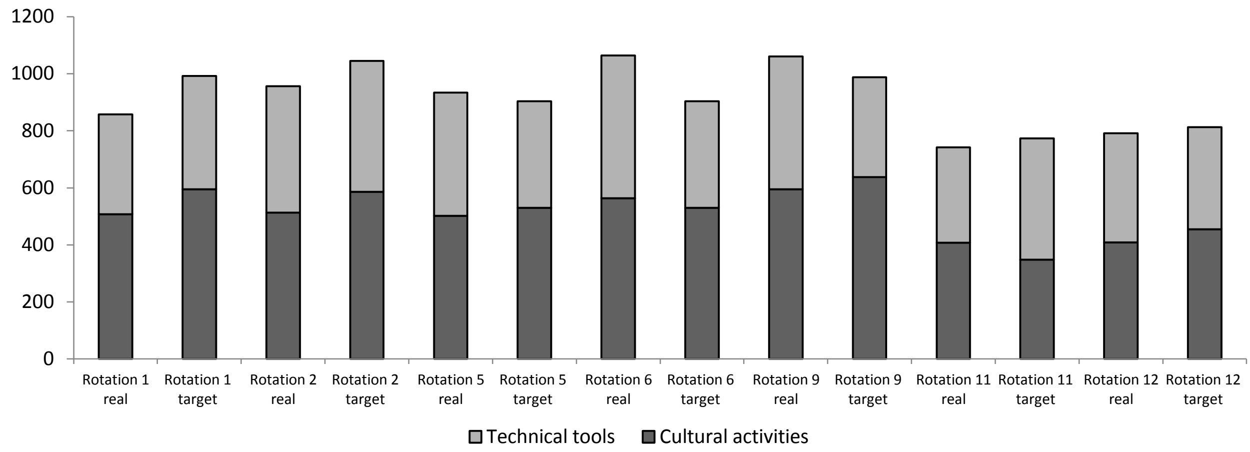


Figure 71: Real and target costs (sum of technical tools and cropping activities) of durum wheat of the 7 rotations (€/ha).

The dynamic analysis of net income is very attractive for durum wheat because, with the methodologies and choices of cultivation available to date, it is not profitable in the centre and south of Italy (Figure 72). In the north the difference between real and target is nearly zero, whereas in the centre and south the target values are 45% higher than real ones. This demonstrate how new methods and strategies are required to improve yields and economic sustainability of durum wheat and of the whole rotation (Figure 73).

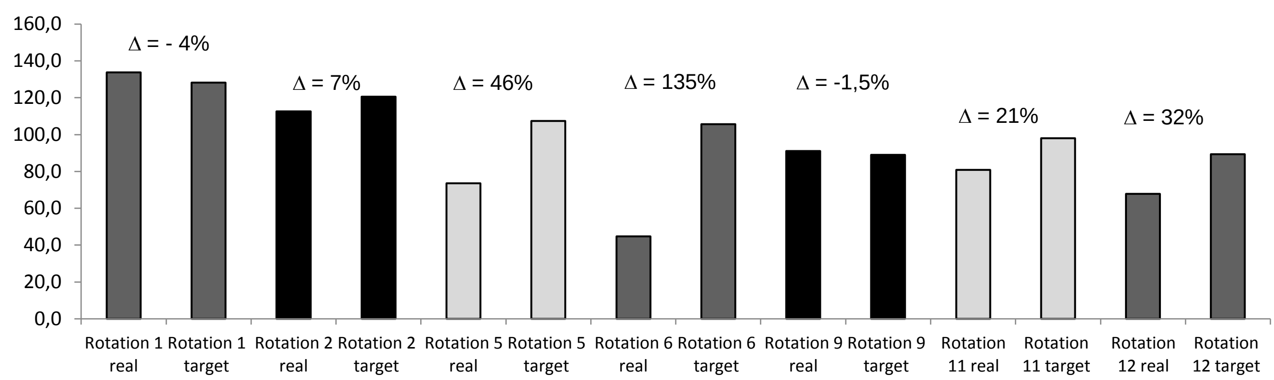


Figure 72: Real and target net income of durum wheat of the 7 rotations (€/t durum wheat).

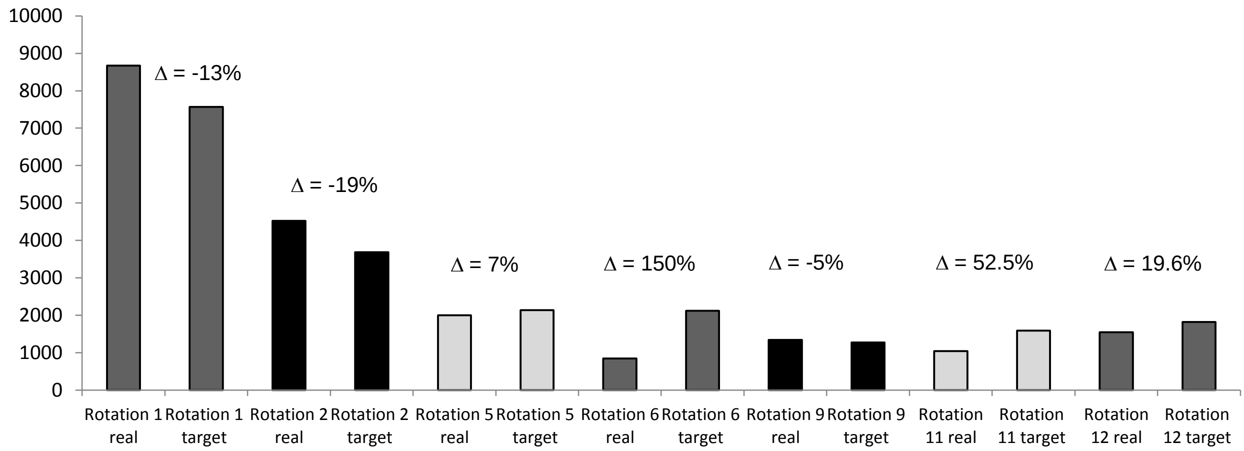


Figure 73: Real and target net income of the 7 rotations (€/ha).

Taking into account these outcomes a set of issues were identified where improvement could be undertaken. The notions, strategies and concepts chosen as essential or innovative for improving sustainability of durum wheat were collected in Table 5, that describes 9 themes where farmers can operate to optimize crops growing.

Table 5: A list of sectors where wheat producers can operate to improve sustainability of their fields.

	Topic	Key factors or actions to answer topics
1	Crop rotation	If possible rotate wheat with dicotyledonous or fodder crops
2	Tillage	Choice tillage depth and intensity in relation to soil texture, climate, seeding age and crop rotation. Promote minimum tillage and no till with broadleaves crops.
3	Seeding age time	Define seeding time in relation to climate of the area and variety
4	Seeds	Use certified seeds
5	Seeding density	According to the variety, seeding timing and soil conditions (use of *granoduro.net®*)
6	Variety choice	Choose varieties tested in the area, tailored to climate zone and with enough productivity and technological quality.
7	Chemical weeding	Optimize weeds control (use of *granoduro.net®*)
8	Nitrogen fertilization	Optimize timing and amount of nitrogen fertilization to achieve high productivity and high protein content. Balance nitrogen in relation to rotation, natural availability of soil, variety and climate trends (use of *granoduro.net®*)
9	Fungicide protection	Assess risk of disease occurrence. This risk depends on varietal susceptibility, growth stage of crop, weather trend and pathogen pressure (use of *granoduro.net®*).

One of the most important aspects is the optimization of fertilization plans and the use of rotations for reducing environmental impacts. Monoculture and fertilization plans not based on a nitrogen balancing calculation must be strongly discouraged.

The main weaknesses identified in the second project steps are finally: wrong fertilization plans and timing of spread out, too intense soil tillage, limited use of rotations, and incorrect use of pesticides. To solve these shortcomings in the following project step (cropping season 2011/2012) the use of the handbook and *granoduro.net*® was tested as innovative cropping strategy.

3.3.3 Field comparison between current and innovative durum wheat management

During 2011/2012 growing season, *granoduro.net®* was tested to estimate its potential to improve economic, social and environmental sustainability of durum wheat.

The goal of this project step was to demonstrate to growers that a careful planning of crop rotations and the use of a DSS for wheat management produce benefits from a sustainability point of view and added-value to production. To achieve this, two different durum wheat cropping strategies were compared in thirteen farms across Italy:

1. farmer's usual crop management (with only farmer tactic and strategic choices);
2. crop management through the use of the Decision Support System (DSS) *granoduro.net®* for tactic decisions and the Handbook for the strategic ones.

The thirteen farms involved in the study were located in the most important areas of durum wheat cultivation in Italy: four in the north (Emilia Romagna region), seven in the centre of Italy (Tuscany and Marche regions), while the last two in the south (Apulia region).

The crop rotations tested were durum wheat in rotation with waxy maize, grain sorghum, common and durum wheat, sunflower, oilseed rape, sugar beet, field bean, chickpea, fodder pea and tomato.

Sustainability was assessed as for the project steps before in terms of carbon, water and ecological footprint, net income, agronomic NUE, mycotoxin contamination and carbon sequestration (Ruggeri et al., 2012). The main data for indicators calculation were collected through a questionnaire:

- cropping activities and technical tools during crop cultivation;
- direct costs €/hectare for each field practice;
- use of fuel (litres/hectare) for each cropping activity;
- use of pesticides and fertilizers (litres or kilograms/hectare).

The questionnaire used to collect data is displayed in the Figures 74, 75, 76 and 77. The first part focuses on general information (Figure 74), the second asks data on cropping activities performed (Figure 75), the third requires information about technical tools spread out, while in the last part data on yield, quality parameters (Figure 76) and the implementation of measures of mitigation of pesticides risk are requested (Figure 77).

Farm and fields data collection

			Farmer's usual Crop management	Use of granoduro.net™ and the Handbook for sustainable cultivation
Cropping year				
Farm Name		Hectares		
Address		Rotation (2010-2011)		
Owner Name and Surname		Durum wheat variety		
Telephone		Date of sowing		
e-mail				
VAT number or fiscal code				
Description crop unit				
County				
Municipality				
Locality				
Height above mean sea level				

Figure 74:The questionnaire for the cropping season 2011/2012. General information section.

		Farmer's usual Crop management			Use of granoduro.net™ and the Handbook for sustainable cultivation		
	Cultural activities	Date dd/mm/yy	Fuel consumption (liters/ha)	Costs €/Ha	Date dd/mm/yy	Fuel consumption (liters/ha)	Costs €/Ha
Primary soil tillage	Ploughing 45/50 cm						
	Ploughing 25/30 cm						
	Combined grubber (30-40 cm)						
	Ripping						
	Other (to specify)						
Secondary soil tillage	Harrowing (30-35 cm)						
	Harrowing with revolving						
	Harrowing with rigid teeth or						
	Between rows weeding						
	Between rows milling						
	Other (to specify)						
	Other (to specify)						
Conservation tillage	Direct sowing (minimum tillage)						
	Sod sowing						
Seeding on tillaged soil	Wheat sowing machine						
	Combined sowing machine						
	Other (to specify)						
Fertilization	Pre-sowing Organic matter						
	Pre-sowing						
	First post-sowing						
	Second post-sowing						
	Third post-sowing						
	Foliar fertilization						
	Other (to specify)						
Weeds control	Pre-sowing total kill herbicide						
	Pre-emergence						
	First post-emergence						
	Second post-emergence						
Pests control	First treatment - fungicide						
	Second treatment - fungicide						
	Third treatment - fungicide						
	Insecticide						
	Other (to specify)						
Irrigation	Sprinkler irrigation						
	Other (to specify)						
Harvesting	Harvesting with chopping						
	Harvesting without chopping						
	Chopping straw						
	Baling straw						
	Loading straw						
	Transport straw to farm center						
	Transport wheat to farm center						
	Other (to specify)						

Figure 75:The questionnaire for the cropping season 2011/2012. Cropping activities section.

	Technical tools	Farmer's usual Crop management				Use of granoduro.net™ and the Handbook for sustainable cultivation			
		Name pesticide	Date dd/mm/yy	Amount (liters o Kg/ha)	Costs €/Ha	Name pesticide	Date dd/mm/yy	Amount (liters o Kg/ha)	Costs €/Ha
Seed	Seeds without dressing								
	Seeds dressing								
	Other (to specify)								
Weeds control	Pre-sowing total kill herbicide								
	Pre-emergence								
	First post-emergence								
	Second post-emergence								
Pest Control	First treatment - fungicide								
	Second treatment - fungicide								
	Third treatment - fungicide								
	Insecticide								
	Other (to specify)								
Fertilization	Pre-sowing Organic matter								
	Fertilizer Pre-sowing								
	First Fertilizer Post-emergence								
	Second Fertilizer Post-								
	Third Fertilizer Post-emergence								
	Leaf fertilizers								
	Other (to specify)								

Figure 76:The questionnaire for the cropping season 2011/2012. Technical tools section.

Production characteristics	Farmer's usual Crop management	Use of granoduro.net™ and the Handbook for sustainable cultivation
Crop yield (t/ha)		
Straw (t/ha)		
Selling price €/t of wheat		
Selling price €/t of straw		
Protein (% on dry matter)		
Hectoliter weight (Kg/hl)		
DON contamination (ppb)		
Ashes		

Eco-conditionality Measures	Farmer's usual Crop management	Use of granoduro.net™ and the Handbook for sustainable cultivation
Use of cover crop ("yes" or "no")		
Use of hedges, buffer strips, buffer zones etc. ("yes" or "no")		
Use of anti-drift nozzles ("yes" or "no")		
Mitigation measures of runoff (hilly ditches, etc.) ("yes" or		
Use of subsurface drainage tubes ("yes" or "no")		

Figure 77: The questionnaire for the cropping season 2011/2012. Yield, qualitative outcomes and measures of mitigation of risk section.

In total thirteen different scenarios (rotations) were tested (Table 6).

Table 6: Area, contribute to soil fertility and rotations of the 13 scenarios monitored in the 2011/2012.

Area	Scenarios	Contribution of the rotation to soil fertility	Durum wheat in rotation with:
North	1	Richness	Tomato
North	2	Richness	Tomato
North	3	Pauperizing	Waxy maize
North	4	Pauperizing	Grain Sorghum
Centre	5	Rich	Field bean
Centre	6	Neutral	Sunflower
Centre	7	Neutral	Sunflower
Centre	8	Richness	Chickpea
Centre	9	Neutral	Sunflower
Centre	10	Neutral	Oilseed rape/Sunflower
South	11	Richness	Tomato
South	12	Richness	Oilseed rape
South	13	Neutral	Sunflower

The field comparisons were done by large plots (i.e. not strip experiment), ranging from half hectare to some hectares. Usually one big plot was split up into two parts and managed one side following farmer's choices, the other following the advices of *granoduro.net®* and the handbook. The comparisons highlighted some differences on the amount of fertilizers applied on crops, number and timing of fungicides treatments, whereas on soil tillage, seeding density and herbicide usage the differences were minimal or negligible between the two approaches. Any difference between the two cropping strategies were accounted in the questionnaire by farmers at the end of the cropping season. Once questionnaires were filled out, the calculation of performance indicators, both economic and environmental, was performed by means of a LCA approach.

Some plots were photographed, as shown in Figures 78, 79, 80, 81 and 82. The first two were taken during ripening. In the Figures 78 and 79 the optimization of fertilization through *granoduro.net®* increased the bending strength of wheat. Instead in the section managed by farmer the amount of nitrogen spread out was standard quantity and no nitrogen balance between inputs and outputs was calculated. As a consequence, the amount of nitrogen used was higher than needs and wheat lodged when heavy rain occurred.

The other three photos are referred to wheat stem extension stage and differences between the two managements were not visible yet.

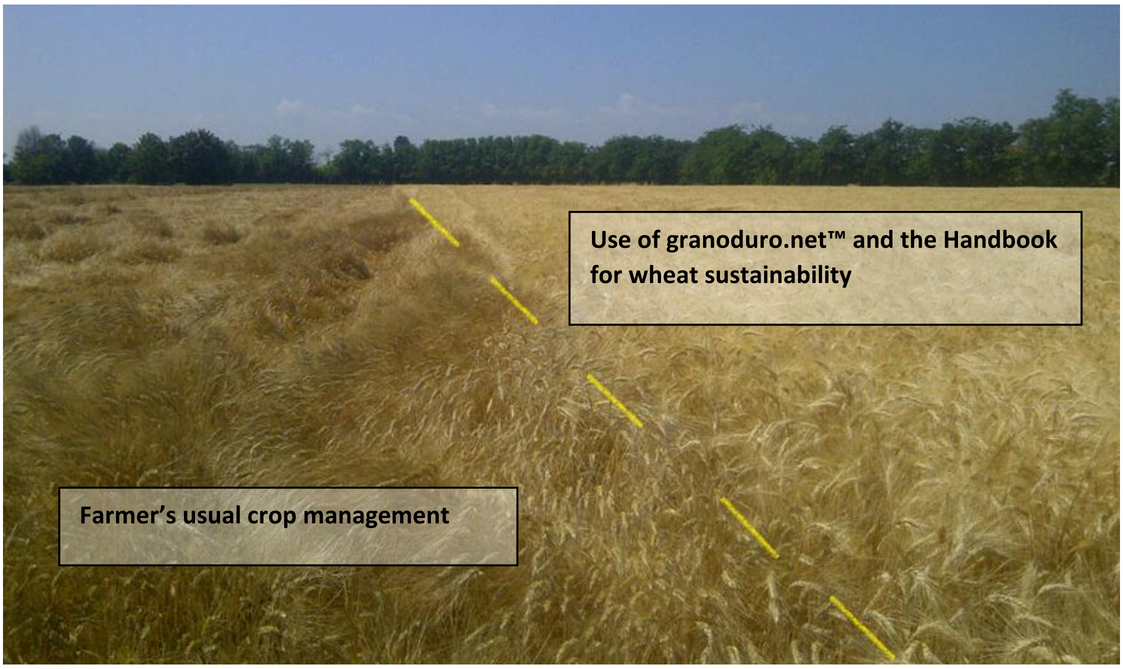


Figure 78: The plot of scenario 1 subjected to comparison. Farmer's usual crop management versus the use of granoduro.net® and an handbook for wheat sustainability.

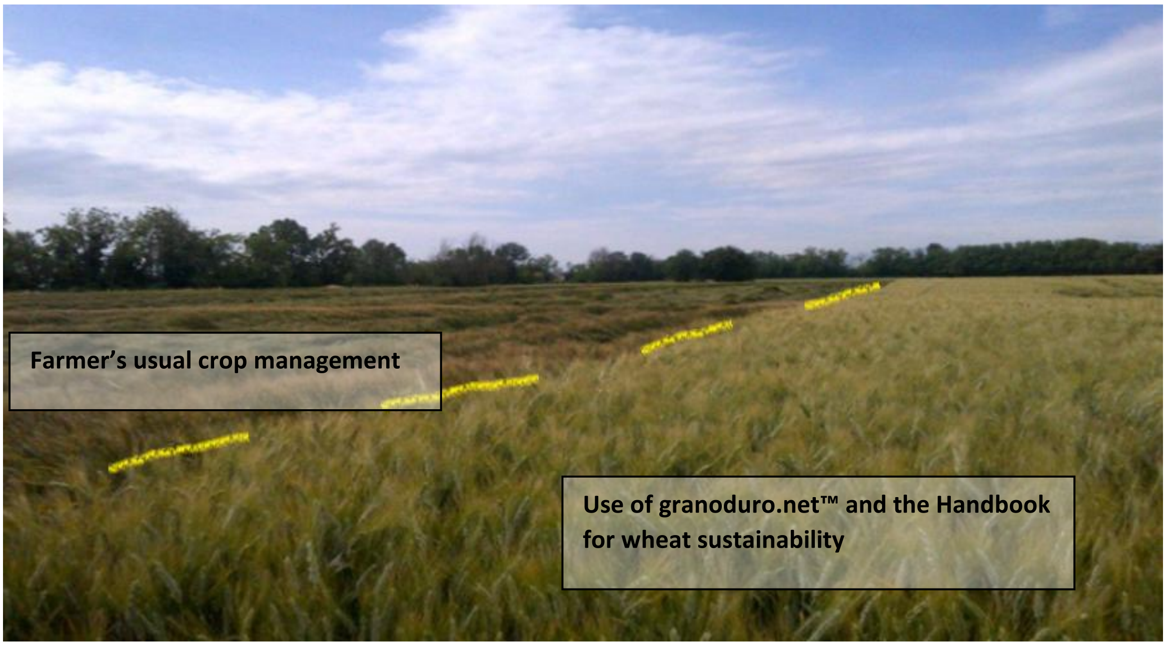


Figure 79: The plot of scenario 2 subjected to comparison. Farmer's usual crop management versus the use of granoduro.net® and an handbook for wheat sustainability.

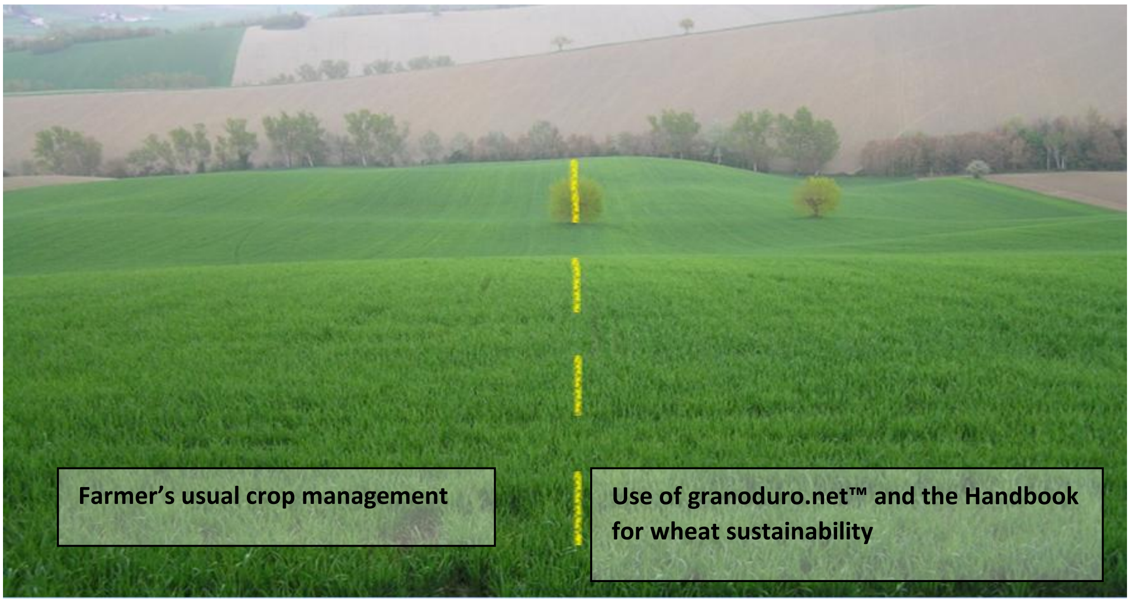


Figure 80: The plot of scenario 6 subjected to comparison. Farmer's usual crop management versus the use of granoduro.net® and an handbook for wheat sustainability.

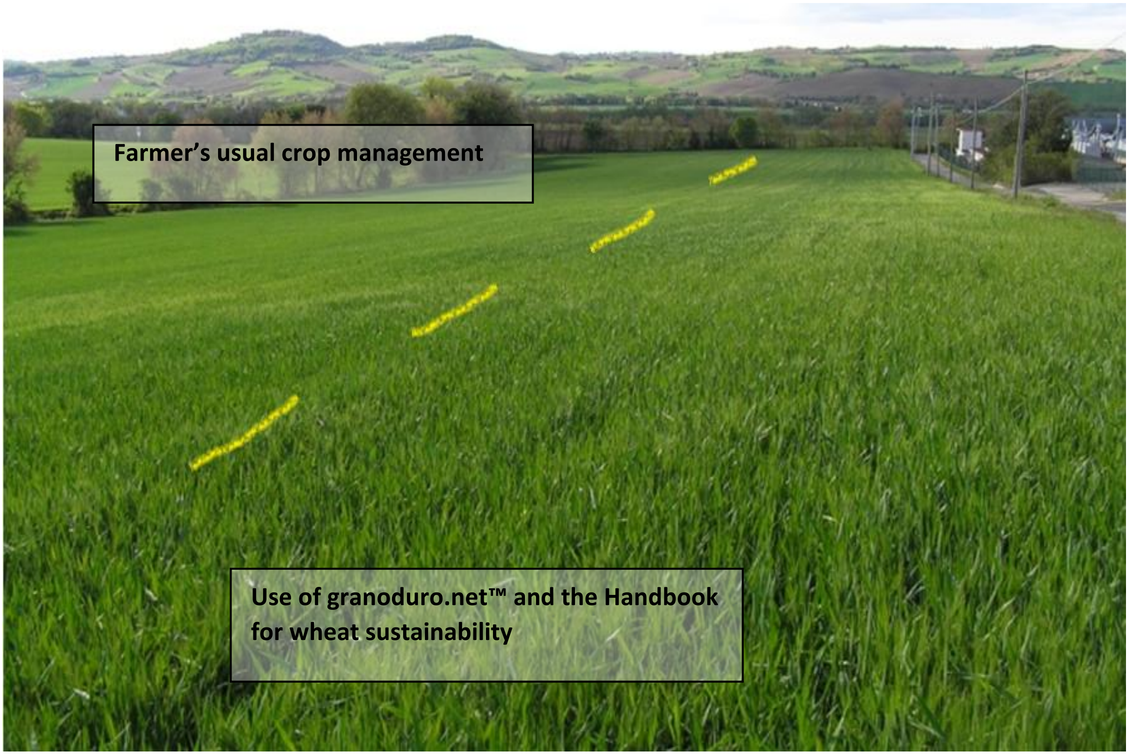


Figure 81: The plot of scenario 7 subjected to comparison. Farmer's usual crop management versus the use of granoduro.net® and an handbook for wheat sustainability.

Figure 82: The plot of scenario 9 subjected to comparison. Farmer's usual crop management versus the use of granoduro.net® and an handbook for wheat sustainability.

Indices, parameters, and indicators referring to durum wheat cultivated within each rotation are collected in the Table 7 *a,b,c.* In particular the following data were collected: yield (tons/hectare), yield at 13% of humidity (tons/hectare), yield at 0% of humidity (tons/hectare), straw yield (tons/hectare), quality parameters as protein content (% of dry matter), test weight (kilograms/hl), humidity at harvesting (%), mycotoxin DON (ppb) and ash (% of dry matter). Quality parameters were calculated by laboratory testing performed for samples gathered by plots under evaluation.
From the economic point of view data gathered were: straw price (€/ton), kernels price (€/ton), GMP straw (€/hectare), GMP kernels (€/hectare), Total GMP (€/hectare), cropping activities costs (€/ton and €/hectare), technical tools costs (€/ton and €/hectare), and total direct costs (€/ton and €/hectare).

Agronomic performance was estimated through the index: nitrogen up-taken by kernels (kilograms/hectare), total protein (tons/hectare), theoretical biomass above soil (tons/hectare), theoretical biomass (straw + roots) (tons/hectare), fuel consumption (litres/hectare), nitrogen supplied (kilograms/hectare), nitrogen from soil crop residues (kilograms/hectare), agronomic NUE (kilograms/kilograms), carbon sequestration of kernels (tons/hectare), carbon sequestration of biomass (tons/hectare), and total carbon sequestration (tons/hectare).

Table 7 a: Yield, quality parameters and indicators of durum wheat of the 13 scenarios compared in the 2011/2012 cropping season.

Farm	Type of rotation	Durum wheat in rotation with:	granoduro.net®	Yield (t/ha)	Yield at 13% of humidity (t/ha)	Yield at 0% of humidity (t/ha)	Protein content (% of dry matter)	Test weight (kg/hl)	Humidity at harvesting (%)	Mycotoxin DON (ppb)	Ash (% of dry matter)	Straw yield (t/ha)
1	Richness	Tomato	Yes	9.1	9.5	8.3	14.2	87.5	9.3	17.5	1.8	6.0
			No	8.2	8.5	7.4	14.4	87.6	9.3	138.0	1.9	6.5
2	Richness	Tomato	Yes	7.9	8.1	7.1	14.6	85.5	10.7	17.5	1.9	6.0
			No	7.2	7.4	6.4	13.9	87.0	11.1	56.0	2.1	6.5
3	Pauperizing	Waxy maize	Yes	7.3	7.6	6.6	17.0	84.7	9.9	17.5	1.9	4.9
			No	7.9	8.2	7.1	17.0	85.1	9.8	17.5	2.0	4.5
4	Pauperizing	Grain Sorghum	Yes	4.0	4.1	3.6	15.6	84.0	10.5	17.5	1.7	3.0
			No	4.5	4.6	4.0	15.4	86.1	10.6	218.0	2.0	3.0
5	Richness	Field bean	Yes	8.0	8.2	7.2	12.9	85.3	10.9	17.5	2.0	4.3
			No	8.0	8.3	7.2	14.2	84.2	10.3	17.5	2.2	4.3
6	Neutral	Sunflower	Yes	7.7	8.0	7.0	12.6	86.4	9.7	70.0	2.3	4.5
			No	7.3	7.5	6.5	12.9	86.8	10.3	17.5	2.1	4.5
7	Neutral	Sunflower	Yes	4.9	5.1	4.4	12.2	88.0	8.9	17.5	1.8	0.0
			No	4.6	4.8	4.2	14.7	87.2	9.2	17.5	2.0	0.0
8	Richness	Chickpea	Yes	5.7	5.8	5.1	13.3	85.4	10.1	17.5	1.8	0.0
			No	6.4	6.6	5.7	12.8	84.8	10.2	94.0	2.0	0.0
9	Neutral	Sunflower	Yes	5.8	5.8	5.1	14.8	83.1	13.3	518.0	2.1	3.0
			No	6.2	6.3	5.5	13.2	84.9	11.0	144.0	2.0	3.0
10	Neutral	Oilseed rape/Sunflower	Yes	5.8	6.0	5.2	13.1	84.7	10.2	100.0	2.2	0.0
			No	5.6	5.8	5.0	14.1	82.5	10.1	17.5	2.1	0.0
11	Richness	Tomato	Yes	5.0	5.3	4.6	15.7	87.6	8.6	17.5	2.0	2.0
			No	4.3	4.5	3.9	15.3	88.1	8.8	17.5	1.9	2.0
12	Richness	Oilseed rape	Yes	4.8	5.0	4.3	12.7	87.0	9.6	17.5	2.1	2.0
			No	5.1	5.3	4.6	14.7	86.4	9.5	112.8	1.8	2.0
13	Neutral	Sunflower	Yes	4.0	4.1	3.6	13.5	86.8	10.0	17.5	1.9	2.0
			No	4.0	4.2	3.6	14.2	85.5	9.5	17.5	2.1	2.0

Table 7 b: Economic variables and indicators of durum wheat of the 13 scenarios compared in the 2011/2012 cropping season.

Farm	granoduro.net®	Price straw (€/t)	Price of kernels (€/t)	GMP kernels (€/ha)	GMP straw (€/ha)	Total GMP (€/ha)	Crop. activities costs (€/ha)	Technical tools costs (€/ha)	Total direct costs (€/ha)	Crop. activities costs (€/t)	Technical tools costs (€/t)	Total direct costs (€/t)	Net Income (€/ha)
1	Yes	30.0	271.4	2574.1	180.0	2754.1	443.0	374.0	817.0	46.7	39.4	86.1	1937.1
	No	30.0	271.4	2319.8	195.0	2514.8	473.0	508.0	981.0	55.3	59.4	114.8	1533.8
2	Yes	60.0	271.4	2201.6	360.0	2561.6	433.0	407.0	840.0	53.4	50.2	103.5	1721.6
	No	60.0	271.4	1997.6	390.0	2387.6	483.0	555.0	1038.0	65.6	75.4	141.0	1349.6
3	Yes	25.0	271.4	2063.9	122.5	2186.4	610.8	375.3	986.1	80.3	49.3	129.7	1200.3
	No	25.0	271.4	2228.2	112.5	2340.7	650.9	408.8	1059.7	79.3	49.8	129.1	1280.9
4	Yes	50.0	271.4	1117.1	150.0	1267.1	665.0	317.4	982.4	161.6	77.1	238.7	284.7
	No	50.0	271.4	1255.5	150.0	1405.5	665.0	469.0	1134.0	143.7	101.4	245.1	271.5
5	Yes	60.0	271.4	2232.6	258.0	2490.6	519.5	435.3	954.8	63.1	52.9	116.1	1535.8
	No	60.0	271.4	2247.9	258.0	2505.9	519.5	462.2	981.7	62.7	55.8	118.5	1524.2
6	Yes	50.0	271.4	2169.9	225.0	2394.9	608.5	360.0	968.5	76.1	45.0	121.1	1426.4
	No	50.0	271.4	2042.1	225.0	2267.1	598.5	405.0	1003.5	79.5	53.8	133.4	1263.6
7	Yes	50.0	271.4	1377.8	0.0	1377.8	404.0	314.0	718.0	79.6	61.8	141.4	659.8
	No	50.0	271.4	1303.5	0.0	1303.5	398.0	409.8	807.8	82.9	85.3	168.2	495.7
8	Yes	50.0	271.4	1587.1	0.0	1587.1	595.0	422.3	1017.3	101.7	72.2	174.0	569.8
	No	50.0	271.4	1793.2	0.0	1793.2	630.0	532.3	1162.3	95.3	80.6	175.9	630.9
9	Yes	55.0	271.4	1577.6	165.0	1742.6	538.0	327.0	865.0	92.5	56.3	148.8	877.6
	No	55.0	271.4	1707.0	165.0	1872.0	573.0	449.0	1022.0	91.1	71.4	162.5	850.0
10	Yes	55.0	271.4	1624.7	0.0	1624.7	465.0	606.5	1071.5	77.7	101.3	179.0	553.2
	No	55.0	271.4	1571.3	0.0	1571.3	465.0	678.5	1143.5	80.3	117.2	197.5	427.8
11	Yes	100.0	340.0	1793.2	200.0	1993.2	410.0	305.3	715.3	77.7	57.9	135.6	1277.9
	No	100.0	340.0	1535.6	200.0	1735.6	404.0	325.5	729.5	89.5	72.1	161.5	1006.1
12	Yes	100.0	340.0	1685.6	200.0	1885.6	443.0	335.8	778.8	89.4	67.7	157.1	1106.8
	No	100.0	340.0	1804.1	200.0	2004.1	446.0	355.5	801.5	84.1	67.0	151.1	1202.6
13	Yes	100.0	340.0	1396.9	200.0	1596.9	415.5	312.6	728.1	101.1	76.1	177.2	868.8
	No	100.0	340.0	1414.8	200.0	1614.8	416.0	355.5	771.5	100.0	85.4	185.4	843.3

Table 7 c: Agronomic and environmental variables and indicators of durum wheat of the 13 scenarios compared in the 2011/2012 cropping season.

Farm	granoduro.net®	Nitrogen up-taken by kernels (kg/ha)	Nitrogen applied (kg /ha)	Nitrogen from soil crop residues (kg/ha)	Agronomic NUE (kg/kg)	Total protein (t/ha)	Theoretical biomass above soil (t/ha)	Theoretical biomass (straw + roots) (t/ha)	Fuel consumption (l/ha)	Carbon Footprint (tCO_2 eq/ha)	Carbon Footprint (tCO_2 eq/t)	Water Footprint (m^3H_2O/ha)	Water Footprint (m^3H_2O/t)	Ecological Footprint (global ha/ha)	Ecological Footprint (global ha/t)	Carbon sequestration (kernels) (t/ha)	Carbon sequestration (biomass) (t/ha)	Total Carbon sequestration (t/ha)
1	Yes	205.6	166.8	90.0	49.5	1.2	12.4	15.5	114.0	2.62	0.25	12295	1176	2.75	0.263	5.2	6.8	12.0
	No	187.6	195.8	90.0	38.0	1.1	11.2	13.9	137.0	2.96	0.314	10549	1119	2.79	0.296	4.7	6.1	10.8
2	Yes	180.8	160.0	102.0	44.1	1.0	10.6	13.2	130.0	2.58	0.284	10834	1193	2.76	0.303	4.4	5.8	10.2
	No	156.5	212.8	102.0	30.1	0.9	9.6	12.0	141.0	3.2	0.386	10008	1209	2.79	0.338	4.0	5.3	9.3
3	Yes	197.0	176.0	64.0	37.6	1.1	9.9	12.4	180.5	2.85	0.338	9357	1109	2.79	0.33	4.1	5.5	9.6
	No	213.0	190.3	64.0	37.5	1.2	10.7	13.4	183.0	2.79	0.306	10062	1105	2.78	0.306	4.5	5.9	10.4
4	Yes	97.7	122.0	87.0	29.4	0.6	5.4	6.7	329.0	2.3	0.499	5508	1198	2.72	0.591	2.2	3.0	5.2
	No	108.4	204.5	87.0	19.7	0.6	6.0	7.5	329.0	3.2	0.619	9498	1836	2.8	0.542	2.5	3.3	5.8
5	Yes	162.5	143.5	112.0	49.9	0.9	10.7	13.4	114.5	2.19	0.238	11438	1239	2.76	0.299	4.5	5.9	10.4
	No	179.5	183.6	112.0	39.2	1.0	10.8	13.5	118.5	2.65	0.287	13116	1421	2.79	0.303	4.5	5.9	10.4
6	Yes	153.2	145.0	63.0	48.0	0.9	10.4	13.0	130.5	2.1	0.238	11394	1287	2.75	0.31	4.3	5.7	10.1
	No	148.6	200.0	63.0	32.7	0.8	9.8	12.3	127.5	1.54	0.184	10647	1269	2.7	0.322	4.1	5.4	9.5
7	Yes	94.5	114.0	39.0	38.7	0.5	6.6	8.3	120.0	1.94	0.348	7031	1264	2.67	0.479	2.8	3.6	6.4
	No	107.5	163.0	39.0	25.6	0.6	6.3	7.8	127.0	2.47	0.468	7489	1418	2.72	0.516	2.6	3.4	6.1
8	Yes	118.4	144.5	97.0	35.2	0.7	7.6	9.5	112.5	1.86	0.285	9848	1514	2.69	0.414	3.2	4.2	7.4
	No	128.8	167.0	97.0	34.4	0.7	8.6	10.8	116.0	2.74	0.373	11367	1545	2.78	0.378	3.6	4.7	8.3
9	Yes	131.1	142.1	71.0	35.6	0.7	7.6	9.5	85.0	1.8	0.268	10098	1507	2.66	0.396	3.2	4.2	7.3
	No	126.2	164.6	71.0	33.2	0.7	8.2	10.3	88.5	2.42	0.343	10987	1554	2.73	0.387	3.4	4.5	7.9
10	Yes	119.5	205.0	58.0	25.4	0.7	7.8	9.8	56.0	2.51	0.377	10783	1617	2.75	0.412	3.3	4.3	7.5
	No	124.3	213.0	58.0	23.6	0.7	7.6	9.4	56.0	2.65	0.411	11335	1761	2.75	0.427	3.1	4.2	7.3
11	Yes	126.0	99.6	105.0	46.1	0.7	6.9	8.6	143.2	1.55	0.269	8941	1550	2.7	0.467	2.9	3.8	6.7
	No	105.6	89.0	105.0	44.1	0.6	5.9	7.4	136.8	1.41	0.285	7849	1584	2.68	0.541	2.5	3.2	5.7
12	Yes	95.9	100.0	74.0	43.1	0.5	6.5	8.1	136.9	1.7	0.31	9096	1659	2.74	0.499	2.7	3.6	6.3
	No	119.0	89.0	74.0	51.9	0.7	6.9	8.7	139.9	1.59	0.271	9796	1671	2.73	0.465	2.9	3.8	6.7
13	Yes	84.6	75.0	62.0	47.7	0.5	5.4	6.7	125.7	1.41	0.31	7834	1717	2.71	0.595	2.2	2.9	5.2
	No	89.9	89.0	62.0	40.7	0.5	5.4	6.8	126.0	1.56	0.34	8062	1753	2.72	0.592	2.3	3.0	5.3

To check if *granoduro.net®* was able to improve the sustainability of plots a Student t-test with a confidence interval of 90% (α level two-tailed test 0.1) was performed (Table 8). The choice of 90% relies on the lack of significant outcomes for confidential interval at 95% and 99%.

Table 8: Mean values of the more interesting variables and indicators assessed in the 13 scenarios of the cropping season 2011/2012.

Performance of 13 comparisons		
	granoduro.net®	Mean ± Standard error
Yield (t/ha)	No	6.3 ± 0.43
	Yes	6.3 ± 0.48
Protein (% dry matter)	No	14.3 ± 0.31
	Yes	14 ± 0.4
Test weight (kg/hl)	No	85.9 ± 0.43
	Yes	85.8 ± 0.41
DON (µg/kg)	No	68.1 ± 18.6
	Yes	66.4 ± 38.3
Ash (% dry matter)	No	2.02 ± 0.03
	Yes	1.96 ± 0.05
Gross Marketable Product kernels (€/ha)	No	1786.2 ± 100.4
	Yes	1800.2 ± 116
Cropping activities costs (€/ha)	No	517.1 ± 26.6
	Yes	503.9 ± 25.1
Technical tools costs (€/ha)	No	454.9 ± 26.8
	Yes	376.3 ± 22.7
Total costs (€/ha)	No	972 ± 41
	Yes	880.2 ± 34.3
Total costs (€/t)	No	160.3 ± 9.97
	Yes	146.8 ± 11
Net Income (€/ha)	No	975.4 ± 117.6
	Yes	1078.4 ± 137.8
Carbon footprint (tCO_2 eq/ha)	No	2.39 ± 0.18
	Yes	2.11 ± 0.12
Carbon footprint (tCO_2 eq/t)	No	0.352 ± 0.029
	Yes	0.308 ± 0.02
Water footprint (m^3H_20/ha)	No	10058.8 ± 438.5
	Yes	9573.6 ± 532.8
Water footprint (m^3H_20/t)	No	1480.4 ± 68.6
	Yes	1386.9 ± 58.6
Ecological footprint (global ha/ha)	No	2.75 ± 0.011
	Yes	2.73 ± 0.01
Ecological footprint (global ha/t)	No	0.42 ± 0.03
	Yes	0.41 ± 0.03
Nitrogen (kg/ha)	No	166.3 ± 13.06
	Yes	137.96 ± 9.84
Agronomic (NUE kg/kg)	No	34.7 ± 2.4
	Yes	40.8 ± 2.2
Total Carbon Sequestration (t/ha)	No	7.96 ± 0.55
	Yes	8.02 ± 0.61

The cropping season 2011/2012 was extremely favourable for durum wheat in Italy in terms of yields, quality and health of grains. The temperature was around the average and the rainfalls was abundant during key durum wheat phonological stages. The development of mycotoxin by *Fusarium* spp. was strongly unfavourable. Therefore, the conditions resulted to be not favourable to identify the characteristics of different approaches and the potential benefits of using innovative farming systems from a disease management point of view. Only values of three indicators on costs and two on the use of fertilizers resulted to be significantly different in the two management strategies (Table 9).

Table 9: List of indicators resulted significant at a Student t-test with a confidence interval of 90% (α level two-tailed test 0.1, assumed equal variance) in the season 2011/2012.

	t-test for Equal Means, for Independent Samples	df	Sig. (2-tail)	Difference between means	Difference standard error	Confidence interval for the difference at 95%. Min-Max Confidence Intervals	
Technical tools costs (€/ha)	2.237	24	0.035	78.58846	35.1361	6.07117	151.1058
Total costs (€/ha)	1.717	24	0.099	91.78692	53.4582	-18.54541	202.1193
Technical tools costs (€/t)	1.815	24	0.082	12.86604	7.08988	-1.7667621	27.49884
Nitrogen (kg/ha)	1.731	24	0.096	28.31154	16.3546	-5.44264	62.06572
Agronomic NUE (kg/kg)	-1.871	24	0.074	-6.09711	3.25961	-12.824612	0.630401

Total direct costs (€/t) of crop management following *granoduro.net® (b)* were statistically lower than farmers management *(a)*, especially with rich or neutral contribution by previous crop (-10% approximately) (Figure 83).

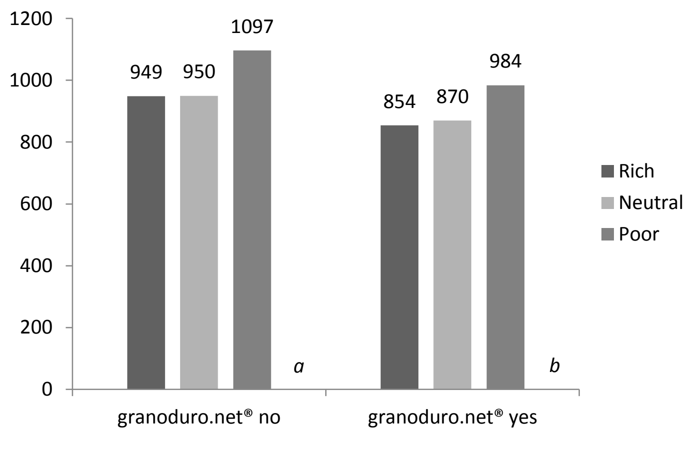


Figure 83: Total direct costs (€/ha) for the durum wheat of the 13 scenarios categorized as enriching, neutral and pauperizing. Statistical differences; a,ab,b…= Student-t Test (p=0.1).

In Figures 84 and 85 total costs were split up into the main activities, such as tillage, seeding, fertilization, pesticides and harvest/transport, and into technical tools and cropping activities respectively. In particular, *granoduro.net® (b)* reduced the cost by acting on pesticides and fertilizers, while less relevance was noted for tillage, seeding and harvest/transport to farm centre (Figure 84). This is confirmed also in Figure 85 where it is reported that the benefits of *granoduro.net® (b)* occurred especially for technical tools costs.

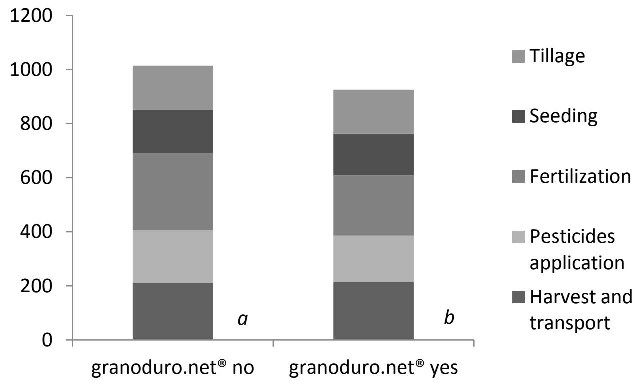


Figure 84: Total direct costs (€/ha) for the durum wheat of the 13 scenarios. Costs are split up into tillage, seeding, fertilization, pesticides application and harvest/transport to farm centre. Statistical differences; a,ab,b…= Student-t Test (p=0.1).

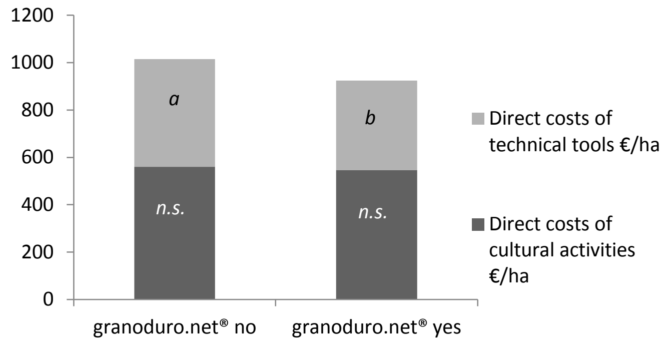


Figure 85: Total direct costs (€/ha) for the durum wheat of the 13 scenarios. Costs are split up into technical tools and cropping activities. Technical tools costs with granoduro.net® were statistically different by no-granoduro.net® use. This did not happen for direct costs of cropping activities. Statistical differences; a,ab,b…= Student-t Test (p=0.1), n.s.= not significant.

Interestingly, the values of the indicator Agronomic NUE (Figure 86) referring to farmers' *(a)* and *granoduro.net®* management *(b)* were statistically significant. In particular, the use of *granoduro.net®* increased the efficiency of nitrogen use by 5-8%, i.e. same yields were obtained by the two managements but the one following *granoduro.net®* used a lower dosage of nitrogen.

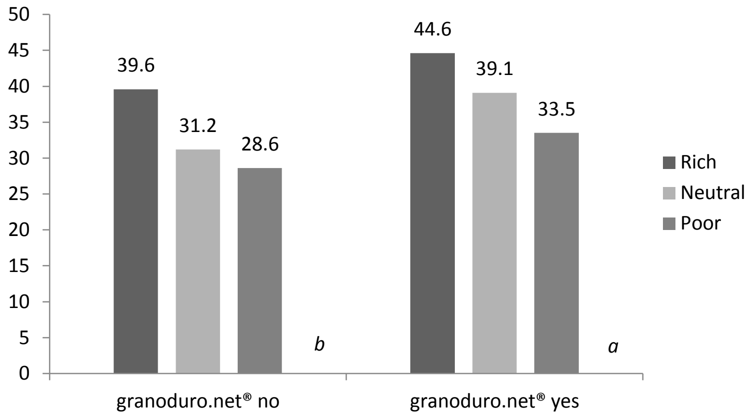


Figure 86: Agronomic NUE (kg/kg of N applied) for the durum wheat of the 13 scenarios categorized as enriching, neutral and pauperizing. Statistical differences; a,ab,b…= Student-t Test (p=0.1).

Data of the cropping season 2011/2012 demonstrated that, when durum wheat is rotated with leguminous or horticultural crops, crop cultivation direct costs (€/ha), use of diesel fuel (l/ha), carbon footprint (tCO_2eq/ha or tCO_2eq/t) and ecological footprint (global ha/t) are lower and Agronomic NUE (kg/kg) higher than farmer scenario.

In particular, when durum wheat is cultivated within a favourable rotation with leguminous gas emission are 36% lower (Figure 87), direct costs of cultivation are 31% lower (Figure 88), and yields improve by 15-20% rather than within an unfavourable rotation with cereals or industrial crops (Figure 89).

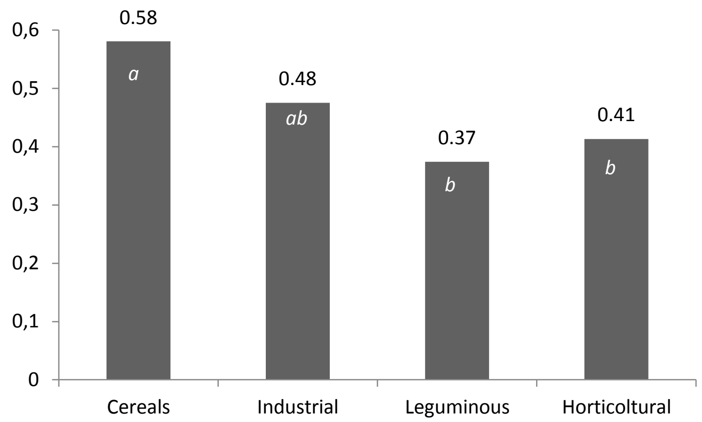


Figure 87: Carbon footprint (tCO_2eq/t durum wheat) for the 13 scenarios categorized as rotation of durum wheat with cereals, industrial, leguminous or horticultural crops. Statistical differences. a,ab,b…= Student-Newman-Keuls Test (p=0.05).

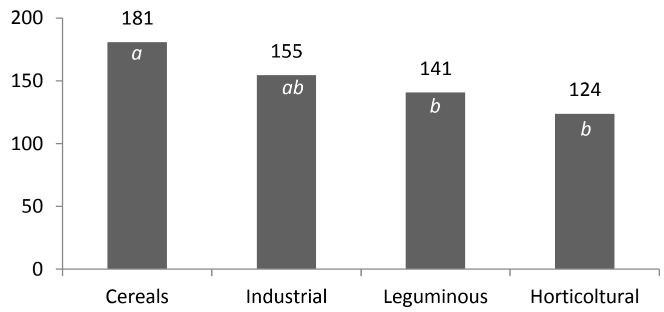


Figure 88: Total direct costs (€/t durum wheat) for the 13 scenarios categorized as rotation of durum wheat with cereals, industrial, leguminous or horticultural crops. Statistical differences. a,ab,b…= Student-Newman-Keuls Test (p=0.05).

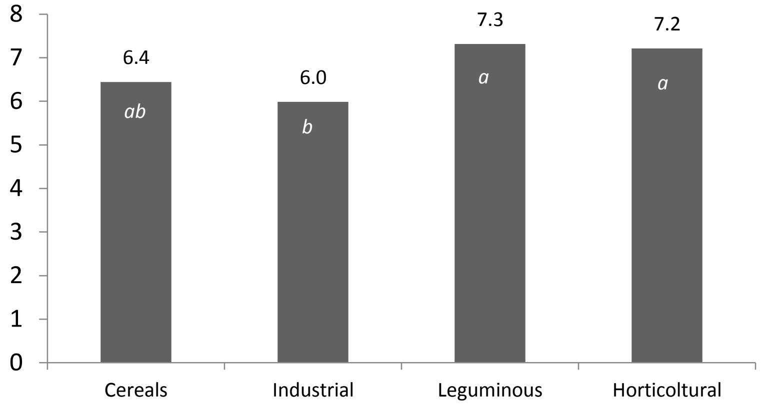


Figure 89: Yield (€/ha durum wheat) for the 13 scenarios categorized as rotation of durum wheat with cereals, industrial, leguminous or horticultural crops. Statistical differences. a,ab,b…= Student-Newman-Keuls Test (p=0.05).

The results achieved in this first year of comparison were considered very positive by stakeholders, even if significant differences were achieved only for few indicators.

The use of *granoduro.net®* and the handbook allowed to increase the awareness of farmers, technicians and agronomists of which variables influence durum wheat performance. This new approach proved as plot-specific information is mandatory for increasing the quality of decisions throughout crop season.

Stakeholders learnt that agricultural practices can influence the environmental, economic and food safety performances of durum wheat cultivation. In particular, the use of rotations and the optimization of fertilizers, tillage, seeding and weeds and pests control are crucial to increase sustainability. The choice of an appropriate crop rotation is a key point for the sustainability of a farming system. Monoculture of durum wheat is not recommended also for quality reasons because its cropping residues (straw and chaff) are a habitat for fungi fostering DON contamination.

The use of *granoduro.net®* and the handbook in pilot farms, respectively for tactic and strategic decisions, was repeated in cropping season 2012/2013 and compared with the usual farmer's crop management.

Data about management practices performed were collected and indicators calculated directly through a functionality implemented on *granoduro.net®* (i.e., completely independent from the software SimaPro 7 and the database Ecoinvent used in the years 2009/2010 and 2010/2011 to calculate the footprint indicators). Indeed, new databases about emissions and consumption of fuel were developed and implemented into *granoduro.net®* thanks to Horta S.r.l. expertise and this allowed to refine and speed up the indicators calculation. The new procedure led to more accurate values of carbon and ecological footprint, usually lower than the ones estimated by the software SimaPro 7 and the database Ecoinvent used in the first two years.

Moreover, in this second pilot farms year the potentiality of *granoduro.net®* were studied in the light of a SWOT analysis (Hill and Westbrook, 1997), i.e. the strengths, weaknesses, opportunities and threats of the use of *granoduro.net®* were analysed:

Strengths

- solid database on pests and pesticides built through field trials over the last 15 years;
- easy tool to manage;
- based on mechanistic models;
- no commercial purposes, it is only a decision support system.

Weaknesses

- limited portfolio of durum wheat varieties to choose on: Levante, Latinur, Saragolla, Normanno, Odisseo, Iride, Aureo, Maestrale, Svevo,Grecale, Miradoux, Pigreco, Monastir, Yelodur, Ramirez, Maracas, PR22D66, PR22D89, Tirex, Biensur, Achille, San Carlo, Casare, Claudio, Emilio Lepido, Massimo meridio, Simeto and Duilio.

Opportunities

- increase efficiency of farming systems and optimization of costs;
- more communication and relationships between Barilla S.p.A., its suppliers, farmers associations and single farmers;
- consciousness of farmers toward which variables influence crop yield and quality and how farm activities are related to costs;
- collect positive feedbacks from farmers for increasing sustainability also at the base level of the food chain;
- oriented to CAP (Common Agricultural Policy) and sustainable use of pesticides (Directive 128/2009/CEE).

Threats

- cooperatives or Chemical Industries may see the system as a limit to their agri-input selling activity;
- Italian farmers have limited accessibility to and skills for on-line web consultancy;
- farmers' suspicion of giving their data to the industry;
- cost to start up the system;
- costs for maintaining the system.

By considering these aspects, 22 comparisons were planned. The 22 farms involved in the study were located in the most important areas of durum wheat cultivation in Italy, the majority into Emilia Romagna region, some in the centre of Italy (Tuscany and Marche regions), while three in the south (Apulia and Campania regions).

Characteristics of these rotations were collected by farmers through the same questionnaire of the previous cropping season and the calculated indicators are displayed in the Table 10 *a,b,c,d*.

The interviewed farmers cultivated durum wheat in rotation with some of the most widespread broadleaves in Italy: sugar beet, tomato, potato, sunflower, chickpea and leguminous (i.e. alfalfa and clover). Also less favourable rotations with grass species like sorghum, ray grass and wheat were tested. As for the previous experimental year differences between the two cropping strategies were accounted in the questionnaire by farmers at the end of the cropping season. Once questionnaires were filled out, the calculation performance indicators, both economic and environmental, was performed by means of a LCA approach.

In the 22 comparisons significant differences were not observed between the two cropping strategies, even for the amount of fertilizers applied on crops and number and timing of fungicides treatments. Small differences were instead identified for the sowing density and soil tillage. This happened probably for two reasons: the farmers involved in the comparison were already durum wheat opinion leader in their district, and cultivated wheat in an efficient way even before the starting of the project. Secondly some growers had already taken part to the project the year before. As a consequence, intentionally or unconsciously they imitated choices advised for the year before and dissimilarities fading out irremediably.

Table 10 a: Yield, quality variables, economic variables and indicators of durum wheat of the first 11 scenarios compared in the 2012/2013 cropping season.

Area	Farm	Variety of durum wheat	Rotation of durum wheat with:	granoduro.net®	Yield at 13% of humidity (t/ha)	Protein (% of dry matter)	Test weight (kg/hl)	Price kernels (€/t)	GMP kernels (€/ha)	GMP kernels (€/t)	Cropping activities costs (€/ha)	Technical tools costs (€/ha)	Total direct costs (€/ha)
North	1	Normanno	Sugar beet	Yes	7.5	11.8	84.6	240.0	1788.0	240.0	539.0	492.0	1031.0
		Normanno	Sugar beet	No	7.7	12.8	80.5	240.0	1836.0	240.0	554.0	585.0	1139.0
North	2	Normanno	Sugar beet	Yes	5.4	14.0	85.0	260.0	1404.0	260.0	385.0	451.0	836.0
		Normanno	Sugar beet	No	4.9	13.5	84.2	250.0	1225.0	250.0	400.0	517.5	917.5
North	3	Normanno	Alfalfa	Yes	5.4	13.5	85.1	250.0	1345.0	250.0	445.0	378.4	823.4
		Normanno	Alfalfa	No	5.0	12.0	84.5	240.0	1188.0	240.0	445.0	517.5	962.5
North	4	Levante	Tomato	Yes	6.6	14.5	83.5	260.0	1716.0	260.0	483.0	365.0	848.0
		Dylan	Tomato	No	5.9	13.1	80.3	250.0	1475.0	250.0	488.0	455.0	943.0
North	5	Levante	Potato	Yes	7.5	13.5	79.0	250.0	1875.0	250.0	475.0	409.0	884.0
		Levante	Potato	No	7.0	13.6	81.4	250.0	1750.0	250.0	489.0	423.0	912.0
North	6	Odisseo	Sugar beet	Yes	8.3	13.8	77.6	250.0	2085.0	250.0	573.0	485.3	1058.3
		Odisseo	Sorghum	No	8.6	14.2	80.8	260.0	2230.8	260.0	575.0	447.6	1022.6
North	7	San Carlo	Tomato	Yes	7.4	13.2	83.7	250.0	1860.0	250.0	496.0	269.0	765.0
		San Carlo	Tomato	No	6.5	12.6	83.7	240.0	1562.4	240.0	572.0	306.0	878.0
North	8	Levante	Tomato	Yes	6.4	14.5	82.8	260.0	1664.0	260.0	483.0	382.0	865.0
		Dylan	Tomato	No	6.2	14.7	83.4	260.0	1612.0	260.0	488.0	475.0	963.0
Centre	9	Normanno	Sunflower	Yes	4.2	12.9	77.0	240.0	1008.0	240.0	575.0	513.0	1088.0
		Normanno	Sunflower	No	3.8	13.5	77.5	250.0	945.0	250.0	610.0	608.0	1218.0
Centre	10	Normanno	Chickpea	Yes	3.6	12.3	75.8	240.0	864.0	240.0	570.0	402.4	972.4
		Normanno	Chickpea	No	3.9	12.5	75.9	240.0	936.0	240.0	600.0	521.0	1121.0
Centre	11	Normanno	Sunflower	Yes	4.9	14.0	79.0	260.0	1274.0	260.0	540.0	548.2	1088.2
		Normanno	Sunflower	No	4.9	14.1	79.2	260.0	1274.0	260.0	565.0	619.0	1184.0

Table 10 b: Economic, environmental and nitrogen efficiency variables of durum wheat of the first 11 scenarios compared in the 2012/2013 cropping season.

Farm	Cropping activities costs (€/t)	Technical tools costs (€/t)	Total direct costs (€/t)	Net income (€/ha)	Net income (€/t)	Carbon footprint (tCO_2eq/t)	Carbon footprint (tCO_2eq/ha)	Water footprint (m^3H_20/t)	Water footprint (m^3H_2O/ha)	Ecological footprint (global ha/t)	Ecological footprint (global ha/ha)	Agronomic NUE (kg/kg)
1	72.3	66.0	138.4	757.0	101.6	0.213	1.82	1054.0	9024.0	0.307	2.63	49.7
	72.4	76.5	148.9	697.0	91.1	0.255	2.24	1052.0	9254.0	0.299	2.63	48.4
2	71.3	83.5	154.8	568.0	105.2	0.335	2.08	1105.0	6860.0	0.424	2.63	36.2
	81.6	105.6	187.2	307.5	62.8	0.334	1.88	1116.0	6268.0	0.463	2.61	40.3
3	82.7	70.3	153.0	521.7	97.0	0.205	1.27	1106.0	6837.0	0.420	2.60	58.8
	89.9	104.5	194.4	225.5	45.6	0.340	1.93	1131.0	6433.0	0.464	2.64	34.2
4	73.2	55.3	128.5	868.0	131.5	0.360	2.73	1127.0	8551.0	0.364	2.76	35.4
	82.7	77.1	159.8	532.0	90.2	0.280	1.90	1146.0	7769.0	0.400	2.72	49.2
5	63.3	54.5	117.9	991.0	132.1	0.270	2.17	1136.0	9144.0	0.330	2.65	43.9
	69.9	60.4	130.3	838.0	119.7	0.213	1.82	1054.0	9024.0	0.307	2.63	49.7
6	68.7	58.2	126.9	1026.7	123.1	0.228	2.19	1064.0	10195.0	0.279	2.67	46.5
	67.0	52.2	119.2	1208.2	140.8	0.220	2.17	1061.0	10471.0	0.271	2.67	47.8
7	66.7	36.2	102.8	1095.0	147.2	0.292	2.49	1084.0	9267.0	0.323	2.76	43.0
	87.9	47.0	134.9	684.4	105.1	0.401	3.00	1097.0	8202.0	0.374	2.79	29.7
8	75.5	59.7	135.2	799.0	124.8	0.271	1.99	1130.0	8314.0	0.360	2.65	42.2
	78.7	76.6	155.3	649.0	104.7	0.239	1.71	1138.0	8112.0	0.368	2.63	45.9
9	136.9	122.1	259.0	-80.0	-19.0	0.494	2.39	1430.0	6902.0	0.563	2.72	24.2
	161.4	160.8	322.2	-273.0	-72.2	0.603	2.62	1647.0	7158.0	0.633	2.75	19.7
10	158.3	111.8	270.1	-108.4	-30.1	0.413	1.71	1373.0	5679.0	0.636	2.63	26.1
	153.8	133.6	287.4	-185.0	-47.4	0.445	1.99	1583.0	7096.0	0.595	2.67	24.3
11	110.2	111.9	222.1	185.8	37.9	0.359	2.02	1269.0	7146.0	0.471	2.65	29.8
	115.3	126.3	241.6	90.0	18.4	0.410	2.31	1436.0	8088.0	0.478	2.69	26.2

Table 10 c: Yield, quality variables, economic variables and indicators of durum wheat of the last 11 scenarios compared in the 2012/2013 cropping season.

Area	Farm	Variety of durum wheat	Rotation of durum wheat with:	granoduro.net®	Yield at 13% of humidity (t/ha)	Protein (% dry matter)	Test weight (kg/hl)	Price kernels (€/t)	GMP kernels (€/ha)	GMP kernels (€/t)	Cropping activities costs (€/ha)	Technical tools costs (€/ha)	Total direct costs (€/ha)
Centre	12	Normanno	Sunflower	Yes	4.0	14.0	76.0	250.0	1000.0	250.0	604.0	427.4	1031.4
		Normanno	Sunflower	No	4.4	12.6	77.5	240.0	1056.0	240.0	632.0	563.3	1195.3
Centre	13	Normanno	Clover	Yes	3.0	13.6	76.1	250.0	750.0	250.0	640.0	292.0	932.0
		Normanno	Clover	No	3.0	13.6	76.0	250.0	750.0	250.0	640.0	369.0	1009.0
Centre	14	Svevo	Sunflower	Yes	5.1	13.4	77.4	250.0	1275.0	250.0	530.0	298.0	828.0
		Svevo	Sunflower	No	6.0	14.0	78.0	250.0	1500.0	250.0	565.0	413.0	978.0
Centre	15	Iride	Sunflower/Pea	Yes	6.0	12.0	80.0	240.0	1440.0	240.0	509.0	337.0	846.0
		Iride	Sunflower/Pea	No	6.0	12.0	80.0	240.0	1440.0	240.0	509.0	389.0	898.0
Centre	16	Odisseo	Durum wheat	Yes	6.7	13.1	82.8	250.0	1667.5	250.0	642.0	552.0	1194.0
		Odisseo	Durum wheat	No	6.4	14.1	82.2	260.0	1656.2	260.0	642.0	621.0	1263.0
Centre	17	Odisseo	Durum wheat	Yes	6.4	13.5	83.6	250.0	1597.5	250.0	597.0	553.0	1150.0
		Odisseo	Durum wheat	No	7.4	13.7	82.5	250.0	1850.0	250.0	597.0	584.0	1181.0
Centre	18	Iride	Ryegrass	Yes	4.5	12.2	82.4	240.0	1080.0	240.0	440.0	552.0	992.0
		Iride	Durum wheat	No	4.0	11.3	80.1	240.0	960.0	240.0	500.0	582.0	1082.0
South	19	Aureo	Field bean	Yes	4.2	16.7	81.8	305.0	1290.2	305.0	442.0	414.0	856.0
		Aureo	Tomato	No	4.2	12.0	82.3	285.0	1202.7	285.0	415.0	464.0	879.0
South	20	Aureo	Durum wheat	Yes	4.5	16.7	84.3	305.0	1366.4	305.0	482.0	374.0	856.0
		Aureo	Tomato	No	3.8	12.7	83.0	285.0	1077.3	285.0	412.0	514.0	926.0
South	21	Aureo	Durum wheat	Yes	4.7	17.1	81.5	305.0	1424.4	305.0	506.0	389.0	895.0
		Aureo	Chickpea	No	3.5	17.0	82.3	305.0	1067.5	305.0	395.0	578.0	973.0
South	22	Aureo	Sunflower	Yes	4.0	16.0	83.3	305.0	1210.9	305.0	340.0	460.8	800.8
		Aureo	Sunflower	No	4.3	14.8	83.2	305.0	1317.6	305.0	343.0	514.0	857.0

Table 10 d: Economic, environmental and nitrogen efficiency variables of durum wheat of the last 11 scenarios compared in the 2012/2013 cropping season.

Farm	Crop. activities costs (€/t)	Technical tools costs (€/t)	Total direct costs (€/t)	Net income (€/ha)	Net income (€/t)	Carbon footprint (tCO_2eq/ha)	Carbon footprint (tCO_2eq/t)	Water footprint (m^3H_2O/ha)	Water footprint (m^3H_2O/t)	Ecological footprint (global ha/ha)	Ecological footprint (global ha/t)	Agronomic NUE (kg/kg)
12	151.0	106.9	257.9	-31.4	-7.9	1.96	0.387	7021.0	1388.0	2.64	0.523	29.3
	143.6	128.0	271.6	-139.3	-31.6	2.40	0.474	8201.0	1622.0	2.69	0.531	24.0
13	213.3	97.3	310.7	-182.0	-60.7	1.44	0.417	4728.0	1371.0	2.62	0.758	26.1
	213.3	123.0	336.3	-259.0	-86.3	1.44	0.417	4728.0	1371.0	2.62	0.758	26.1
14	103.9	58.4	162.4	447.0	87.6	1.54	0.260	7409.0	1264.0	2.62	0.447	41.3
	94.2	68.8	163.0	522.0	87.0	1.63	0.237	8611.0	1249.0	2.65	0.385	47.7
15	84.8	56.2	141.0	594.0	99.0	1.58	0.229	9685.0	1404.0	2.63	0.381	47.3
	84.8	64.8	149.7	542.0	90.3	2.06	0.299	10642.0	1543.0	2.66	0.386	35.5
16	96.3	82.8	179.0	473.5	71.0	2.44	0.319	9952.0	1299.0	2.71	0.354	34.5
	100.8	97.5	198.3	393.2	61.73	2.41	0.330	10733.0	1467.0	2.72	0.372	31.1
17	93.4	86.5	180.0	447.5	70.03	2.06	0.280	9808.0	1333.0	2.68	0.365	40.3
	80.7	78.9	159.6	669.0	90.41	2.17	0.252	12471.0	1447.0	2.70	0.313	43.3
18	97.8	122.7	220.4	88.0	19.6	2.53	0.488	8547.0	1652.0	2.72	0.525	22.1
	125.0	145.5	270.5	-122.0	-30.5	2.44	0.532	8396.0	1826.0	2.71	0.589	20.7
19	104.5	97.9	202.4	434.2	102.6	1.95	0.452	6738.0	1564.0	2.66	0.617	33.7
	98.3	110.0	208.3	323.7	76.7	2.36	0.488	8938.0	1847.0	2.70	0.559	25.2
20	107.6	83.5	191.1	510.4	113.9	2.57	0.499	9745.0	1892.0	2.79	0.541	23.2
	109.0	136.0	245.0	151.3	40.0	2.93	0.674	9474.0	2181.0	2.79	0.642	17.3
21	108.4	83.3	191.6	529.4	113.4	2.32	0.490	6383.0	1351.0	2.75	0.581	31.2
	112.9	165.1	278.0	94.5	27.0	2.76	0.686	7687.0	1911.0	2.75	0.685	18.2
22	85.6	116.1	201.7	410.1	103.3	2.09	0.364	6852.0	1501.0	2.67	0.585	36.5
	79.4	119.0	198.4	460.6	106.62	2.50	0.504	10270.0	2068.0	2.75	0.555	24.7

To check if *granoduro.net®* was able to improve the sustainability of plots, a Student's t-test with a confidence interval of 95% (α level two-tailed test 0.05) was performed on data obtained (Table 11).

Table 11: Mean values of the more interesting variables and indicators assessed in the 22 scenarios of the cropping season 2012/2013.

Performance of the 22 comparisons		
	granoduro.net®	Mean ± Standard error
Yield (t/ha)	No	5.34 ± 0.325
	Yes	5.47 ± 0.312
Protein (% of dry matter)	No	13.38 ± 0.264
	Yes	13.91 ± 0.322
Test weight (kg/hl)	No	80.84 ± 0.553
	Yes	81.01 ± 0.686
Gross Marketable Product (€/ha)	No	1359.61 ± 78.297
	Yes	1408.41 ± 74.251
Gross Marketable Product (€/t)	No	256.82 ± 4.31
	Yes	259.55 ± 4.878
Cropping activities costs (€/ha)	No	519.82 ± 18.978
	Yes	513.45 ± 16.538
Technical tools costs (€/ha)	No	502.99 ± 18.616
	Yes	424.75 ± 18.607
Total costs (€/ha)	No	1022.81 ± 27.085
	Yes	938.21 ± 26.154
Cropping activities costs (€/t)	No	104.66 ± 7.672
	Yes	101.17 ± 7.726
Technical tools costs (€/t)	No	102.60 ± 7.465
	Yes	82.78 ± 5.421
Total costs (€/t)	No	207.27 ± 13.768
	Yes	183.95 ± 11.772
Net Income (€/ha)	No	336.80 ± 83.299
	Yes	470.21 ± 79.227
Net Income (€/t)	No	49.55 ± 13.884
	Yes	75.60 ± 12.613
Carbon footprint (tCO_2eq/ha)	No	2.21 ± 0.088
	Yes	2.06 ± 0.083
Carbon footprint (tCO_2eq/t)	No	0.39 ± 0.031
	Yes	0.35 ± 0.021
Water footprint (kg/ha)	No	8546.64 ± 370.06
	Yes	7944.9 ± 328.62
Water footprint (kg/t)	No	1454.2 ± 74.49
	Yes	1313.5 ± 45.5
Ecological footprint (global ha/ha)	No	2.69 ± 0.011
	Yes	2.67 ± 0.012
Ecological footprint (global ha/t)	No	0.474 ± 0.029
	Yes	0.46 ± 0.027
Agronomic NUE (kg/kg)	No	33.14 ± 2.433
	Yes	36.42 ± 2.052

The standard error is an important indicator of how precise is the estimation of the population mean. The size of the standard error is good or acceptable for all indicators studied in the 22 scenarios except for Net

Income where probably the sample size was not enough to reach a high accuracy of estimation of population parameter. On the other hand, the quantitative and qualitative indices present a very low dispersion of values within the set, as well as ecological and carbon footprint. They proved the low variability of the sampling distribution and the high quality of the sample under evaluation.

The cropping season 2012/2013 was not favourable for durum wheat in Italy in terms of yields, quality and health of grains. The temperatures were lower than average from spring to June. The rainfall was abundant and excessive during the whole winter and spring. The development of mycotoxin on wheat ears by *Fusarium spp.* was supported by wet weather conditions. The heavy and constant rainfalls impeded the treatments and the fertilizations. The waterlogging was frequent and some experimental plots failed due to flooding. This happened especially in the north and centre of Italy. The precipitation was double than average and the root asphyxia during spring months reduced the potentiality of innovative farming systems. Therefore, as happened in the previous year, the trials were performed in conditions not favourable to identify advantage or disadvantage of using *granoduro.net®,* nonetheless some differences were found (Table 12).

Table 12: List of indicators resulted significant through a Student's t-test with a confidence interval of 95% (α level two-tailed test 0.05, assumed equal variance) in the season 2012/2013.

	t-test for Equal Means, for Independent Samples	df	Sig. (2-tail)	Difference between means	Difference standard error	Confidence interval for the difference at 95%. Min-Max Confidence Intervals	
Technical tools costs (€/ha)	2.973	42	0.005	78.2455	26.3210	25.1274	131.3635
Technical tools costs (€/t)	2.149	42	0.037	19.8227	9.2260	1.2040	38.4415
Total costs (€/ha)	2.247	42	0.030	84.6091	37.6512	8.6259	160.5922

The 22 scenarios were split up into two groups:

- durum wheat in rotation with crops improving soil fertility (scenarios called "Rich"),
- durum wheat in rotation with crops which maintain or decrease soil fertility (scenarios called "Neutral - Poor").

Tomato, field bean, chickpea, sugar beet, potato, pea, alfalfa and clover were considered enriching crops. Neutral or negative effects on soil fertility and durum wheat productivity was attributed to crops such as sunflower, sorghum, wheat and ryegrass. The previous statistical analysis did not take into account the distinction between rich and neutral - poor, but it was done only on the comparison between the use of *granoduro.net®* and farmers choices.

Regarding costs, the use of *granoduro.net®* allowed to decrease the use of technical tools. The reduction of dosage of fertilizers respect to usual farm choices allowed saving money. Instead, the cropping activities costs were essentially equal. Thanks to pesticides treatments optimization and the reduction of nitrogen fertilizations, the total costs were lower with *granoduro.net® (b)* (Figures 90-95).

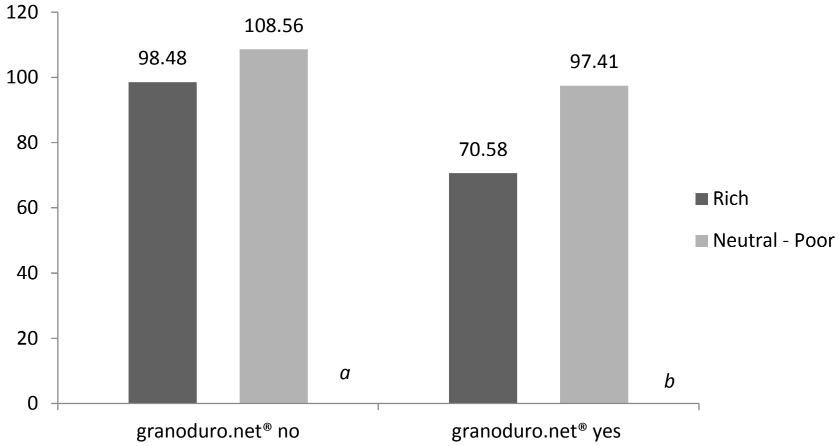


Figure 90: Technical tools costs (€/t) for the durum wheat of the 22 scenarios categorized as enriching and neutral-pauperizing. Statistical differences; a,ab,b…= Student-t Test (p=0.1).

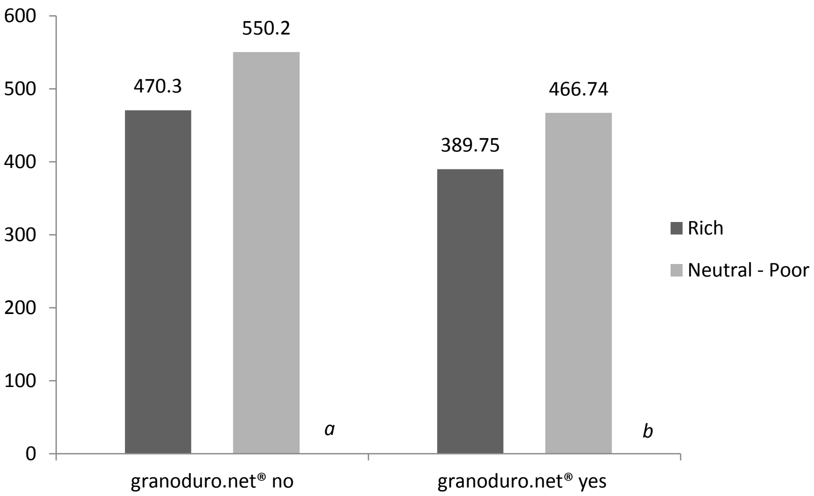


Figure 91: Technical tools costs (€/ha) for the durum wheat of the 22 scenarios categorized as enriching and neutral-pauperizing. Statistical differences; a,ab,b…= Student-t Test (p=0.1).

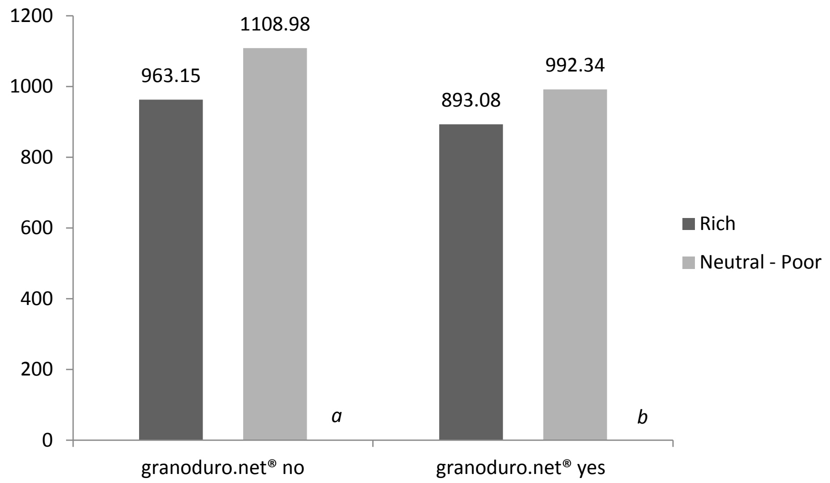


Figure 92: Total direct costs (€/ha) for the durum wheat of the 22 scenarios categorized as enriching and neutral-pauperizing. Statistical differences; a,ab,b…= Student-t Test (p=0.1).

The net income was not statistical. It occurred because with neutral – poor processions the difference between the two alternatives were limited. (Figures 93 and 94).

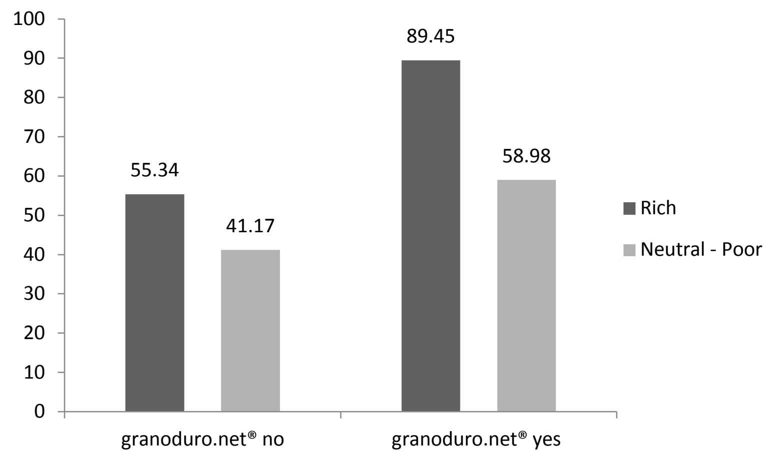


Figure 93: Net income (€/t) for the durum wheat of the 22 scenarios categorized as enriching and neutral-pauperizing. No statistical differences.

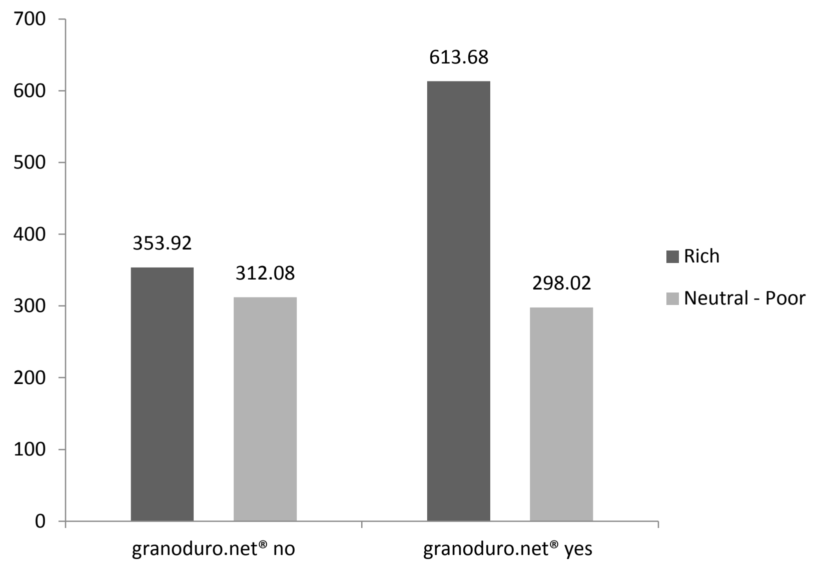


Figure 94: Net income (€/ha) for the durum wheat of the 22 scenarios categorized as enriching and neutral-pauperizing. No statistical differences.

As happened the previous year, the carbon sequestration was not statistically significant. The indicator depends mainly on biomass photosynthesized by green tissues and yield harvested. No differences were underlined about these variables and this explains why differences between the two alternatives are low.

With *granoduro.net®*, the emission of CO_2, the consumption of water and the ecological footprint were equal or lower than the non-use of the support. The trend is most noticeable with carbon footprint, whereas with water and ecological footprint limited differences were noted. However, all indicators were not statistically significant. Unlike previous year, the indicator Agronomic NUE is not statistically significant (Figure 95).

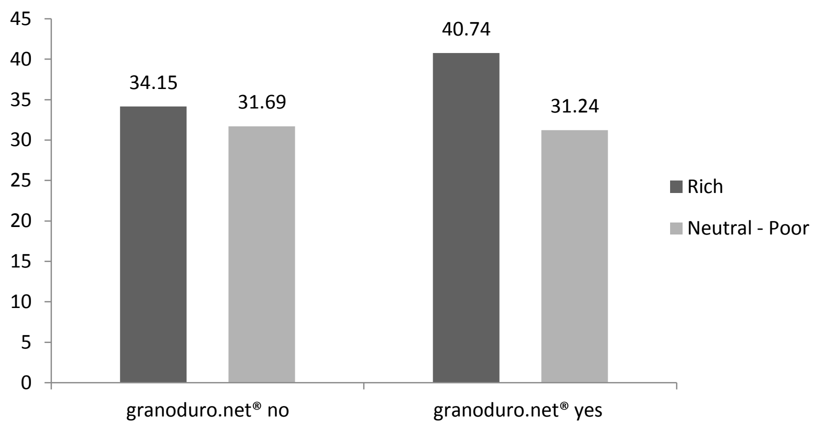


Figure 95: Agronomic NUE (kg/kg of N applied) for the durum wheat of the 22 scenarios categorized as enriching and neutral-pauperizing. No statistical differences.

The project has demonstrated the importance of an integrated approach to study the sustainability of cropping systems. The study of 2012/2013 demonstrates that often environmental friendly practices are economically convenient too (such as minimum tillage recommended by the Decalogue and/or fractioned fertilization as suggested by *granoduro.net®*) because they increase their efficiency. Switching from a rotation with only cereals to one with also dicotyledonous reduces environmental impacts and DON risk, conversely net income increases.

Finally, data of the two cropping seasons (2011/2012 and 2012/2013) were joined together to form one sample of 35 comparisons between *granoduro.net®* and farmers' managements and a new statistical analysis was performed (Table 13).

Table 13: Mean of the more interesting variables and indicators assessed in the 35 scenarios of the cropping seasons 2011/2012 and 2012/2013.

Performance of the 35 comparisons		
	granoduro.net®	Mean ± Standard error
Yield (t/ha)	No	5.70 ± 0.268
	Yes	5.80 ±0.271
Protein (% of dry matter)	No	13.75 ± 0.216
	Yes	13.95 ± 0.248
Test weight (kg/hl)	No	82.71 ± 0.563
	Yes	82.81 ± 0.605
GMP (€/ha)	No	1518.1 ± 70.36
	Yes	1553.9 ± 70.42
Cropping activities costs (€/ha)	No	518.80 ± 15.252
	Yes	509.89 ± 13.772
Technical tools costs (€/ha)	No	485.14 ± 15.645
	Yes	406.77 ± 14.765
Total costs (€/ha)	No	1003.9 ± 22.87
	Yes	916.67 ± 21.037
Cropping activities costs (€/t)	No	97.48 ± 5.494
	Yes	95.05 ± 5.759
Technical tools costs (€/t)	No	92.34 ± 5.538
	Yes	75.09 ± 4.142
Total costs (€/t)	No	189.83 ± 10.087
	Yes	170.15 ± 8.896
Net Income (€/ha)	No	573.99 ± 85.49
	Yes	696.12 ± 86.403
Carbon footprint (tCO_2eq/ha)	No	2.28 ± 0.086
	Yes	2.079 ± 0.069
Carbon footprint (tCO_2eq/t)	No	0.378 ± 0.022
	Yes	0.333 ± 0.015
Water footprint (m^3H_20/ha)	No	9108.3 ± 306.72
	Yes	8549.8 ± 312.03
Water footprint (m^3H_20/t)	No	1463.9 ± 52.68
	Yes	1340.8 ± 35.92
Ecological footprint (global ha/ha)	No	2.712 ± 0.010
	Yes	2.694 ± 0.0093
Ecological footprint (global ha/t)	No	0.453 ± 0.022
	Yes	0.443 ± 0.021
Agronomic NUE (kg/kg)	No	33.71 ± 1.757
	Yes	38.05 ± 1.546

A Student's t-test was carried out and for the following indicators significant differences were obtained for the two different managements: technical tools (€/ha) and total direct costs (€/ha) were significant at a confidence interval of 99% (α level two-tailed test 0.01), technical tools (€/t) at a confidence interval of 95% (α level two-tailed test 0.05), whereas carbon footprint (CO_2eq/ha and CO_2eq/t), water footprint (m^3H_20/t) and agronomic NUE (kg/kg) at a confidence interval of 90% (α level two-tailed test 0.10) (Table 14).

The standard deviation average of these indicators is limited and it means a low spread in the sampling distribution. The accuracy of the sample (35 comparisons) is good for the majority of the indices, demonstrating that the dispersion of values within the set is low. Only Net Income has a deviation error more than the 10%.

Table 14: List of indicators resulted significant at a Student's t-test with a confidence interval of 99, 95 and 90% (α level two-tailed test 0.01, 0.05 and 0.10, assumed equal variance) in the seasons 2011/2012 and 2012/2013.

	t-test for Equal Means, for Independent Samples	df	Sig. (2-tail)	Difference between means	Difference standard error	Confidence interval for the difference at 95%. Min-Max Confidence Intervals	
Technical tools costs (€/ha)	3.643	68	0.001	78.3714	21.5119	35.4451	121.2978
Technical tools costs (€/t)	2.493	68	0.015	17.2429	6.9152	3.4439	31.0418
Total costs (€/ha)	2.808	68	0.006	87.2743	31.0774	25.2603	149.2883
Carbon Footprint (tCO_2eq/ha)	1.838	68	0.070	0.20286	0.11038	-0.01739	0.42311
Carbon Footprint (tCO_2eq/t)	1.675	68	0.098	0.045171	0.026962	-0.008631	0.098974
Water Footprint (m^3H_20/t)	1.932	68	0.058	123.171	63.763	-4.065	250.408
Agronomic NUE (kg/kg)	-1.852	68	0.068	-4.3343	2.3398	-9.0033	0.3348

These results prove the usefulness of *granoduro.net®* and the handbook to improve sustainability of durum wheat and of the whole rotation in which it is included.

4 Conclusion

This PhD study attempts to give an answer to the current debates concerning the meaning of sustainability, the feature of indicators, and the frameworks in which they should be located, which remain often inconclusive. Pannell and Schilizzi (1999) and Pannell and Glenn (2000) said that sustainability indicators are adapted tools for attempting to manage the changeability of the events in the future. Therefore, the development of transparent indicators is essential to clarify which aspects of the sustainability are relevant into practice. This proposal is a prototype for making progress in this direction. It might be used and adjusted according to needs by other future users (other crops and/or other nations) to consolidate the theoretical sustainability paradigms and to transform them into recommendations for agricultural practice.

The experimentation performed within this PhD allowed to close the gap between theoretical and practical principles of sustainability. Indeed, thanks to Barilla availability to plan multi-years field validation, the project can be considered as an example of how theoretical principles can be put into practice. The different steps of the validation process (i.e. the theoretical study, the comparison between real and target values and the two years of practical use of the handbook and the DSS *granoduro.net®*) were able to demonstrate to farmers and experts that impacts can be monitored and reduced and, therefore, demonstrated that sustainability is actionable and calculable. The project increased the predisposition of growers toward the reaching of a higher degree of sustainability and the consultancy of expert technicians should drive more and more grower efforts towards this path. A strong integration of social, economic and environmental interests of farmers, technicians, warehousing centres is essential to achieve the objective of a higher sustainability of durum wheat. As said Dumanski (1997), if it is pursued in an efficient way, it will ensure that agriculture becomes part of the environmental solution, rather than remaining an environmental problem.

The handbook and *granoduro.net®* proved to be tools that help farmers improving the quality of their decisions, both strategic (choice of rotations, tillage, choice of varieties, fertilization techniques and use of certified seeds) and tactical (in response to events raised by pests, weeds and nutrition needs).

In more details, it was confirmed that traditional cereals crop rotations are less performing than rotations of durum wheat with broadleaves crops and that a long-term scheduling of crop rotations (more than 3 years) is crucial for sustainability purposes. Unfortunately, to date the crop's choice is often done at the beginning of each season: rarely farmers carry out a rotation planning over the years, taking into consideration the effects of previous crop residues, nitrogen schedule and the possibility to spare tillage in the subsequent year. The development of reasoned and planned rotations is one of the most difficult goals to be transmitted to farmers because it is hampered by price volatility and the limited number of alternative crops that can be rotated with durum wheat. The use of rotations and the overcoming of these two obstacles is the main challenge of the future.

With this project Barilla S.p.A. won the 2013 edition of the European CSR Award Scheme, an initiative promoted by the European Commission to give visibility to the best practices of Corporate Social Responsibility in Europe.

The study continued during cropping season 2013/2014: 80.000 tons of durum wheat were cultivated in Italy by means of the Handbook and *granoduro.net®* and bestow on Barilla. The same approach is planned for cropping season 2014/2015 during which 140.000 tons of durum wheat are expected to be cultivated following the web assistance of an improved version of *granoduro.net®*. A new tool to monitor soil water balancing will be available, as well as an improved list of durum wheat varieties for which the phenological model will be calibrated. Moreover, new indicators of sustainability concerning health, soil, air, biodiversity, energy and water compartments will be calculated and monitored. Human and environmental toxicity of pesticides, carbon sequestration, erosion, soil compactions by machinery, water supply, water use technical efficiency, recycle, use of fuel and indirect evaluation of biodiversity will be the most important topics under evaluation.

One of the worst phenomena occurring around DSS is that their models are developed and die after some few years, because nobody maintains them, nobody disseminate them to production sector and they are not fitted to real needs of food sector. It happens because advices are not suitable to farm structure (big surfaces and few employed) and are focused only on one tactic or strategic choice. Instead, a competitive system should have an holistic view, i.e., in a single tool users can find all what they need to increase productivity of their fields. Advices to improve sustainability should not imply more hassle and annoyance, possibly they should save time and never have to increase the elapsed time to perform the activity. The same happens for economic issues: advices by DSS have to save money or at least not be more expensive than common practices.

Also the practicality of support is essential. Scholars and scientists should work all together to put into one single tool the huge amount of scientific knowledge about pesticides, crops, weather, pathogens resting into university faculties and institutes. Moreover dissemination should not be only into conferences attended only by scientists and scholars. Conversely, closer relations with prospective users matched with permanent technical consultancy is important to introduce the service and to gain confidence. Farmers, farmer organisations or associations should be the right audience.

Therefore the success of a tool requires initially a correct view of what farmers and society need, the integration of many different knowledge, an initial financial support, a widespread communication and dissemination and eventually a cost-benefit analysis to understand where costs can be reduced and profit increased in order to guarantee support survival. In this perspective the success of a DSS is pursued only through an increasing number of users over the years. It will be a obligatory path because if costs associated with developing and implementing a computerized decision support system are substantial, its maintaining is even more expensive.

The implementation of granoduro.net® was financed in since 2008 with the perspective of doing applied research and to redeploy disease models implemented in the university into productive sector. After some years of dissemination and communication and a continuous updating and upgrading of hardware and software (i.e web-site and models), the catchment of users has become remarkable and costs of maintenance began to raise year by year. For these reason its financial subsistence has required a cost-benefit analysis where costs were compared with profits to determine whether it has been a good investment. The application of a cost-benefit analysis requires the implementation of a cost-benefit model by means of a case study showing the costs and benefits of a choice (Ye et al., 2009). Concerning granoduro.net®, benefits resulting from the sale to farmers, technicians and agronomists. Benefits originates also by local, regional or national founds fostering projects to increase the sustainability of cereals/flour/pasta chains.

On the other side, costs can be split up into two parts: costs for validation of models and for up-to-date advices. The costs for validation consist in experimental plots to test varieties (such as their nitrogen uptake ability, diseases tolerance and phenological characterization), amount of fertilizers, timing of fertilization, date of sowing, seeding density, timing of treatments, number of treatments and pesticides effective. In addition, experimental trials require a first design, field surveys, soil tillage, sowing, treatments, fertilizations, harvesting and qualitative and quantitative analysis. The second most important cost item regards the maintenance of up-to-date pesticide databases, the upgrading of algorithms, purchasing of weather stations, the transmission of weather data from weather stations to server and all computing and web pages updates. No less important are also the costs for dissemination and advertising.

The systemic approach followed in this study will be applied also to other agricultural raw materials related to Barilla's food chain, such as common wheat, rye and tomato coming from all the main supply countries (France, Turkey, Greece and some areas of north America). This will be a further step toward sustainability of the whole Barilla's food chain, and hopefully a good example to be replicated by other big and small food companies.

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