Abstract

This study evaluates the impacts of reduction in chemical inputs use, as defined to the Farm to Fork strategy, on the Italian agricultural sector based on current production practices and technologies, as well as market and political framework. The impacts are evaluated in terms of some economic, environmental and social indicators, and are shown and discussed both geographic area and types of farming. The analysis was conducted on all Farm Accountancy Data Network (FADN) sample of Italian farms in various years, about 40,000 farms, by using the AGRITALIM model.

The main results show an improvement in environmental sustainability of agricultural production in terms of lower use of chemical. Negative socio-economic and productive impacts are observed overall in the national territory, but some areas are more affected. The reduction of income could especially affect some types of farming and smaller farms.

In conclusion, the Farm to Fork strategy could be a fundamental impetus to review some failings and weaknesses of European agriculture. Our analysis show that targeted and forward-looking interventions are especially important for some types of farming, production sectors and territories. New research is needed to support the choices of stakeholders regarding policy support and innovation in agriculture. Political interventions are needed to incentivize farmers to adopt environmentally friendly agricultural practices and limit income losses. Genetic and technological innovations could play a fundamental role in limiting the reductions of agricultural production and modernizing farms.

Keywords: Farm to Fork Strategy; Chemical Inputs; Mathematical Programming Model; Sustainability; Common Agricultural Policy

JEL Classification codes: C61, Q15

1. Introduction

In December 2019 the EU Commission presented the European Green Deal as directly connected with the Commission's strategy to implement the United Nation's 2030 Agenda (European Commission, 2019). More recently, the Communication from the Commission of 20 May 2020 on the Farm to Fork Strategy strengthened further the efforts for building a fair, healthy and environmentally-friendly food system (European Commission, 2020). More specifically, the Farm to Fork Strategy addresses pollution with 50% reduction in use of chemical pesticides by 2030 and aims 20% reduction in fertilizer use plus a decrease of nutrient losses by at least 50% (Montanarella and Panagos, 2021). The impacts of the strategy application can be significant in terms of production of agricultural products and food, use of natural resources (land, water) and chemical inputs (e.g. nitrogen), as well as socio-economic impacts on farms and rural territories. Integrated analyses are necessary to take into account the various aspects regarding the use of natural resources, but at the same time the productive and socio-economic ones (Rounsevell et al., 2014; Alexander et al, 2019; Fitton et al, 2019; Balezentis et al., 2020; Malek and Verburg, 2020; Prudhomme et al, 2020).

Economic models can provide these types of evaluation and, specifically, the micro-economic approach of mathematical programming models allows the technical aspects of agricultural production and of resources uses to be taken into account (Godard et al., 2008). Various types of models have been developed over the years that can be grouped into three groups: a. agro-economic supply models (e.g., FSSIM, EFEM, FARMIS); b. Partial Equilibrium models (e.g., CAPRI, GLOBIOM, ESIM); c. Computable General Equilibrium models (e.g., GTAP, MAGNET). Some of these models use data provided by the Farm Accountancy Data Network (FADN), such as FSSIM, EFEM, FARMIS and CAPRI models (Angenendt et al, 2018).

In this research context, the main objective of this study is to evaluate the possible impact of Farm to Fork Strategy in the agricultural sector in Italy, using the AGRIcultural TerritoriAL tIme economic (AGRITALIM) model. This model belongs to the group of agro-economic supply models, uses FADN data and is based on non-linear mathematical programming, which combine Leontief technology for variable costs with a non-linear cost function (such as the CAPRI model). Compared to models already found in literature, AGRITALIM model has some innovative aspects. Specifically, the model considers several years and then the same or similar farm is homogeneous from a structural and productive orientation point of view, but different states of nature in terms of market (prices of outputs and inputs) and production conditions (quantities of outputs and inputs) are observed. Furthermore, the AGRITALIM model is very detailed from a territorial point of view, considering NUTS2 and NUTS3 areas, and altimetric levels. All these characteristics are important in the simulation phase and in terms of information for stakeholders.

The simulated scenarios consider the obligation of reduction in use of chemical inputs (20% of fertilizers and 50% of more hazardous pesticides) in each farm. In other words, each single farm is obliged to reduce the use of chemical inputs according to the percentages defined by the strategy. The hypothesis of acting at farm level allows to quantify the relevance of chemical inputs for all farms based on current conditions of market, of political framework and technologies. However, the simulations carried out have no intention of proposing political actions and measures. The impacts are evaluated in terms of some economic, environmental and social indicators (e.g., added value, income, uses of mineral fertilizers and pesticides, family and external labour), land use and production quantities of crops, milk and meat.

The crucial question of the research is to understand what might involve the achievement of the objectives set by the Farm to Fork strategy regarding the use of chemical inputs. The assessment is based on current market conditions, political framework and technologies, in order to comprehend which sectors and territories are most in need greatest of political support, research and innovation.

The main research hypotheses consider that the impacts can be differentiated depending on the various elements and aspects of different nature (economic, environmental and social). Furthermore, it should be considered that the impacts may differ by geographic areas, altimetric levels and types of farming. Compared to recent research about the impacts of the Farm to Fork strategy (Beckman et al., 2020; Noleppa and Cartsburg, 2021; Barreiro-Hurle et al., 2021), this paper offers some innovative aspects that can further stimulate discussion and future research on this issue. Our analysis considers results of different nature and is distinguished by territories and sectors, and therefore the results can provide useful information to national and local stakeholders and policy makers. Moreover, in the coming months, important decisions on the new agricultural policy will be taken, as well as relevant political and scientific questions concerning genetic improvement and technologies 4.0 use are being discussed. Our research fits well into this whole scientific and political context.

2. Material and Methods

2.1. Data and characteristics of farms sample

The data base on which the model is built totals 40,408 Italian farms of the FADN sample, about 10,000 for each year of the period considered 2015-2018 (9,569 farms for 2015 year; 10,153 farms for 2016 year; 10,380 farms for 2017 year; 10,306 farms for 2018 year). The sample isn't constant and represents all Italian farms observed in the FADN sample. Therefore, some farms are observed for several years, and others don't. For farms observed more years, the overall sample captures the differences in terms of market and production aspects. In any case, the farms not observed for more years, add observations to the overall sample, similar or not to those present in other years.

We outline the main features of the farm sample, first considering the resources used in its geographical districts and territorial areas, then the productive activities carried out.

The Utilized Agricultural Area (UAA) approximately equals 1.254 kha, 43.6% located in Northern Italy, 19.6% in Central Italy and 15.1% in the South and Islands (Table 1a). About the altimetric level, 41.7% of the UAA is located in the hills, 35.2% in the plains and 23.2% in the mountains. 56% of the Added Value is produced in Northern Italy, 28.4% in South and Islands, and the remainder, 15.7%, in Central Italy. 48.2% of the Added Value is obtained in the plains and 36.2% in the hills.

Table 1a

The percentages of observed family work employment are roughly in line with the percentage of the number of farms, thus denoting a substantial homogeneity of hours per farm (h/farm) in the various territories.

The presence of livestock obviously conditions the purchase and use of feed, which is concentrated for 80% in Northern Italy, where about 72% of the livestock units (LSU) are located, and for 66.4% in the lowland areas, where about 63% of LSU are raised. Also, for these productive factors the use in the lowlands is much more intensive than in the hills and mountains.

The use of water in the entire sample reaches 287 m3/ha, with average values of 396 m3/ha in Northern Italy and 557 m3/ha in the plains. Of this total, the groundwater use in the entire sample is 58 m3/ha (20% of the total), with average values of 132 m3/ha in Southern Italy and 117 m3/ha in the plains (41.4% and 21% of the respective totals).

The use of mineral fertilizers and manure reaches values of 52 kg/ha and 202 kg/ha respectively on the whole sample. However, there are very marked differences compared to the average, since in the North East the applications of fertilizers reach 235 kg/ha, while the use of manure reaches 418 kg/ha. In the plains these applications reach respectively 266 kg/ha and 285 kg/ha.

The FADN database distinguishes pesticides on the basis of their degree of toxicity: the group of classified pesticides includes very toxic and toxic (I), harmful (II) and irritants (III and IV); then there is the whole group of unclassified (0). It is interesting to note that the overall physical use of classified and unclassified pesticides is basically the same, while irritants are prevalent among the former, while very toxic and toxic have a limited weight.

The figure 1 shows the intensity of chemical inputs use for the various Italian regions. The data used are the quantity per hectare of fertilizers and of pesticides and these variables were associated with the 21 Italian regions (Coordinate Reference System: WGS84 / UTM zone 33N) in order to obtain thematic maps. For each variable analysed, the values were divided into 3 quantiles (or tertiles) within each of which there are 7 regions. A low intensity of chemical inputs use is represented with the lighter colour, and vice versa (a higher intensity with the darker colour).

Figure 1

In other words, the average use per hectare of fertilizers and pesticides was calculated for each region, and three groups of seven regions were obtained based on the average use. Therefore, in the first group (darker colour) there are the seven regions that have higher values, while in the third group (lighter colour) there are the regions that have lower values, passing through the group of seven regions that have intermediate values.

In general, the regions that have a greater intensity of chemical inputs use are the regions of Northern Italy and as regards Southern Italy, Campania and Puglia.

Table 1b shows the crop and animal production, distinguishing for tons of crops sold and reused, tons of milk, number of heads of livestock raised for meat. It can be noticed that more than 55% of the wheat, fresh fruit, tubers and roots produced for sale come from Northern Italy and more than 60% from the plains.

Table 1b

The grapes are obtained mainly in the north (47.3%) and in the South of Italy (39.6%), in the hills (53.2%) and in the plains (41.6%). Much of the production of leafy vegetables (62.1%) and olives (78.7%) is concentrated in Southern Italy and the Islands. Olives are mainly produced in the hills (57.2%), while the production of leafy vegetables is divided almost equally between the three altimetric levels. The production of dried fruit is also distributed in almost equal parts between North, Center, South Italy and the Islands, and is concentrated in the hilly areas (73.4%). Most of the crops reused in farm activity are produced in Northern Italy (63.6% silage and 78.9% wheat) and in the plains (over 70%). Hay production is more or less equally divided between Northern Italy (53.9%) and Central South (46.1%) and between the three altimetric levels. Grazing is mainly practiced in southern Italy (including the islands) with a percentage of 62.3%, and in the mountains (56.6%). 90% of the milk produced in Italy is from cows: 72.6% of it is obtained in Northern Italy and 54.3% in the plains. 89% of buffalo milk is produced in Southern Italy and about 62% in the plains. More than half of sheep's milk (54.7%) is obtained in the Islands but production in the Center is also large (35.8%). 68.4% of this milk is obtained in the hilly areas. Finally, goat's milk is mainly produced in the South (52.3%) and Northern Italy (41.2%) and in the mountain areas (45.5%).

As regards the number of head of meat, poultry, pig and cattle farms are concentrated in Northern Italy with percentages higher than 69%, and reach 91.5% in the case of pigs. As for the altimetric areas, 86.8% of pigs and 50.7% of cattle are raised on the plain; the rest of the cattle are divided between hills and mountains. Poultry are raised in the hills (53%) and in the plains (41%). Finally, sheep are mainly raised in the South (59.8%) and in Central Italy (31.5%), especially in the hilly areas (55.2%) and in the mountains (36.3%).

2.2.AGRITALIM model

The AGRIcultural TerritoriAL tIme econoMic (AGRITALIM) model is an agro-economic supply model that represents the entire FADN sample of Italian farms in various years (2015, 2016, 2017, 2018), distinguishing by geographical areas (NUTS-1 NUTS-2, NUTS-3) and altimetric levels (plain, hill, mountain). The model is calibrated using the Positive Mathematical Programming (PMP) approach (Arfini and Paris, 1995; Howitt, 1995; Paris and Howitt, 1998; Heckelei and Wolff, 2003; Cortignani and Severini, 2012; Heckelei et al., 2012; de Frahan, 2016). This approach not only automatically and exactly calibrates the model to observed activity levels, but also avoids adding ad-hoc constraints and over-specialised responses of the model to policy changes. As all economic models represented with mathematical programming, there are certain methodological limitations that need to be considered when introducing explicit technologies and management practices: without data on the current adoption of these technologies and practices, the calibration of the model becomes challenging, and zero adoption has to be assumed in the baseline.

The model uses a large part of FADN data concerning economic, financial, productive, market, political, structural aspects. This allows carrying out different types of analysis as regards the farms choices induced by agricultural and environmental policy, market conditions and climate change, use of resources as, for instance, irrigation water management. The model has some dynamic elements, as can consider structural changes (e.g., tree crops, number of animals and related areas) by way the annualization of the investments made (depreciation rates).

The general mathematical representation of AGRITALIM model is shown in the Appendix.

To follow, the main components and fundamental characteristics of the objective function (Table 2) and constraints (Table 3) are showed.

The model maximizes the operating income of the various farms, considering elements of market (prices of outputs and inputs), production function (quantities of yields and inputs), agricultural policy, and depreciation costs (Table 2).

Table 2

Model variables include crop hectares, number of animals, hours of labour, quantities of feed, water pumped from wells, additional areas of tree crops, additional areas of stables and structures.

The costs related to the additional depreciable capital (tree area, stables and animal facilities) are annualized in the objective function as depreciation costs. The latter are obtained by dividing the replacement value of those depreciable capitals by the years of their technical duration indicated by the FADN. For tree crops it is assumed that the variation of the surface involves investments both in the planting of orchards and in harvesting machinery. The variation in the size of herds and flocks is associated with investments in stables and farming facilities.

The model is subject to different types of constraints (Table 3) concerning land, labour and water availability, tree crops area (including the additional area), stables and facilities area (including the additional area), animal nutrition (in terms of ratio between reused crops and animals) and ratios between categories of animals (productive and not).

Table 3

In other words, the mathematical model maximizes operating income by choosing productive activities (hectares of crops and number of animal), and is constrained by the resources availability (land, labour, water). As for labour and water, the model allows additional variables (hours of labour and quantity of water pumping). Other variables of the model concern the possibility of purchasing external feeds and additional area of fixed capital. As for the feed, in fact, the model considers that the animals are fed with crops produced on the farm and with feed purchases on the market.

The additional areas of tree crops and animals are possible in the simulation phase, to foresee some expansions in terms of farm structures; if this occurs, additional depreciation rates are considered in terms of costs.

The calculation of the operating income considers elements of market, production function and policy. Market prices refer to animal and vegetable products, to some crop production inputs (e.g. fertilizers and pesticides), and to all the additional variables purchased on the market (labour, feed, water). Production functions consider relationships between quantities of output and inputs used. For some production activities is not possible to distinguish between price and quantity, and the average cost is used (e.g., for animals). The quantities of inputs needed per unit of production activities (matrix of technical coefficient) are used in the specification of the constraints and determine the needs in terms of land, labour, water, feeding and structures. Total needs must respect the resources availability, with the possibility of additional variables.

2.3. Simulated scenarios

Table 4 reports the simulated scenarios which consider the obligation to reduce the use of chemical inputs (20% of fertilizers and 50% of pesticides) and apply it as a maximum constraint at a single farm level. To manage the reduction of pesticides, the various toxicological classes involved were considered. Specifically, two scenarios were considered. The Sim1 scenario acts only on chemical fertilizers, reducing the possible use at farm level by 20% compared to the baseline, and Sim2 scenario also considers the reduction of pesticides classified as very toxic, toxic and harmful. The scenario regarding pesticide reduction alone is not relevant in terms of the results and information to be provided. From the point of view of the mathematical formulation, the constraints are shown in the Annex (A.3. Constraints on use of chemical inputs).

Table 4

The simulations carried out have no intention of proposing political actions and measures but to quantify the relevance of chemical inputs for each farm, based on current conditions of market, of political framework and technologies.

The scenarios were chosen to distinguish the impact of fertilizers and pesticides, considering that the productivity of chemical inputs is different for the various cropping activities. In general, fertilizers have a lower productivity in less profitable crops, and the pesticides are especially essential to obtain high-income crops (e.g., fruit and vegetables

The impacts are evaluated in terms of some economic, environmental and social indicators (e.g., added value, income, uses of mineral fertilizers and pesticides, family and external labour), land use and production quantities of crops, milk and meat. Generally, worsening of socio-economic results and an improvement of environmental ones are expected. This general trend could differ for the various geographical areas considering the different levels of agricultural practices intensity.

3. Results

This section describes the results of the simulations under the two scenarios of reduction in use of chemical inputs. The impacts are presented in terms of variation in the resources and use of inputs, and vegetables/animal production, over the baseline values, reported in the Tables 1a and 1b. The impacts are shown and discussed for total area and, as regards the Sim2 scenario, by geographical area and altimetric level. The presentation of the results will first concern the impacts on the of resources and use of inputs, then move on to the impacts on production activities.

Furthermore, the impacts on operating income are shown, both for the total and for size classes (UAA and economic). The section ends with some simulation results showed on maps, regarding the use of nitrogen, income and total labour hours.

3.1. General impacts on resources and use of inputs

The Sim1 scenario requires reducing the farm use of mineral fertilizers by 20%. Table 5a shows that this restriction modifies the production activities, also leading to a reduction in the use of pesticides, -9.5% for classified and -12.2% for unclassified, and in the use of manure, -6.3%. Evenly, Sim2 simulation that also reduces the use of very toxic, toxic and harmful pesticides by 50%, affects the use of all the other chemical inputs. In fact, there is a 19.4% decrease for irritating pesticides that, combined to the 50% cut for toxic and very toxic, reduces of 28.4% the whole use of classified pesticides. Also, there is a 13.1% decrease for unclassified pesticides, a 25.0% reduction for mineral fertilizers and 13.0% for manure. This occurs because crops require different chemical inputs at the same time, and therefore the reduction in the use of one input affects the cultivation activity, and indirectly the other inputs. To consider that the productivity of chemical inputs is different for the various cultivation activities, and in general, fertilizers have a lower productivity in less profitable crops, and the pesticides are especially essential to obtain high-income crops (e.g., fruit and vegetables). This involves a differentiated reduction for the various chemical inputs.

Table 5a

The impact also transfers to the use of other resources and farming productive factors. The UAA decreases -4.7% in Sim1 and -7.6% in Sim2, and the impact is greater in areas where intensive agriculture is conducted, such as North East (-9.3%), North West (-8.7%), plain (-11.6%). Appreciable reductions also affect the use of family and external labour. Generally, the model simulations reduce external labour more than family labour since it determines an explicit cost for the maximization process. Thus, the hours of family work employed decrease from -2.8% for Sim1 to the 6.7% for Sim2 and, yet, the hours of external work collapse to -26.2% in Sim2. The reduction in labour hours is observed in all territories, reaching -8.0% for family labour and -42.2% for external labour in North East.

Overall, the irrigation water use is reduced. In the less restrictive scenario, Sim1, the use of total water and groundwater is reduced by similar percentages, -8.6% vs. -7.8%. With the most restrictive simulations groundwater suffers the higher percentage reductions, -15.6% vs -14.8% for the total water use. In particular, in Sim2 the reductions in the use of irrigation water in the lowland areas, as well as in the geographic areas, are around 16%; only in the North West the use of water decreases by 16.5%. Considering the absolute values, the reductions of the groundwater use are observed in Southern areas (-20.2%) and in the lowland areas (-15.1%).

Finally, it should be noted that the LUS remains almost constant: this requires increasing feed purchases which grow by 4.1% in Sim1 and 5.9% in Sim2. In the last simulation, the increase is essential in all territories to maintain the number of LSUs and especially in northern Italy (6.6% and 4.8%) where most of the breeding are concentrated.

The impact on added value is determined by the compression of production activities, although partly balanced by the reduction in costs due to the lower use of the various production inputs. The result is a progressive decrease in the added value, from 2.1% to 5.3% proceeding from Sim1 to Sim2. The impact on added value is more intense in areas where there are fewer choices among crop and livestock production options (hill 5.9% and mountain 6.0%).

3.2. Impacts on the agricultural production and income

The decrease in sold crops affects all geographic areas (Table 5b). The greatest reductions occur in the plain areas (all with percentages lower than -12.8%) and then in the hills (lower than -9.4%); in the mountains the impacts are more contained apart from fresh fruit (-20.4%) and grapes (-19.8%) that especially involve the production of apples in Trentino-Alto Adige and grapes in Toscana.

Also reused crops suffer major decreases for silage and grain, varying from -7.0% to -16.2% in the various scenarios: silage is reduced by 21.5% in the Islands, by 14.5% in the South and by 10.6% in the Center. Grain decreases by about 17.0% in Northern Italy and 14.9% in the South. Hay and pasture especially grows in the Northern Italy and in the Centre, and all these increases occur mainly in the lowlands: 1.7% and 3.7% respectively.

Table 5b

The production of buffalo milk decreases considerably (-4.4%, -6.3%) mainly due to a reduction in the geographical area of greatest production: -7.0% in southern Italy, -6.9% in the plains. The production of sheep's milk remains constant, while the production of goat's milk increases (+ 0.6%, 2.9%) especially in northern Italy (2.9% in the north-west and 13, 1% in the north-east) and in the plains (14.1%). There are also differences in the variations of the different meat products: in fact, while bovine production undergoes a slight decline (-0.6%, -0.9%), the other categories of animals remain almost stable, as for sheep, or increase, as for pigs (1.2%). Moreover, poultry increases especially in North West (2.6%), as well as swine (1.4%); beef cattle decreases in North East (-2.3%) and sheep further slightly increase in Southern Italy (0.7%).

Table 5c shows the impact on operating income in the various simulations, both in total terms and by size classes of farms. Overall, the reduction of income is equal to -2.2% and -6.1% in the two scenarios, that determine a reduction per hectare respectively equal to 31 and 86 €/ha (not shows in the table).

For some types of farming the impact is more negative. In the Sim2 scenario, for specialist horticulture and permanent crops it is greater than 10%. Moreover, the most impacted farms are small ones both in terms of UAA (-12.4%) and Economic Size (-11.1%).

Table 5c

3.3. Impacts in the Italian regions.

In this paragraph, some simulation results are shown on maps, using the QGIS software. In general, a Geographic Information System is used to study of space-time phenomena and allows to analyze and represent data by associating them with their geographical position on the earth's surface.

The variables used are the percentage changes observed in the Sim2 scenario regarding the use of nitrogen, income and total labour hours. These variables were associated with the 21 Italian regions (Coordinate Reference System: WGS84 / UTM zone 33N) in order to obtain thematic maps. For each variable analyzed, the values were divided into 3 quantiles (or tertiles) within each of which there are 7 regions. A low intensity of the phenomenon is represented with the lighter colour, and vice versa (a higher intensity with the darker colour). In other words, the lighter colour means a lower percentage change, while the darker colour a greater percentage change.

Figure 2

In other words, the percentage change (of nitrogen use, income level and hours of labour) observed in the Sim2 scenario was considered for each region, and three groups of seven regions were obtained based on the percentage change values. Therefore, in the first group (darker colour) there are the seven regions that have higher percentage variations, while in the third group (lighter colour) there are the regions that have lower percentage variations, passing through the group of seven regions that have intermediate percentage changes.

Comparing these results with the maps in Figure 1, note that the greatest reductions in nitrogen use tend to occur in regions where the average use per hectare of chemical inputs is higher. As regards the three maps in Figure 2, a relationship between use of nitrogen, income and labour is observed. In fact, in general, larger reductions of nitrogen use also determine larger reductions in income and labour. In summary, also analysing the individual regions emerges that the Farm to Fork strategy could have positive impacts from an environmental point of view, but at the same time have negative impact on income and labour.

4. Discussions

The obtained results offer many insights for discussions on agricultural production, input use and environment, and economic aspects. However, some characteristics and limitations of economic modelling must be highlighted.

4.1. Agricultural production

In line with our results, recent studies show that the targets set by the Farm to Fork strategy could lead to a reduction in agricultural production in the short and medium term (Beckman et al., 2020; Noleppa and Cartsburg, 2021; Barreiro-Hurle et al., 2021). The downsizing in the local products availability could greatly reduce the operations of key Italian agro-food chains, reducing economies of scale and agglomeration and increasing the risks of the supply chains management. There is a wide literature on these aspects and among the main risks of managing commercial chains are listed the inadequacy of production or processing capacity, the variability of production levels, the lack of certain inputs (Manuj and Mentzer, 2008). All these risks increase if supply is reduced and the ability to control the quality and quantitative availability decreases. Moreover, the reductions of agricultural production could generate major problems for Protected Designations of Origin (PDOs), whose specifications being stringent in linking the brand to local production prevent the replacement of the latter with sources from other areas.

Coming to the livestock production, milk and beef do not suffer significant reductions, thanks to the increase in the purchase of feed. Yet, problems with the feed supply and a possible increase in their prices could lead to different results. Furthermore, feed purchases would increase in all areas of the national territory, therefore, imports and transport by ship and road would be necessary to reach the various areas. This will have costs that could increase feed prices or make it more difficult to supply, especially in some areas. Encouraging local production of protein forage crops could be of primary interest to help farmers depend less on purchased feed, provide agronomic benefits to farming systems and increase EU protein self-sufficiency (Carof et al., 2019). The mentioned impacts of our analysis can lead to a different geography of the various types of animal husbandry.

Especially in mixed livestock farms, the reduction in the use of chemical inputs for crops leads to a contraction of the forage area. This determines a reduction of livestock needing greater forage surface (e.g. bovine), and in part there is an increase in the animals needing less surface (e.g. poultry and swine). Even in some mixed farms, vegetal activity is reduced and is partially replaced by small-sized animal (especially poultry). As for sheep farms, overall changes are very minimal, while the pasture area decreases. This is because, in order to maintain the same number of sheep animals, a greater pasture area is needed which, especially in some areas and in some periods, has a lower productivity than other forage crops.

The use of pesticides, in particular fungicides and insecticides, is essential for the cultivation of tree crops. Some tree crops are more demanding (e.g. fresh and dried fruits, and grapes) and others less (e.g. olive trees). However, even in the case of the olive, especially for the more intensive plants, treatment interventions for diseases are important, and a reduction in the use of pesticides could cause a relevant decrease in production.

4.2. Input use and environment

Our results show a link between restrictions on the use of various fertilizers and pesticides, and other factors of production, that reveal cross impacts of reduction and substitution between the various factors. In general, in agreement with Suh and Moss (2021) it can be concluded that the agricultural sector has little flexibility in adjusting the demand for inputs in response to changes in input availability. Yet, substitutable relationships among labor, capital, and intermediate inputs exist, which may reduce the pressures on production levels. For high restrictions use, technical and technological development seems essential to determine an efficient substitution between production factors and, in general, to limit the negative effects in terms of output quantities.

Reductions in the use of chemical inputs occur mainly in plain areas. However, other effects connected with these transformations should not be overlooked. On the one hand, as shown by Beckman et al. (2020), a transfer of environmental impacts to other areas is determined with the increase in the use of their feed production. On the other hand, mainly in areas already with a high production intensity such as the North West plains, the production of poultry and pigs is growing: this increases the problems of sewage disposal, even in the face of a reduction in the cultivated area. The intensification of pig production could determine the worsened of environmental indicators, in particular of potential losses of nitrogen (Jouan et al, 2020).

Our results on the Italian geographic areas and their altimetric levels suggest that, although attractive, the idea of a system based on simple and uniform mechanisms for the whole territory, which offers appreciable environmental benefits, could be inadequate. Due to the vast diversity of agronomic, environmental and economic conditions across the UE areas, it is impossible to design a set of simple rules that are universally applicable to the whole territory. Efficient environmental management requires place-specific adjustment, or spatial targeting, which is the diametric opposite to universal rules (Brady et al., 2017).

4.3. Socio-economic and political issues

The economic results shows that any monetary support of the agricultural policies, defined on the basis of lost income, as a whole would involve an acceptable expenditure compared with the available financial resources. Yet, it should be emphasized that this does not apply to some farm types for which could be very expensive, in terms of lost income, to comply with environmental standards (e.g. horticultural, permanent). Furthermore, to compensate for these farms, mechanisms should be put in place that include them in EU I pillar policies, where in many cases they are not currently involved in those measures. The policy support should consider the different costs of application (in terms of lost income) in the various territories (as shown in the results) in order to incentivize and adequately support the compliance of environmental policies and achieve the set objectives. This aspect is partly considered in the II pillar measures that differentiate the monetary support per hectare and head by different groups of crops and livestock. Still, additional premiums could be added to the achievement of environmental objectives, based on the different initial conditions. Measures to support eco-efficiency would also be more easily acceptable by policy makers than the imposition of radical measures that reduce farm profitability (Coderoni and Esposti, 2018). Furthermore, considering that the most impacted farms could be the smallest ones, both in terms of surface area and economic, these farms could be exempted from compliance with any environmental rules, as is also the case with greening practices.

From the social point of view, notice that the reduction of labour in agriculture could affect some social categories, and certainly among these immigrants. In fact, agricultural activity, especially in some territories (e.g. south and north-east) is an important source of employment, and therefore of social and economic integration.

4.4. Economic modelling

Some characteristics and limitations of the economic model must be listed and discussed to provide insights and improvements to be achieved in the next analyses. First of all, no economic model can be a perfect description of reality, but the very process of constructing, testing, and revising models forces economists and policymakers to tighten their views about how an economy works (Ouliaris, 2011). Additional limitations due to not capturing the full scope of the transition to sustainable food systems promoted by the strategies (e.g. change in the functioning of the value chain, impacts of soil degradation, etc.) also prevent providing a comprehensive assessment of their impacts (Barreiro-Hurle et al, 2021).

The model is based on income maximisation, and it is well known that many other factors also affect choices, including but not only behavioural ones (Dessart et al., 2019). In the analysis presented, the farm choices are based on economic objectives not by specific recommendations on maximising social and environmental benefits.

As for the simulated scenarios, to consider is the distance from baseline values to aspirational targets. The model is based on EU mid-term outlook and responds reasonably well to marginal changes in parameters. However, it becomes problematic when these changes are unprecedented. In particular, when the changes have not been observed in the past, the shocks can potentially lead to an over- or under-reaction of the system and frequently require additional judgement. When dealing with systemic changes, other research tools such as foresight and prospective can be used in a complementary manner to inform some of the parameters that could reflect novel practices and business models that could be developed by farmers to adapt to the new sustainable food systems paradigm (Barreiro-Hurle et al, 2021).

5. Conclusions

This analysis highlighted different aspects of Italian agriculture which should act the European strategy called Farm to Fork and, in particular, focused on the influence of chemical inputs on agricultural production. The estimated impacts show possible trends and changes in the use of production factors, in agricultural production, in economic results, and can provide useful information to decision makers in terms of political choices regarding environmental targets and economic measures. In fact, the achievement of an environmental target could impact differently on the various farms considering the different structural, economic, technical-productive and managerial characteristics. To consider also that the various territories have different relationship between production activities and use of resources. Our analysis does not consider aspects regarding innovation that could improve productivity in agriculture, and therefore, obtain the same quantity of output but with a lower use of production inputs, including chemical ones. Specifically in case of technological innovation, waste can be reduced, and the efficiency of production inputs can be improved. The genetic improvement over the past 20 years has allowed to use natural resources (e.g. soil) in a more sustainable way and not depend totally on imports from other countries (Noleppa and Cartsburg, 2021). Therefore, in general innovation seems fundamental to achieve the environmental targets of the Green Deal and Farm to Fork strategy, and to produce satisfactorily within the European Union.

The reduction of domestic production (in Italy and in Europe in general) could relocate more intensive and polluting agricultural production to other parts of the world (Fuchs et al., 2020).

To avoid this, in the coming years European agriculture is challenged to achieve environmental objectives without affecting agro-food production. Agricultural sustainable intensification is needed to tackle food insecurity and global change. Local environmental conditions determine the needs and potentials for increasing sustainability of farming practices. Yet, the implementation potentials also depend on socio-economic factors, as farmers need to adopt novel practices, and consumer demand affects the economic feasibility (Scherer et al., 2018).

Common Agricultural Policy is prospecting eco-schemes as new instruments to be implemented by Member States to support this transition towards the Green Deal targets. These schemes refer to practices for organic farming, integrated pest management, agro-ecology, husbandry and animal welfare plans, carbon farming, precision farming, improved management of nutrients, water resources protection, GHG emissions related practices. Combining payments and practices should incentivize farms to implement the latter and reduce the use of inputs while preserving farms income and agro-food production. Still, this challenge is very ambitious and requires modifying the payment calculation system, defining commitments, aid applications, timing for payments and financing, and the management of unused funds.

Some limitations of the analysis should be highlighted. The analysis put forward does not fully capture the underlying drivers of the policy initiatives assessed. The Farm to Fork strategy include many more targets than those we have selected for analysis, such as the reduction of food waste, the move towards different diets or the demand side promotion of organic and sustainably produced food. In addition, the assumptions about the impacts on farm management and yields of the reduction in chemical inputs use do not capture potential beneficial side-effects on agricultural production and beyond (e.g. health benefits).

The model is not comprehensive in the representation of technologies and farm practices. There are many more technologies and farm practices that could be included, which could contribute to achieving the objectives while minimising the impacts on production. In any case, there are certain methodological limitations that need to be considered when introducing explicit technologies and management practices within an economic model: without data on the current adoption of these technologies and practices, the calibration of the model becomes challenging (and zero adoption has to be assumed in the baseline).

The impact on livestock sector is underestimated as the reduction of antimicrobials is not considered, and no limits are imposed on the purchase of feeds on the market, which already currently sees a large deficit between internal production and needs. Moreover, the representation of the livestock sector should also be improved if we want to capture the impacts of enhanced animal welfare levels and different production systems and the potential changes towards organic or more extensive livestock production methods. These production methods could accelerate the transition towards sustainable food systems.

Lastly, the changes in the levels of European agro-food production can have notable impacts on the international market and on product prices (Beckman et al., 2020).

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Appendix: Mathematical representation of the AGRITALIM model

A.1. Objective function

$$\max Z = \mathbf{GPS} + \mathbf{CAP} + \mathbf{RCA} - \mathbf{VC} - \mathbf{QC} - \mathbf{EXL} - \mathbf{FP} - \mathbf{PW} - \mathbf{DRO} - \mathbf{DRNI}$$

Operating income = $\boldsymbol{Z}$

Gross Saleable Production $= \mathbf{GPS} = \boldsymbol{pc} * \boldsymbol{yc} * \boldsymbol{XC} + \boldsymbol{pm} * \boldsymbol{ym} * \boldsymbol{XA} + \boldsymbol{revnm} * \boldsymbol{XA}$

CAP payments $= \mathbf{CAP} = \boldsymbol{dp} + \boldsymbol{cpc} * \boldsymbol{XC} + \boldsymbol{cpa} * \boldsymbol{XA}$

Revenues from Complementary Activities $= \mathbf{RCA}$

Variable Costs $= \mathbf{VC} = \boldsymbol{pfp} * \boldsymbol{qfp} * \boldsymbol{XC} + \boldsymbol{acc} * \boldsymbol{XC} + \boldsymbol{aca} * \boldsymbol{XA}$

Quadratic Costs = $\mathbf{QC} = \frac{1}{2} \boldsymbol{XC}' \boldsymbol{Q} \boldsymbol{XC} + \frac{1}{2} \boldsymbol{XA}' \boldsymbol{Q} \boldsymbol{XA}$

External Labour = $= \mathbf{EXL} = \boldsymbol{ph} * \boldsymbol{XH}$

Feed Purchased $= \mathbf{FP} = \boldsymbol{pf} * \boldsymbol{XF}$

Pumped Water $= \mathbf{PW} = \boldsymbol{pw} * \boldsymbol{XW}$

Depreciation Rates Observed $= \mathbf{DRO}$

Depreciation Rates New Investments $= \mathbf{DRNI} = \boldsymbol{drtc} * \boldsymbol{ADTC} + \boldsymbol{drsf} * \boldsymbol{ADSF}$

Variables

XC = hectares of crops

XA = number of animals

XH = hours of labour

XF = quantity of feed

XW = quantity of water pumping

ADTC = additional area of tree crops

ADSF = additional area of stables and facilities

Market

pc = prices of crops

pm = prices of milk

pfp = prices of factors of production (fertilizers, pesticides)

ph = prices of external labour

pf = prices of feed purchased

pw = prices of water pumped

drtc = depreciation rates of new investments (tree crops)
drsf = depreciation rates of new investments (animals)

Production function
yc = yields of crops
ym = yields of milk
qfp = quantities of factors of production (fertilizers, pesticides)

Common Agricultural Policy payments
dp = decoupled payments
cpc = coupled payments for crops
cpa = coupled payments for animals

Revenues and average costs
revnm = revenues from other animal products no milk (meat, eggs, honey,…)
acc = average costs for crops (per hectare)
aca = average costs for animals (per number)

A.2. General constraints

$$\sum_{j} XC_{j,n} \leq ald_{n} \quad \forall\, n$$

$$\sum_{j} ml_{j,n} * XC_{j,n} + \sum_{ja} ml_{ja,n} * XA_{ja,n} \leq alb_{n} \quad \forall\, n$$

$$\sum_{j} mw_{j,n} * XC_{j,n} \leq awt_{n} \quad \forall\, n$$

$$\sum_{jt} XC_{jt,n} \leq atc_{n} + ADTC_{n} \quad \forall\, n$$

$$\sum_{ja} msf_{n} * XA_{ja,n} \leq asf_{n} + ADSF_{n} \quad \forall\, n$$

$$\sum_{ja} mf_{n} * XA_{ja,n} \leq afp_{n} + XF_{n} \quad \forall\, n$$

$$\sum_{jan} rc_{n} * XA_{jan,n} \geq \sum_{jap} XC_{jap,n} \quad \forall\, n$$

Sets shown in the mathematical representation j = types of crops

n = farms

ja = types of animals

jt = tree crops

jan = types of animals non-productive

jap = types of animals productive

Other sets (not shown in the mathematical representation): geographical area [NUTS 2 and NUTS 3], altimetric level, types of cultivation (field, vegetable garden, greenhouse), following crops, main vegetable product, animal production, time

Matrix coefficients

ml = labour (manual and mechanical) needs per each crop and animal

mw = water needs per each irrigated crop

msf = square meter of stables and facilities per each animal

mf = feed needs for each animal

rc = ratio between productive and non-productive animals

Availabilities

ald = land availability per each farm

alb = labour availability per each farm

awt = water availability per each source (e.g. water unit association, well,…) and farm

atc = tree crops area per each farm

asf = total square meter of stables and facilities

afp = quantity of feeds produced in farm

A.3. Constraints on use of chemical inputs

$$\sum_{j,tf} qfp_{j,tf,n} * XC_{j,n} \leq QF_n^0 * 0.8 \quad \forall n$$

$$\sum_{j,tp,tc} qfp_{j,tp,tc,n} * XC_{j,n} \leq QP_n^0 * 0.5 \quad \forall n$$

$$QF_n^0 = \sum_{j,tf} qfp_{j,tf,n} * XC_{j,n}^0 \quad \forall n$$

$$QP_n^0 = \sum_{j,tp,tc} qfp_{j,tp,tc,n} * XC_{j,n}^0 \quad \forall n$$

Sets

tf = types of fertilizers (e.g. solid minerals)

tp = types of pesticides

tc = toxicological classes (e.g. very toxic, toxic and harmful)

Matrix coefficients, availabilities and variables

qfp = quantities of factors of production (fertilizers, pesticides)

QF^0 = quantity of fertilizers used in the baseline

QP^0 = quantity of pesticides used in the baseline

XC^0 = hectares of crops observed in the baseline