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Barriers and Opportunities for Sustainable Farming Practices and Crop Diversification Strategies in Mediterranean Cereal-Based Systems

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Agricultural intensification negatively affects the environment through soil degradation, loss of agrobiodiversity, greenhouse gas emissions, and nutrient leaching. Thus, the introduction of crop diversification strategies and alternative management practices is crucial to re-design agricultural intensification systems. To better understand the contribution of crop diversification to more sustainable agricultural systems, an accurate evaluation of synergies and trade-offs is needed. In this context, the 5-year Horizon 2020 DIVERFARMING project aims to define sustainable, diversified cropping systems with low-input farming practices, adopting a multi-disciplinary approach. The overall objective of this study was to improve the understanding of the stakeholders' perceptions of barriers and opportunities for implementing farming practices and crop diversification strategies in intensive rainfed and irrigated cereal-based cropping systems in Italy. Fifty stakeholders, grouped in farmers and technical agricultural advisors, field technical officers from public agricultural administrations, technical experts from NGOs with experience on farming practices, and researchers in agriculture, were engaged by public consultations to capture their practical knowledge of current farming practices for promoting suitable diversified cropping system, as alternative to agricultural intensification systems. The analysis of the stakeholders' perceptions of barriers and opportunities to the transition of cropping systems towards diversification was done using a multi-criteria decision analysis The most important agro-environmental problem identified by the stakeholders in both the cropping systems was the loss of profitability, associated with the risk of farm abandonment, while minimum tillage, maintenance of vegetation covers, application of organic matter/manure and use of green manure, integrated pest management, and change of rotations were identified as the most adequate and effective practices to be adopted in the case study areas. Crop rotation and legumes were the most adequate diversification strategies selected for the intensive rainfed cereal-based cropping systems, while crop rotations with processing tomato and multiple cropping with short cycle maize and wheat were selected as the most appropriate alternatives for irrigated cereal-based production. Our findings highlight relevant strengths and drawbacks for the implementation of diversified cropping systems under low-input agricultural practices. An important strength is that the crop alternatives selected for the diversification are already cultivated as monocultures and are adapted to the local pedoclimatic conditions, while a major weakness is that few farmers are experts in crop diversification. These results can provide insights to support the planning of agricultural policies at different levels.

Keywords: crop rotation, intercropping, low-input agricultural practices, multi-criteria decision process, multiple cropping, soil challenges, survey, stakeholder perception

1 INTRODUCTION

Agricultural intensification aims at maximising crop productivity in space and time by adopting new technologies and modernisation of production techniques (Pancino et al., 2019). It is based on specialised agri-food production in either crop or livestock systems, associated with low genetic and landscape diversity (Hufnagel et al., 2020). Agricultural intensification is characterised by high use of external inputs, especially energy and agrochemicals that negatively affects the environment (Messéan et al., 2021) through soil degradation, progressive depletion of soil organic matter (SOM), decline of soil quality and agrobiodiversity, greenhouse gas emissions (Kirschenmann, 2010; Bommarco et al., 2013; Wezel et al., 2018), and nutrient losses from agricultural soils that cause water pollution and eutrophication (Garnett et al., 2013; Hunter et al., 2017).

Scientists agree that agricultural sustainability still needs crucial changes to balance an economically viable and socially fair food production with environmental goals (Rockstrom et al., 2017; Rodriguez et al., 2021). This is particularly evident in the Mediterranean Basin, where the highly specialised agricultural systems are mostly oriented on cereal-based intensive cropping systems under rainfed or irrigated conditions as monoculture, or short-rotations such as wheat-summer irrigated crops, or mixed succession with bare fallow (Di Bene et al., 2016), leading to high incidences of pests and diseases, loss of soil fertility and biodiversity among other things.

Therefore, the introduction of appropriate crop diversification strategies and alternative management practices in typical intensive systems is crucial for promoting the redesign of agricultural systems (Kremer and Miles., 2012; Iocola et al., 2020). This transition is an important path to reach the goals of ensuring the availability of resources (e.g., nutrients, water, and land) by increasing the dependence on ecosystem services that minimise the use of external inputs (Bonnet et al., 2021) and promote healthy agroecosystems (Rodriguez et al., 2021).

Enhancing temporal and spatial crop diversity in arable cropping systems can improve crop productivity and resource use efficiency (Tamburini et al., 2020) by delivering multiple ecosystem services (Kremen and Miles, 2012; Beillouin et al., 2019; Iocola et al., 2020) through crop rotations, integration of cover crops as agro-ecological service crops (Diacono et al., 2019), green manure, and species mixtures such as multiple cropping and/or intercropping (Francaviglia et al., 2019, 2020) that can include legumes (Pelzer et al., 2017; Stagnari et al., 2017), leys, grassland, and minor crops of local interest (Hufnagel et al., 2020), with overall socio-economic benefits (Feliciano, 2019; Rosa-Schleich et al., 2019). Coupling agricultural diversification (AD) with more diverse management strategies by adopting cover crops for green manure or fodder, conservation agriculture (i.e., tillage, crop diversification and residue management), organic farming, and fertilisation management, also contributes to increase crop yields, profitability and cropping system resilience in the long-term (Rosa-Schleich et al., 2019; Hufnagel et al., 2020). However, the economic costs in the short-term can offset the environmental and ecological benefits, thus some financial instruments might be needed to increase the adoption of combined AD strategies rather than single crop diversification systems (Rosa-Schleich et al., 2019).

Despite the large scientific consensus on the potential agro-ecological and socio-economic benefits of crop diversification, the agronomic solutions for crop diversification strategies are often hampered and not always affordable by various technical, organisational, and institutional barriers, linked to the overall functioning of the dominant agro-food chains (Kleijn et al., 2019; Iocola et al., 2020). In this context, new crops could be out of market, or they can be affected by technical knowledge gaps and lack of skills for production, especially in the initial implementation phases.

The awareness on the benefits of crop rotations and the costs of machinery or new labour organization are still scarce, while market uncertainty is high. These and other simplification forces affect farmers choices in the use of their agricultural land and entrepreneur resources, indicating a specialisation scenario for several agricultural products in different regions (Mortensen and Smith, 2020). Therefore, research and policy play a key role in supporting more sustainable practices for agri-food production while ensuring environmental improvements (Rodriguez et al., 2021). At EU level, the launch of the Farm to Fork and Biodiversity Strategies within the Green Deal aimed at encouraging a more sustainable and resilient form of food production systems, with a neutral or positive environmental impact (European Commission, 2019; European Commission, 2020a,b). In this context, food legumes and legume-inclusive production systems can play a crucial role by delivering multiple services in accordance with sustainability principles (Stagnari et al., 2017).

To better understand the contribution of AD to more sustainable agricultural systems there is a need to accurately evaluate synergies and trade-offs resulting from the implementation of crop diversification strategies of the elements composing the diversified cropping systems to avoid introducing new problems into the agri-food system (Kremer and Miles., 2012; Iocola et al., 2020).

In this context, the 5-year Horizon 2020 DIVERFARMING project (www.diverfarming.eu) aims to define sustainable, diversified cropping systems with low-input farming practices, adopting a multi-disciplinary approach across Europe. There is a gap on the specific local knowledge of soil and land management to support transitions towards diversified cropping systems by involving local stakeholders and actors of agri-food systems from the beginning of research activities with participatory methods (Bampa et al., 2019).

Thus, to fill this gap, the overall objective of this study was to improve the understanding of the perceptions of different stakeholders on the barriers and opportunities for implementing farming practices and crop diversification strategies in cereal-based cropping systems Italy. At first, this study engaged stakeholders by public consultations to capture their practical knowledge of current farming practices for promoting suitable diversified cropping systems both in irrigated and rainfed areas, as alternatives to the intensive ones.

The analysis of the stakeholders' perceptions of barriers and opportunities to AD transition was done using a multi-criteria decision process (Calatrava et al., 2021). The consultations also aimed to investigate the interest of stakeholders on potential crop associations and alternative low-input farming strategies for decreasing external inputs and minimising agri-environmental and socio-economic problems. The consultations were guided by the following research questions:

1) What are the most important agro-environmental problems and the priorities for action in the case study areas?
2) What are the most adequate farming practices and their effectiveness for each cropping system and case study area?
3) How do stakeholders' perceptions of barriers and opportunities to crop diversification relate to the characteristic cropping systems adopted in the case study areas?

2 MATERIALS AND METHODS

2.1 Agricultural Context and Case Study Areas

In 2019, utilised agricultural area (UAA) in the 27 Countries of the European Union (EU-27) covered 1,629,058.10 km^2, corresponding to 36.8% of the total land area. The UAA is mainly based on arable land (61.4%), permanent grassland (31.2%), and permanent crops (7.4%). In recent decades, European agriculture has specialised on the production of few crop species named majors crops, with the aim to increase the economic efficiency of agri-food systems (Messéan et al., 2021). In the last 10-year, cereal production in Europe covered about 85% of the total production (Eurostat, 2020; https://ec.europa.eu/eurostat/databrowser/view/tag00025/default/table?lang=en).

Within EU member states, Italy is one of the most important in terms of UAA and agri-food products of high quality (Dal Ferro and Borin, 2017). Similarly to EU-27, in Italy more than half of the UAA is occupied by arable land (52.8%), which include both rainfed and irrigated crops. Pastures and meadows cover 28.8% and are quite common in the Northern region (mainly Aosta Valley and Trentino-South Tyrol regions), while permanent crops (e.g., vineyards, olive groves, etc.) cover 18.4%. In Italy, agricultural systems are highly variable, depending on orographic layout, latitude extension from north to south, and heterogeneous pedoclimatic conditions, that influence the development of diversified landscapes with specific local and highly specialised agri-food value chains.

In this context, agricultural areas are dominated by cropping systems mostly oriented on winter and summer cereals, in monocropping or short-rotation with other rainfed or summer irrigated crops such as processing tomato (*Solanum lycopersicum* L.), forage-based systems, or other mixed succession also including bare fallow (Di Bene et al., 2016). In 2019, the cereal-based cropping systems cover an area of 3, 086, 163.00 ha, representing 45.9% of the national UAA. In the last 10-year (2010–2019), the UAA decreased, but the area cultivated with winter cereals such as durum wheat (*Triticum durum* Desf.), winter wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare* L.) increased by 3.4%, 0.9%, and 1.0%, respectively (ISTAT, 2021; http://dati.istat.it/?lang=en&SubSessionId=a0433fd1-878a-4fd3-853d-aeb580487429). This trend showed different features looking at crops' shift among the areas of Northern and Southern Italy. In the North, the reduction of maize (*Zea mais* L.) cultivation (up to 38% in Lombardy) has favoured the increase of wheat cultivation areas. Although maize still represents the first national cereal crop in terms of production and level of yield per hectare, the sector has progressively lost competitiveness due to a series of converging critical issues: the drop in prices, the high fixed costs, and the increased risk from pathogens to which these crops are exposed which also affects the variable component of costs. Conversely, in the South there has been an increase of about 6% of the agricultural land cultivated with cereals, mainly due to the expansion of durum wheat cultivation, which can be traced back to the increase in prices due to the scarcity of supply compared to demand, both nationally and globally (ISTAT, 2021; http://dati.istat.it/?lang=en&SubSessionId=a0433fd1-878a-4fd3-853d-aeb580487429).

Therefore, considering the above-mentioned context, the DIVERFARMING case studies were selected to represent the most widespread irrigated and rainfed cereal-based cropping systems in both the Northern and Southern Italian areas (**Figure 1**). The cropping system investigated as common farming baseline in both study areas are generally specialised in rainfed and irrigated cereal-based cropping systems for food production, adopting a 2-year cash crops rotation, based on processing tomato followed by cereals.

FIGURE 1 | Selected case study areas: Po Valley in Northern Italy (green colour) and Capitanata Plain in Southern Italy (orange colour).

In the Northern part such as the Po Valley, the primary sector is mainly characterised by well-structured professional farms, including a variety of specialised intensive production systems such as arable cereal-based and horticulture cropping systems (no livestock), animal farming systems (all crops used as on-farm livestock feed), mixed farming systems (crops for selling and for on-farm livestock feed), because of the presence of many agri-food companies such as Barilla Group and Casalasco cooperative for industrial tomato production (Pancino et al., 2019). On the other hand, in the Southern areas such as the Capitanata Plain in Apulia Region, the primary sector is less specialised compared to the Northern systems and it is generally oriented to the production of rainfed winter cereals, mainly durum wheat, and irrigated summer horticultural crops, mostly processing tomato (Blasi et al., 2015; Diotallevi et al., 2015; Di Bene et al., 2016; Farina et al., 2017).

2.2 Survey Questionnaire

Five different categories of stakeholders were surveyed: 1) Farmers; 2) private farm advisory services; 3) public agricultural technical officers; 4) agricultural researchers; and 5) experts from non-governmental organizations (NGOs) with experience on farming. Between 20 and 30 stakeholders were intended to be consulted with the following distribution: 1) Farmers and technical agricultural advisors (n = 12–15); 2) field technical officers from public agricultural administrations (n = 3–5); 3) technical experts from NGOs with experience on farming practices (n = 2–5); and 4) researchers in agriculture (n = 3–5). The study did not intend to survey a representative sample of stakeholders but to gather the opinions of selected stakeholders that were experts on Italian cereal cropping systems. They were contacted, not only to answer the survey questionnaire, but also to participate in other participatory assessment activities carried out within the Horizon 2020 DIVERFARMING project. The stakeholders were selected with the involvement of Italian farmers associations and agricultural cooperatives and companies, that proposed potential participating stakeholders based on their knowledge and experience on the corresponding cereal-based cropping systems in the areas of study, and therefore do not constitute a representative sample. A total of 50 stakeholders were finally selected and directly invited to fill in the questionnaire.

Perceptions of relevant stakeholders on the most adequate farming practices and diversification strategies to increase cropping systems sustainability were collected using a common survey questionnaire developed within the Horizon 2020 DIVERFARMING project. For the Italian case studies, the questionnaire was specifically tailored and adapted to the peculiarities of the cropping systems and pedoclimatic conditions of the investigated case study areas based on an explicit literature review, focused on diversified strategies and sustainable farming practices for rainfed and irrigated cereal-based cropping systems (Francaviglia and Di Bene, 2019; Francaviglia et al., 2019, 2020).

The survey questionnaire was implemented online using the Survey Monkey platform and was organised in two parts. The first part was focused on the identification and qualitative assessment of agro-environmental problems, priorities for action, and effectiveness of farming practices. It was composed by four blocks of questions:

1) Stakeholder's general information (e.g., name, gender, type of stakeholder, affiliation, etc.);
2) identification and qualitative assessment of the most relevant agro-environmental and socio-economic problems of each cropping system considered in the case study areas (choice made from an open list of options), and assessment of the priority for possible actions and measures that could be selected to address the previously identified problems (choice made from an open list of options);
3) identification of farming practices considered by the stakeholders most appropriate for the implementation in the specific cropping system and the considered study areas (choice made from a list of options with open options for additional potentially implementable farming practices that can be proposed by the stakeholders). Moreover, for those practices not considered suitable, the stakeholders were asked to indicate the main reasons for not selecting them;
4) qualitative assessment of the effectiveness of the farming practices to face the agro-environmental and socio-economic problems previously identified by the stakeholders.

The second part of the survey was focused on the identification of the best crop diversification strategies for both the rainfed and irrigated cereal-based cropping systems in the Po Valley and Capitanata Plain case study areas. More precisely, the surveyed stakeholders were asked to identify from a list of options which type of diversification could be the most appropriate to be adopted in the specific cropping system and case study area. The list of crop diversification options followed the results of the literature review as reported in Francaviglia et al. (2019, 2020). Three major crop diversification options were proposed as follows:

1) Intercropping: complementary crops from different families with different nutritional requirements that are grown simultaneously on the same field within a single growing season. The practice of growing two or more crops together at the same time in a beneficial manner aimed at increasing land productivity, crop quality, and ecosystem services. Row intercropping refers to structured arrangements of different species planted in alternate rows. Strip intercropping is a more industrialised version with rows of individual crops wide enough to be harvested with machinery. Mixed intercropping means randomly arranged plants of different species bunched together with no separation in rows or strips. Relay intercropping indicates the interplanting of two or more crop species before the main crop reaches maturity and they simultaneously grow during part of the crop cycle.
2) crop rotation: complementary crops from different families with different nutritional requirements and different crop cycles that are grown on the same field in sequence for a period of two or more years (alternating crops in different years);
3) multiple cropping: complementary crops from different families with different nutritional requirements and different crop cycles that are grown on the same field in seasonally succession (a second crop is planted after the first crop has reached maturity, within the same year) to preserve the productive capacity of the soil.

After the selection of the preferred type of crop diversification, the stakeholders were asked to identify two crops from an open list of several combinations that they considered most adequate for the diversification of the cropping system in the Po Valley and Capitanata Plain in Foggia Province case study areas. Anyhow, they could also indicate alternative diversification crops if those proposed in the list were not exhaustive.

2.3 Data Analysis

2.3.1 Statistical Analysis

The assessment of the severity of the agro-environmental problems, the priority for action, and the effectiveness of farming practices were measured using a six-level categorical ordered scale ranging from "Very low/null" to "Very high." The use of this scale was justified by the non-existence of possible neutral positions in the assessment of the aforementioned aspects as well as by the need to prevent the consulted stakeholders without an opinion from using the middle point as a "save-the-face response" instead of using the "do not know/do not answer" option (Sturgis et al., 2012). Then, the qualitative answers were converted to numerical correlated values, representing the correspondent quantitative assessment using a 0 to 5 numerical scale, referred to "Very low/null" and "Very high," respectively.

Stakeholders' answers related to the agro-environmental problems and the priority for action were statistically analysed using STATA/SE 15 software (Software for statistics and data science; https://www.stata.com/). Generally, a univariate descriptive analysis of stakeholders' answers was presented. In detail, when variables measured the proportion of stakeholders selecting a given answer, only the number of stakeholders or the proportion of answers per each stakeholder category was shown. Conversely, when variables were continuous, both average and standard deviation values were shown. Finally, for the severity of agro-environmental problems and the assessment of the priority for action due to the categorical nature of the variables, the median was also reported. In the analysis of stakeholders' choice related to the diversification alternatives, the answers were discriminated per type of stakeholder. The Fisher's exact probability test was used to analyse the statistical significance of the differences in the choice of the diversification alternatives among the types of stakeholders. This non-parametric statistical test that exactly measured the association between two categorical values is commonly used as a substitute of Chi-Square test for small samples.

2.3.2 Multi-Criteria Assessment

The analysis of the stakeholders' responses regarding the assessment of the effectiveness of farming practices was done by establishing a ranking of their effectiveness using multi-criteria decision analysis (MCDA).

The use of MCDA requires converting the stakeholder's qualitative assessment into a quantitative assessment for its numerical treatment. The conversion was done using standardised ordinal linguistic labels that have a numerical correlation to collect stakeholder's assessments in the questionnaire. More detail is reported in Calatrava et al. (2021).

The main purpose of MCDA is to evaluate and choose alternatives based on multi-criteria using systematic analyses that overcome the limitations of unstructured decision problems. Several methodologies have been developed to rank alternatives regarding different types of information (Bampa et al., 2019). Multi-criteria alternative selection systems are defined by the following elements (Munda et al., 1993):

$$\{C, D, r, I, \prec\}$$

Where: $C = \{C1, ..., Cj, \ldots Cm\}$ are the m criteria used to compare alternatives. In this analysis, the criteria (C) considered are the preferences of the decision makers, i.e., the stakeholders answering the survey.$D = \{D1, \ldots, Di, ..., Dn\}$ are the n alternatives considered as feasible in the survey (farming practices) that the decision-maker must assess qualitatively. Unlike more complex decision systems, C and D are finite sets that allow avoiding problems of convergence, integrability and measurability.r: $D \times C \rightarrow r$ is a function that generates a matrix in which each term corresponds to a reality associated with each alternative Di and criterion Cj:

$$(Di, Cj) \rightarrow r(Di, Cj) = rij$$

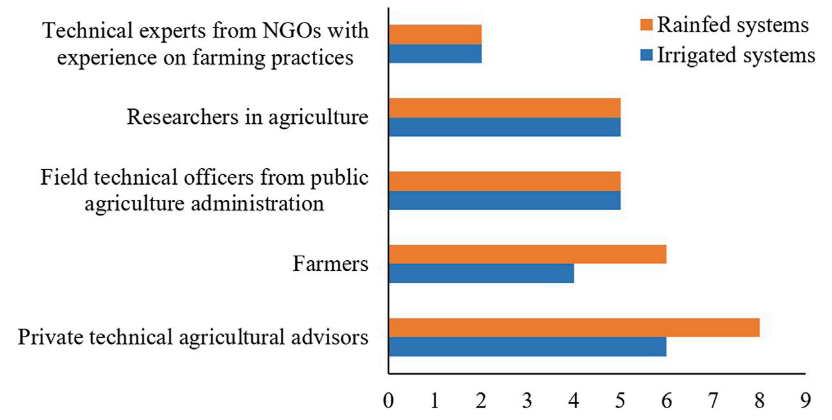

FIGURE 2 | Number of respondents grouped per type of stakeholders for both rainfed and irrigated cereal-based cropping systems.

I: is the set of linguistic labels used by the decision makers to assess each alternative (Di) for each criterion (Cj).$\prec$: are the preferences of the decision-makers with respect to the different alternatives (D) considered in the decision.

The effectiveness of each alternative (Di) was assessed for each criterion, i.e., each decision maker (Cj) qualitatively evaluated each alternative using linguistic terms (I) to express the effectiveness (rij values). The use of linguistic labels allows the decision maker to express his/her perception of the goodness of each alternative. The rij values obtained configure the decision-making matrix that represent the preferences ($\prec$) of the decision-makers with respect to the different alternatives. It is assumed that the decision-maker is rational, in the sense of acting coherently with his/her preferences and objectives and his/her previous knowledge, expressing them through these linguistic labels. More precisely, as previously commented, the importance of the criteria was obtained through direct assignment using a valuation scale with six levels (labels) that ranges between "Very low/null" and "Very high." The question template used was "According to your criterion, the effectiveness of practice Y for addressing agro-environmental problems in rainfed/irrigated cereal production is Very low, Low, Medium low, Medium high, High, and Very high." These standardised ordinal linguistic labels used to collect the stakeholder's qualitative assessments were converted to numerical correlated labels using a 0 to 5 numerical scale, which represent the corresponding quantitative assessment from "Very low/null" to "Very high," respectively.

In this study, the definition of the MCDA was based on a group of agricultural practices representing the alternatives to be selected, the stakeholders' point of view that are based on their prior knowledge and preferences (criteria), and the corresponding assessment of the effectiveness of each alternative. The selection and assessment of alternatives was made in independent decision processes for each cropping system and stakeholder. The aggregation of the different types of stakeholders allowed us to obtain a single result of the priority ranking of farming practices for each cropping system (group decision). In this case, each type of stakeholder was equally weighted in the group's decision. The mathematical calculation to obtain the preferences ranking of farming practices was carried out using the Order Preference Technique for Similarity with the Ideal Solution (TOPSIS) methodology developed by Hwang and Yoon (1981), Zeleny (1982) and Lai et al. (1994). The TOPSIS methodology is based on the calculation of the geometric distance to the ideal solution. The ranking of alternatives is built by prioritizing the alternatives that are closer to the positive ideal solution (PIS) and further from the negative ideal solution (NIS). A relative closeness index, ranging from 0 to 1, is calculated for each alternative as a combination of both the distance to the PIS and to the NIS (Shih et al., 2007). The greater the index the more effective the alternative is. A priority ranking of alternatives (i.e., farming practices) is established based on these relative closeness indices. Those practices with the highest ranking were selected as the most effective ones.

3 RESULTS AND DISCUSSION

3.1 Main Characteristics of Surveyed Stakeholders

A total of forty-eight anonymised stakeholders participated in the survey process for both the rainfed and irrigated cereal-based cropping systems, covering all stakeholder groups (**Figure 2**). Among them, twenty-six (54.17%) were consulted as experts of the rainfed cereal-based cropping systems (average age of stakeholders was 45.15 with ±10.81 as standard deviation), while twenty-two (45.83%) were consulted as experts of the irrigated cereal-based cropping systems (average age of stakeholders was 47.13 with ±10.34 as standard deviation). For both the rainfed and irrigated cereal-based cropping systems, the largest group was represented by private technical agricultural advisors, which covered 30.77% and 27.27% of the total stakeholders involved in the survey process of the rainfed and irrigated cereal-based cropping systems, respectively. Conversely, the technical experts from NGOs with experience on farming practices represented the smallest group, covering 7.69% and

9.09% of the total stakeholders involved in the survey process of the rainfed and irrigated cereal-based cropping systems, respectively.

3.2 Assessment of Agro-Environmental Problems and Priorities for Action

The surveyed stakeholders were asked to qualitatively assess and rating the severity of several agro-environmental problems for both rainfed and irrigated cereal-based cropping systems. The stakeholders' subjective answers on perception of the severity of the agro-environmental problems were converted to a 0 to 5 scale and the main statistics (i.e., average, median, and standard deviation values) are shown in **Tables 1**, **2**, for the rainfed and irrigated cereal-based cropping systems, respectively.

Generally, the stakeholders' perception of the severity of the agro-environmental problems was very similar in both the rainfed and irrigated cereal-based cropping systems and was consistent with the type of cropping systems analysed. The three agro-environmental problems perceived by the stakeholders as the most severe in both the rainfed and irrigated cereal-based cropping systems were loss of profitability and associated risk of farm abandonment, that is clearly linked to a socio-economic concern, followed by loss of SOM content, and soil degradation by erosion. In the case study areas, the decrease of SOM content is mainly caused by the high mineralisation rate due to conventional tillage highly used for seedbed preparation and for weed control. Moreover, other agro-environmental problems assessed as important were the excessive use of plant protection products and use of fertilisers, which also entail high costs for farmers, landscape degradation, and loss of biodiversity (**Tables 1**, **2**). Conversely, soil pollution and waterlogging soil were barely assessed as a serious problem for both the cereal-based cropping systems in the Po Valley and Capitanata Plain case study areas.

After assessing the severity of the agro-environmental problems, the stakeholders were asked to qualitatively evaluate the priority for action to be considered for tackling such problems. The answers related to the qualitative assessment were also converted to a 0 to 5 scale. The average, median, and standard deviation values of such actions were reported in **Tables 3**, **4**, for the rainfed and irrigated cereal-based cropping systems, respectively.

Generally, the stakeholders' qualitative assessment was consistent with the relevant agro-environmental problems as identified in **Tables 1**, **2**. In both the Po Valley and Capitanata Plain case study areas, the surveyed stakeholders assigned the highest priority for action to the increase of the farm profitability for both the rainfed (a mean value of 4.08; **Table 3**) and irrigated cereal-based cropping systems (a mean value of 4.00; **Table 4**). For the rainfed cereal-based cropping systems, other important priorities identified by the stakeholders were represented by the improvement of soil conditions (e.g., increase soil biodiversity and fertility, improve soil structure, and reduce soil erosion) and the reduction of energy consumption aiming at decreasing the costs for farmers (a mean value ranging from 3.77 to 3.68). Conversely, for the irrigated cereal-based cropping systems, the second priority identified by the stakeholders was again the reduction of energy consumption (a mean value of 3.81), followed by the improvement of soil conditions (e.g., increase soil biodiversity and fertility, improve soil structure, and reduce soil erosion) and the modernization of agriculture (a mean value ranging from 3.77 to 3.59, respectively) that improve farmer's incomes. Interestingly, for both rainfed and irrigated cereal-based the cropping systems, the actions related to the recovery of traditional crops, reduction of flooding in fields, and increase of crop yields were assigned the lowest priority by the stakeholders with a mean value of 2.89 for both the cropping systems

TABLE 1 | Stakeholders' qualitative subjective assessment and rating of the severity of agro-environmental problems in rainfed cereal-based cropping systems, measured on a 0 to 5 scale (i.e., 0 = Very low/null, 5 = Very high), listed in a decreasing order.

Problem assessed	Rainfed cereals		
	Average	Median	Standard deviation
Loss of profitability / farm abandonment	4.08	5.00	1.35
Loss of soil organic matter (SOM)	3.73	4.00	1.08
Soil degradation by erosion	3.50	4.00	1.27
Excessive use of plant protection products	3.40	4.00	1.19
Excessive use of fertilisers	3.31	3.00	1.12
Landscape degradation	3.31	3.00	1.26
Loss of biodiversity	3.19	3.00	1.36
Excessive use of machinery	2.77	3.00	1.48
Water pollution	2.64	3.00	1.11
Soil pollution	2.50	3.00	1.06
Waterlogged soils	2.08	2.00	1.20
Excessive use of irrigation water	–	–	–

TABLE 2 | Stakeholders' qualitative subjective assessment and rating of the severity of agro-environmental problems in irrigated cereal-based cropping systems, measured on a 0 to 5 scale (i.e., 0 = Very low/null, 5 = Very high), listed in a decreasing order.

Problem assessed	Irrigated cereals		
	Average	Median	Standard deviation
Loss of profitability / farm abandonment	4.09	4.50	1.27
Loss of soil organic matter (SOM)	3.77	4.00	1.07
Soil degradation by erosion	3.64	4.00	1.26
Excessive use of plant protection products	3.43	4.00	1.25
Excessive use of fertilisers	3.23	3.00	1.19
Landscape degradation	3.09	3.00	1.23
Loss of biodiversity	3.09	3.00	1.41
Excessive use of irrigation water	3.05	3.00	1.33
Water pollution	2.76	3.00	1.00
Excessive use of machinery	2.64	3.00	1.56
Soil pollution	2.60	3.00	1.10
Waterlogged soils	2.14	2.00	1.21

TABLE 3 | Stakeholders' qualitative subjective assessment of the priority for action in rainfed cereal-based cropping systems, measured on a 0 to 5 scale (i.e., 0 = Very low/null, 5 = Very high) and listed in a decreasing order.

Actions	Rainfed cereals		
	Average	Median	Standard Deviation
Increase farm profitability	4.08	4.00	1.15
Increase biodiversity	3.77	4.00	1.34
Increase soil fertility	3.73	4.00	1.19
Improve soil structure	3.73	4.00	1.19
Reduce energy consumption	3.68	4.00	1.22
Reduce soil erosion	3.60	4.00	1.26
Modernisation of agriculture	3.54	3.50	1.10
Increase carbon sequestration in soil and arboreal biomass	3.27	3.00	1.54
Conserve traditional landscapes	3.25	3.50	1.29
Recover traditional crops	3.08	3.00	1.38
Reduce flooding in fields	2.96	3.00	1.62
Increase crop yields	2.64	3.00	1.35

TABLE 4 | Stakeholders' qualitative subjective assessment of the priority for action in irrigated cereal-based cropping systems, measured on a 0 to 5 scale (i.e., 0 = Very low/null, 5 = Very high) and listed in a decreasing order.

Actions	Irrigated cereals		
	Average	Median	Standard Deviation
Increase farm profitability	4.00	4.00	1.18
Reduce energy consumption	3.81	4.00	1.08
Increase soil fertility	3.77	4.00	1.19
Improve soil structure	3.73	4.00	1.16
Increase biodiversity	3.68	4.00	1.43
Modernisation of agriculture	3.59	3.50	1.14
Reduce soil erosion	3.57	4.00	1.33
Increase carbon sequestration in soil and arboreal biomass	3.41	3.50	1.56
Conserve traditional landscapes	3.10	3.50	1.29
Reduce flooding in fields	2.95	3.00	1.56
Recover traditional crops	2.90	3.00	1.37
Increase crop yields	2.81	3.00	1.29

(**Tables 3**, **4**). It is well-known that the choice of a farming practice depends on markets, pedo-climatic conditions, crop rotation aspects, availability of genetic varieties, governmental subsidies, and farmer's preferences. These agronomic practices can have positive or negative effects on soil quality and the wider environment, depending on crop type, rotation, management, and agro-environmental conditions. Choices made on these factors can influence profitability as well as sustainability of crop production systems (Reckling et al., 2016).

3.3 Identification of Adequate Farming Practices and Assessment of Their Effectiveness

From a list of potentially implementable farming practices (i.e., tillage, soil cover, erosion control, fertilisation, plant protection, and farm design), the surveyed stakeholders were asked to identify the most appropriate practices to be implemented in both the rainfed and irrigated cereal-based cropping systems, considering the characteristics of the Po Valley and Capitanata Plain case study areas. The survey also asked to qualitatively assess the effectiveness of those farming practices identified suitable by the stakeholders to face the agro-environmental problems for both the rainfed and irrigated cereal-based cropping system in the case study areas. Conversely, for those practices not considered adequate for both the rainfed and irrigated cropping systems, the stakeholders selected the most important reasons. **Tables 5**, **6** show the percentage of the stakeholders that identified each farming practice as adequate for both the rainfed and irrigated cereal-based cropping systems, respectively. **Supplementary Tables S1, S2** show the rating of preferences for the farming practices resulting from the TOPSIS MCDA relative closeness index. The closeness index ranged from 0 to 1. A higher ranking means that the corresponding farming practice is considered more effective by the surveyed stakeholders. The results from the MCDA allowed us to select the most effective farming practices alternatives. As expected, the ranking of the farming practices provided by the stakeholders (**Supplementary Tables S1, S2**) was similar to the results shown in **Tables 5**, **6** because the most selected adequate farming practices were also the most effective.

Regarding tillage, most stakeholders choose minimum tillage as the most effective alternative farming practice to address the most important agro-environmental problems for both the rainfed and irrigated cropping systems (TOPSIS MCDA ranking score equal to 0.61 and 0.54, respectively; **Supplementary Tables S1, S2**) compared to tillage without heavy implements and no tillage options. Particularly, the percentage of stakeholders that consider this practice as the most adequate and effective for the cereal-based production in the study areas was higher for the irrigated system compared to the rainfed cereal-based production (86.36% vs. 65.38%, respectively). Conversely, a very small number of stakeholders considered conservation tillage with grazing an adequate farming practice for both the rainfed (19.23%) and irrigated cropping systems (13.64%).

Soil cover refers to the fraction of the land covered by crops. This is important for preventing loss of nutrients and pesticides by runoff and reducing the risk of soil erosion, especially during the winter season. In this context, most of the stakeholders identified the maintenance of vegetation covers the most effective and selected practice for both the rainfed and irrigated cereal-based cropping systems. As shown in **Tables 5**, **6**, the percentage of stakeholders that considered the maintenance of vegetation covers as adequate was greater for the irrigated cereal-based cropping systems compared to the rainfed production (72.73% vs. 65.38%, respectively). Nevertheless, the TOPSIS MCDA ranking score for the effectiveness of these practices in the case study areas was similar for both the rainfed and irrigated cropping systems (0.55 and 0.53, respectively; **Supplementary Tables S1, S2**). Among the soil cover, the maintenance of vegetation strips between crop lines was the less selected practice by the stakeholders for the rainfed and

TABLE 5 | Identification of adequate farming practices for rainfed cereal-based cropping systems, listed in a decreasing order. For each practice, values refer to the percentage of stakeholders that identified it suitable.

Farming practice in rainfed systems	Percentage (%)
Tillage	
Minimum tillage	65.38
Tillage without heavy implements	42.31
No-tillage with mechanical weed control (brush cutter)	34.62
No-tillage with chemical weed control	19.23
Conservation tillage with grazing	19.23
Tillage following contour lines	15.38
Soil cover	
Maintain vegetation covers (natural or cover crops)	65.38
Mulching (with crushed pruning offcuts, reeds, etc.)	46.15
Maintain strips of vegetation between crop lines	38.46
Erosion control	
Maintain the natural vegetation on the edges of the farm plots	46.15
Installing hedges on the edges of the plots	46.15
Construction of erosion barriers or margins without vegetation	19.23
Construction of erosion barriers or margins with vegetation	19.23
Fertilisation	
Contribution of organic matter/manure	88.46
Use of green manure	88.46
Precision agriculture to optimise fertilisation (variable rate)	53.85
Combination of mineral and organic fertilisers	50.00
Use of biostimulants and biofertilisers	34.62
Plant protection	
Integrated pest control	61.54
Farm design	
Changing crop rotations	76.92

TABLE 6 | Identification of adequate farming practices for irrigated cereal-based cropping system, listed in a decreasing order. For each practice, values refer to the percentage of stakeholders that identified it suitable.

Farming practice in irrigated systems	Percentage (%)
Tillage	
Minimum tillage	86.36
Tillage without heavy implements	59.09
No-tillage with chemical weed control	27.27
No-tillage with mechanical weed control (brush cutter)	27.27
Tillage following contour lines	18.18
Conservation tillage with grazing	13.64
Soil cover	
Maintain vegetation covers (natural or cover crops)	72.73
Mulching (with crushed pruning offcuts, reeds, etc.)	45.45
Maintain strips of vegetation between crop lines	18.18
Erosion control	
Maintain the natural vegetation on the edges of the farm plots	40.91
Installing hedges on the edges of the plots	36.36
Construction of erosion barriers or margins with vegetation	27.27
Construction of erosion barriers or margins without vegetation	13.64
Fertilisation	
Contribution of organic matter/manure	81.82
Use of green manure	72.73
Precision agriculture to optimise fertilisation (variable rate)	59.09
Combination of mineral and organic fertilisers	54.55
Use of biostimulants and biofertilisers	45.45
Plant protection	
Integrated pest control	68.18
Farm design	
Changing crop rotations	77.27

irrigated cropping systems. Nevertheless, the percentage of stakeholders that considered this practice as adequate was twice in rainfed cereal-based systems compared to the irrigated cereal-based production (38.46% vs. 18.18%, respectively). The rationale is likely to be related to the fact that cover crops are more used and better known by farmers compared to vegetation strips practice.

Regarding erosion control, all the alternatives were not considered a priority for the Po Valley and Capitanata Plain case study areas due to the limited effectiveness for the pedoclimatic conditions. However, other stakeholders identified the maintenance of natural vegetation on the edges of farm plots and the installation of hedges as the most important options to limit water erosion by runoff for both the rainfed and irrigated cereal-based systems (46.15% and 40.91%, respectively) in the Po Valley and Capitanata Plain case study areas (**Tables 5**, **6**). Although in the rainfed cereal-based systems, the two farming practices were considered adequate by the same percentage of stakeholders (46.15%), the TOPSIS MCDA ranking score identified the installation of hedges the most effective alternative for the case study areas, while the maintenance of natural vegetation on the edges of farm plots was considered the second practice most effective (0.40 vs. 0.25; **Supplementary Table S1**). Conversely, in the irrigated cereal-based systems all the alternatives are perceived to have a low effectiveness with a similar TOPSIS MCDA ranking score, ranging from 0.25 to 0.26, for the construction of erosion barriers or margins with vegetation and the three other alternative practices, respectively (**Supplementary Table S2**).

For the fertilisation practices, the stakeholders agreed to choose the application of organic matter/manure and the use of green manure as the most adequate practices for both the cropping systems in the case study areas. Such preferences were higher in the rainfed cereal-based cropping systems compared to the irrigated production (a mean value of 88.46% vs. 77.28%, respectively). Moreover, the adoption of precision agricultural to optimise fertilisation using variable rate and the combined use of mineral and organic fertilisers were considered adequate farming practices by more than half of the stakeholders in both the rainfed and irrigated cereal-based cropping systems (a mean value of 51.93% and 56.82%, respectively). Similarly to the erosion control, in the rainfed cereal-based systems the contribution of organic matter/manure was considered the most effective practice, while the green manure practice was considered the second most effective practice (0.78 vs. 0.68; **Supplementary Table S1**). In the irrigated cereal-based systems, the use of precision agriculture techniques was identified the most effective fertilisation alternative (TOPSIS MCDA ranking score 0.76) compared to the other alternatives (**Supplementary Table S2**) such as the contribution of organic matter/manure (TOPSIS MCDA ranking score 0.62) and the use of green manure (TOPSIS MCDA ranking score 0.56), which were the two alternative farming practices considered most adequate by the stakeholders (**Table 6**). For both the rainfed and irrigated cereal-based cropping systems, the use of biostimulants and biofertilisers was identified as the least effective fertilisation alternative (TOSPIS MCDA ranking score 0.19 and 0.30, respectively; **Supplementary Tables S1, S2**).

TABLE 7 | Reasons given by the stakeholders for not selecting a farming practice as adequate for rainfed cereal-based cropping systems, expressed as percentage of responses, listed in a decreasing order.

Farming practice	Reason*									No. of responses
	A	B	C	D	E	F	G	H	I	
Tillage										
Tillage following contour lines	4.5	50.0	27.3	9.1	4.5	-–	–	–	4.5	22
Conservation tillage with grazing	19.0	23.8	14.3	4.8	4.8	19.0	4.8	–	9.5	21
No tillage with chemical weed control	9.5	9.5	14.3	9.5	9.5	28.6	4.8	–	14.3	21
No tillage with mechanical weed control (brush cutter)	11.8	–	11.8	11.8	17.6	5.9	–	29.4	11.8	17
Tillage without heavy implements	20.0	20.0	26.7	–	6.7	–	6.7	–	20.0	15
Minimum tillage	22.2	11.1	–	11.1	33.3	11.1	–	–	11.1	9
Soil cover										
Maintain strips of vegetation between crop lines	12.5	18.8	31.3	12.5	12.5	–	6.3		6.3	16
Mulching (with crushed pruning offcuts, reeds, etc.)	7.1	14.3	35.7	14.3	14.3	–	7.1		7.1	14
Maintain vegetation covers (natural or cover crops)	11.1	11.1	33.3	22.2	11.1	–	–		11.1	9
Erosion control										
Construction of erosion barriers or margins without vegetation	23.8	33.3	9.5	4.8	9.5	–	–	9.5	9.5	21
Construction of erosion barriers or margins with vegetation	14.3	38.1	14.3	4.8	4.8	–	4.8	9.5	9.5	21
Maintain the natural vegetation on the edges of the plots	28.6	28.6	7.1	21.4	–	–	–	7.1	7.1	14
Installing hedges on the edges of the plots	14.3	35.7	14.3	7.1	–	–	7.1	21.4	–	14
Fertilisation										
Use of biostimulants and biofertilisers	11.8	–	11.8	11.8	17.6	–	5.9	11.8	29.4	17
Combination of mineral and organic fertilisers	–	15.4	15.4	15.4	7.7	15.4	7.7	15.4	7.7	13
Precision agriculture to optimise fertilisation (variable rate)	16.7	16.7	8.3	–	25.0	–	–	16.7	16.7	12
Contribution of organic matter/manure	–	–	33.3	–	–	33.3	–	33.3	–	3
Use of green manure	–	–	33.3	33.3	–	–	–	–	33.3	3
Plant protection										
Integrated pest control	10.0	10.0	10.0	20.0	10.0	20.0	10.0	–	10.0	10
Farm design										
Changing crop rotations	33.3	–	33.3	33.3	–	–	–	–	–	6

**A-I reasons refer to: Limited effectiveness (A), practice is not adequate for the characteristics of the area (B), it is not a traditional practice in the area (C), it is complex/difficult to implement without technical advice (D), it is complex/difficult to carry out even with technical advice (E), this practice is not compatible with other farming practices (F), this practice requires a high investment cost (G), the cost of carrying out this practice is high (H), the benefits of this practice do not outweigh its costs (I).*

Integrated pest management is a crucial EU agro-climate-environmental measure included in the second pillar of common agricultural policy (CAP) under the rural development programs. Therefore, more than 60% of the stakeholders considered the use of integrated pest control an adequate plant protection practice for both the rainfed and irrigated cereal-based systems in the case study areas (**Tables 5**, **6**). Nevertheless, about 40% of the stakeholders did not identify this practice as a priority because of the complexity of its adoption linked to the higher cost of implementation and technical advice. As expected, the TOPSIS MCDA ranking score for the effectiveness of this practice in the case study areas was higher in the irrigated cereal-based systems compared to rainfed cropping systems (0.55 vs. 0.49, respectively; **Supplementary Tables S1, S2**).

Most stakeholders agreed to identify the change of current crop rotations an efficient farm design strategy to improve the sustainability of both the rainfed and irrigated cereal-based cropping systems (76.92% and 77.27%, respectively) by increasing crop diversification and plant protection and reducing the use of fertilisers and pesticides (**Tables 5**, **6**). The TOPSIS MCDA ranking score for the effectiveness of this practice in the case study areas was higher in the rainfed cereal-based systems compared to irrigated cropping systems (0.62 vs. 0.55, respectively; **Supplementary Tables S1, S2**).

The results of the most important reasons given by the stakeholders for those farming practices not considered adequate for both the rainfed and irrigated cropping systems in the Po Valley and Capitanata Plain case study areas, are presented in **Tables 7**, **8**. Although some relevant similarities among farming practices and reasons exist, the main reasons for not choosing a specific farming practice generally varied between the rainfed and irrigated cereal-based cropping systems.

Regarding tillage practices, most stakeholders identified conservation tillage with grazing, tillage following contour lines, and no tillage with chemical or mechanical (brush cutter) weed control as not much adequate for both the rainfed and irrigated cereal-based cropping systems. The most frequent reasons identified by the stakeholders for not choosing the different tillage options in both the cropping systems and case study areas were mainly related to their inadequacy for the characteristics of the area (i.e., conservation tillage with grazing and tillage following contour lines), the limited compatibility with other farming practices (no tillage with chemical weed control) and the high cost of carrying out the practice (no tillage with mechanical weed control). In detail, the relatively flat topography of the case study areas might explain the low number of stakeholders that considered tillage following contour lines as an adequate alternative. Moreover, the inadequacy for the characteristics of the area linked to soil texture that could affect water retention and availability for crops, especially in rainfed cereal-based systems (Francaviglia et al., 2020). Other important reasons considered by the stakeholders for

TABLE 8 | Reasons given by the stakeholders for not selecting a farming practice as adequate for irrigated cereal-based cropping systems, expressed as percentage of responses, listed in a decreasing order.

Farming practice	Reason*									No. of responses
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	
Tillage										
Conservation tillage with grazing	5.3	42.1	15.8	15.8	–	15.8	–	–	5.3	19
Tillage following contour lines	16.7	44.4	27.8	5.6	–	5.6	–	–	–	18
No tillage with chemical weed control	18.8	12.5	18.8	12.5	12.5	18.8	–	–	6.3	16
No tillage with mechanical weed control (brush cutter)	6.3	18.8	12.5	18.8	12.5	6.3	–	18.8	6.3	16
Minimum tillage	10.0	30.0	20.0	10.0	–	10.0	–	–	20.0	10
Tillage without heavy implements	44.4	–	33.3	–	–	11.1	11.1	–	–	9
Soil cover										
Maintain strips of vegetation between crop lines	16.7	33.3	22.2	5.6	5.6	5.6	–	–	11.1	18
Mulching (with crushed pruning offcuts, reeds, etc.)	16.7	16.7	33.3	8.3	8.3	–	–	–	16.7	12
Maintain vegetation covers (natural or cover crops)	33.3	33.3	16.7	–	16.7	–	–	–	–	6
Erosion control										
Construction of erosion barriers or margins without vegetation	21.1	36.8	15.8	10.5	–	5.3	5.3	5.3	–	19
Construction of erosion barriers or margins with vegetation	25.0	43.8	12.5	6.3	–	–	6.3	6.3	–	16
Installing hedges on the edges of the plots	7.1	28.6	21.4	7.1	–	–	7.1	7.1	21.4	14
Maintain the natural vegetation on the edges of the plots	30.8	23.1	23.1	–	–	7.7	7.7	–	7.7	13
Fertilisation										
Use of biostimulants and biofertilisers	16.7	16.7	–	8.3	8.3	8.3	–	25.0	16.7	12
Combination of mineral and organic fertilisers	10.0	20.0	10.0	20.0	10.0	30.0	–	–	–	10
Precision agriculture to optimise fertilisation (variable rate)	11.1	22.2	11.1	–	33.3	–	–	22.2	–	9
Use of green manure	–	50.0	16.7	33.3	–	–	–	–	–	6
Contribution of organic matter/manure	25.0	25.0	–	25.0	25.0	–	–	–	–	4
Plant protection										
Integrated pest control	14.3	42.9	–	–	–	14.3	–	28.6	–	7
Farm design										
Changing crop rotations	20.0	20.0	40.0	–	–	20.0	–	–	–	5

**A-I reasons refer to: Limited effectiveness (A), practice is not adequate for the characteristics of the area (B), it is not a traditional practice in the area (C), it is complex/difficult to implement without technical advice (D), it is complex/difficult to carry out even with technical advice (E),this practice is not compatible with other farming practices (F), this practice requires a high investment cost (G), the cost of carrying out this practice is high (H), the benefits of this practice do not outweigh its costs (I).*

not selecting these farming practices as adequate for both the rainfed and irrigated cereal-based cropping systems were the limited effectiveness, not being a traditional practice in the area, and the complexity/difficulty to implement the practice without technical advice (**Tables 7**, **8**). In the case of minimum tillage, which was the most chosen alternative tillage practice for both the rainfed and irrigated cereal-based cropping systems, the stakeholders identified the limited effectiveness and the inadequacy of the practice for the characteristics of the area as the most frequent reasons for not adopting this practice in the rainfed and irrigated systems, respectively.

Regarding soil cover, the stakeholders identified the maintenance of vegetation strips between crop lines and mulching as not very adequate for both the rainfed and irrigated cereal-based cropping systems. The most frequent reasons reported by the stakeholders for not choosing these practices in both the cropping systems and case study areas were related to their inadequacy for the characteristics of the area and to not being a traditional practice in the area (**Tables 7**, **8**). For the maintenance of vegetation cover, which was the most chosen alternative practice for both the rainfed and irrigated cereal-based cropping systems, the stakeholders identified not being a traditional practice in the area, its limited effectiveness, and its inadequacy for the characteristics of the area as the most frequent reasons for not adopting the practice in both the rainfed and irrigated systems.

For the erosion control practices, most stakeholders agreed that these practices were not adequate for the characteristics of the case study areas for both the rainfed and irrigated cereal-based cropping systems (**Tables 7**, **8**).

Regarding fertilisation, most stakeholders considered the use of biostimulants and biofertilisers, the combination of mineral and organic fertilisers, and the precision agriculture options to optimise fertilisation using variable rate as difficult practices to be adopted in both the rainfed and irrigated cereal-based cropping systems. It is well-known that biostimulants and biofertilisers can reduce the application of chemical fertilisers due to the role of microorganisms included in the products that solubilise soil nutrients and enhance crop yield and quality (Pellegrino and Bedini, 2014; Rodrigues et al., 2018; Calatrava et al., 2021). Nevertheless, most stakeholders agreed to not use them in both the rainfed and irrigated cereal-based systems in the case study areas mainly because this practice is still not widely used due to higher costs compared to chemical fertilisers (Ramakrishna et al., 2019). Moreover, in the short-term, the economic and environmental benefits of this practice do not outweigh the costs. Other reasons were linked to the complexity of the practice, the lack of profitability, and the need for technical advice (**Tables 7**, **8**). For the mineral and organic fertilisers, most stakeholders pointed out the incompatibility of the combined use with other farming practices as an important reason in both the rainfed and irrigated cereal-based systems in the case study areas.

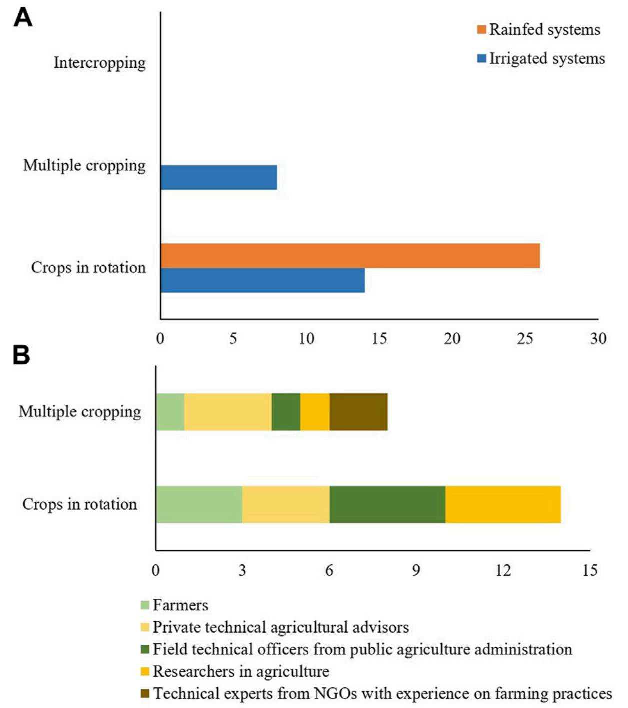

FIGURE 3 | In the Po Valley and Capitanata Plain case study areas, number of consulted stakeholders that identified each type of crop diversification strategy as most adequate for both the rainfed and irrigated systems **(A)**. Number of respondents grouped per type of stakeholders for the irrigated cereal-based cropping systems **(B)**.

Other reasons were linked to the inadequacy of the practice for the characteristics of the area, not being a traditional practice in the area, the complexity/difficulty to implement the practice without technical advice, and the high cost of the practice (**Tables 7, 8**). For precision agriculture, several challenges (socio-economical, agronomical, and technological) could still limit the use of this practice because not many farmers are really familiar with farming innovation and digitalisation tools. In this context, the main drawbacks identified by the stakeholders for not adopting this practice in both the rainfed and irrigated cereal-based cropping systems were mainly linked to the high costs and to the complexity/difficulty to implement the use of variable rate without technical advice. The responses of this survey were in line with those reported by Kernecker et al. (2020), who highlighted that the most important barriers identified by farmers were the investment costs and the lack of perception of the benefits of precision farming technologies. These findings confirmed previous studies (Diacono et al., 2013; Calatrava et al., 2021) that pointed out additional costs for precision agriculture due to the significant investments in equipment/materials and the need of training for using more precise technologies (**Tables 7, 8**). For the use of green manure and the contribution of organic matter/manure only few stakeholders did not consider these practices adequate, and the main reasons changed between the rainfed and irrigated cereal-based cropping systems. In the rainfed cereal-based cropping systems, the reasons for not adopting the green manure practice were related to not being a traditional practice in the area, the complexity/difficulty to implement the practice without technical advice, and the belief that the benefits of this practice in the short-term do not outweigh the costs. Moreover, for the contribution of organic matter/manure the reasons were mainly related to the incompatibility of the practice with other farming practices and to the related high cost (**Table 7**). In the irrigated cereal-based cropping systems the most important reason identified by the stakeholders for not adopting the green manure was mainly related to the inadequacy of the practice for the characteristics of the area, while for the contribution of organic matter/manure the main reasons were mainly related to the limited effectiveness and the complexity/difficulty to implement this practice with or without technical advice (**Table 8**). Similarly to the use of green manure and the contribution of organic matter/manure, the main reasons for not adopting the integrated pest management and the change of crop rotation changed between the rainfed and irrigated cereal-based cropping systems, as shown in **Tables 7, 8**.

3.4 Identification of the Preferred Crop Diversification Strategies

In the second part of the survey, the stakeholders identified the best crop diversification strategies for both the rainfed and irrigated cereal-based cropping systems in the Po Valley and Capitanata Plain case study areas. For the rainfed cereal-based production, all the consulted stakeholders ($n = 26$) identified crop rotation as the most adequate diversification strategy to be adopted in the intensive cropping systems of the Po Valley and Capitanata Plain case study areas. For the irrigated cereal-based production, two thirds of the stakeholders (66%) selected crop rotations as the most appropriate crop diversification strategy, while one third (33%) selected multiple cropping. Interestingly, for both the cropping systems, the consulted stakeholders did not identify intercropping as an adequate crop diversification strategy for the cereal-based production in the Po Valley and Capitanata Plain case study areas (**Figure 3A**). Regarding the irrigated cereal-based cropping systems, the number of respondents that selected crop rotation or multiple cropping as alternative diversification strategies were grouped per type of stakeholders. Although the results of Fisher's exact probability test combining the choice of crop diversification strategy with the type of stakeholders were not statistically significant ($p = 0.348$), 75% of the farmers and 80% of the public technical officers and researchers selected crop rotations as the most adequate option for crop diversification strategy. Conversely, private technical advisors equally chose crop rotation and multiple cropping (50%), while 100% of the technical experts from NGOs considered multiple cropping the most adequate crop diversification option (**Figure 3B**).

The results for crop rotation confirmed the findings of the literature review by Francaviglia et al. (2019, 2020), indicating that this practice is unambiguously considered as the most adequate alternative for crop diversification of the cereal-based production in Italy, while intercropping was not selected because it is a practice mainly adopted in other agro-environmental zones such as the humid conditions of the Atlantic and Boreal regions.

As stated by Francaviglia et al. (2020) longer crop rotations (more than 3-year) resulted in higher crop productivity compared to monoculture for both the rainfed and irrigated cereal-based cropping systems. In this context, Bonciarelli et al. (2016) observed an average yield increase of 18% in a long-term crop rotation of winter and summer cereals in rainfed conditions of Central Italy, while in the semiarid conditions of Southern Italy Martiniello et al. (2012) showed that crop rotations with legumes increased crop productivity both in the rainfed (48%) and irrigated conditions (37%) compared to wheat monoculture. The increase of crop yields due to longer crop rotations (3–5 years) also favours positive changes in SOC content. As reported in the data analysis carried out by Francaviglia et al. (2019), in Southern Italy, SOC changes in longer crop rotation can be 24.9% higher compared to the 2-year rotation or monoculture.

Once the preferred type of crop diversification was identified (i.e., crop rotation and multiple cropping), the surveyed stakeholders selected the most adequate crops (two crops as maximum) for the chosen type of diversification. **Table 9** shows the number of stakeholders that selected each type of diversification and diversification crop for both the rainfed and irrigated cereal-based cropping systems.

For the rainfed cereal-based cropping systems, most stakeholders agreed to introduce legumes in rotation. In detail, grass-clover mixture for fodder use was the most selected crop diversification alternative ($n = 19$), followed by rotation with faba beans, and alfalfa, with a similar number of responses ($n = 13$ and 12, respectively). Although the choice of crop and diversification strategy was not significantly related to the type of stakeholder (Fisher's exact probability test $p = 0.732$), grass-clover mixture for fodder use was mainly selected by farmers, private technical advisors, and public technical officers, while private advisors mainly chose faba beans and alfalfa (**Supplementary Table S3**).

TABLE 9 | List of the most adequate crops selected for each crop diversification strategy for both the rainfed and irrigated cereal-based cropping systems by the stakeholders (number of respondents).

Diversification crop	**Crop diversification strategy***		**No of responses**
	Crops in rotation	**Multiple cropping**	
Rainfed cereal-based cropping systems			
Grass-clover mixture	19	–	19
Faba bean	13	–	13
Alfalfa	12	–	12
Wheat	6	–	6
Protein pea	1	–	1
Spring-summer crop	1	–	1
Total answers	**52**	–	**52**
Irrigated cereal-based cropping systems			
Processing tomato	12	–	12
Wheat	3	5	8
Maize	6	–	6
Short-cycle maize	–	6	6
Hemp	–	2	2
Horticultural crops	1	1	2
Soybean	1	1	2
Sunflower	2	–	2
Barley	1	–	1
Barley, rapeseed or pea	–	1	1
Green manure mixed with legumes, cereals and brassicaceae	1	–	1
Sorghum	1	–	1
Total answers	**28**	**16**	**44**

Each stakeholder chose two possible crops for the type of diversification selected as more adequate. Fisher's exact probability test used for irrigated cereal-based cropping systems (p=0.000; *).*

For the irrigated cereal-based systems, significant differences were found between crop rotation and multiple cropping. Particularly, the results for the Fisher's exact probability test show a statistically significant relation between the crops and the preferred type of diversification (i.e., crop rotation and multiple cropping) identified by the stakeholder. In the case of crop rotation, processing tomato was the most selected rotation alternative ($n = 12$), followed by maize ($n = 6$), and wheat ($n = 3$). A full range of minority options was identified such as sunflower ($n = 2$) and horticultural crops ($n = 1$). For multiple cropping, the most chosen alternatives for crop diversification were short cycle maize ($n = 6$) and wheat ($n = 5$). Similarly to the rainfed cereal-based cropping systems, the choice of crop and diversification strategy was not significantly related to the type of stakeholder (Fisher's exact probability test $p = 0.618$; **Supplementary Table S4**). However, within crop rotation processing tomato was mainly selected by farmers and public technical officers, while researchers mainly chose maize and wheat. For multiple cropping diversification, short-cycle maize and wheat were mainly selected by representatives of NGOs and private technical advisors, respectively.

These findings confirmed some solutions on crop diversification strategies that are supported by the CAP in order to achieve the national sustainability targets of cropping systems at European level (Stoate et al., 2009; Passeri et al., 2016). Moreover, the most adequate farming practices that were selected by the stakeholders are consistent with the strategies proposed in the Agri-Environmental Schemes of several EU countries, the CAP and Rural Development Programs (RDPs), since the 1990s (Matthews, 2013; Turpin et al., 2016). In Italy, the last two programs of the European Agricultural Fund for Rural Development (EAFRD), funded through the regional RDPs, have often paid subsidies to farmers who have voluntarily committed themselves to the introduction of practices such as minimum tillage, green cover and cover crops, green manure, crop rotation, creation of buffer strips against erosion and leaching of nutrients (European Parliament and the Council, 2013).

4 CONCLUSION

Findings allowed to identify relevant strengths and drawbacks for the implementation of diversified cropping systems under low-input agricultural practices. A major strength is that the crop alternatives selected for the diversification are already cultivated as monocultures and are adapted to the local pedoclimatic conditions. Thus, farmers just need to learn how to use them in combination as rotations, multiple cropping, or intercropping.

In this context, RDPs have provided payments per hectare of agricultural area as financial support to favour the adoption of crop diversification strategies by farmers. Other financial support provided by RDPs are connected to the renewal of the machinery and tools, also when this option is useful for the implementation of low impact techniques especially for arable land preparation and sowing. The purchase of tools useful for the implementation of soil protection practices was encouraged through appropriate selection criteria, which rewarded farmers' projects aimed to improve farm environmental performances.

On the other hand, a major weakness is that few farmers are experts in crop diversification. Thus, providing adequate training for public officers and agricultural technical advisors is crucial for successfully implementing diversified cropping systems among farmers. Additionally, the identified low-input farming practices are easy to implement, are not costly, do not require major investments in new machinery nor great farming skills to learn them. This suggests a further significant potential for their implementation at the technical level.

These results can provide insights to support the planning of agricultural policies for sustain crop diversification in order to develop long-term strategies for the agri-food system at different scales.

In the RDPs definition, arable land diversification practices are included into the eco-schemes by the CAP National Strategic Plans. In this context, the stakeholder consultation and territorial features on agricultural needs should be considered more than in the past to tailor local-based solutions for crop diversification.

More in-depth analysis based on this method could support policy makers to distinguish easy to apply practices related to arable land farms from more complex ones that involve structural changes to the entire farm and cropping systems. This demarcation would allow to increase the rate of implementation of eco-schemes, considering production context features, and similarly to design voluntary measures for rural development suitable tailored for ambitious farmers that could lead further agro-ecological transitions towards sustainable and diversified agri-food systems in the production areas.

This step could be enriched by a more widespread field research activity, where long-term trials can allow technical and sociological new practices evaluation. In this context, building a network of field experiments within real farms should be supported. Looking at the new opportunities of the Horizon Europe program, specific funds should be dedicated to the creation of a research infrastructure based on a wide network of living-labs of crop diversification. The goal is to create opportunities for experiential and multidisciplinary dialogue between researchers, farmers' associations, citizens and agri-food chains operators.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**. The datasets generated for this study are available at https://zenodo.org/communities/diverfarming. Further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The study was conducted according to the ethical guidelines of the DIVERFARMING H2020 project (grant agreement 728003), which were approved by the Ethics Committee of the Universidad Politécnica de Cartagena and the European Commission (funder of DIVERFARMING). Informed consent was obtained from all subjects involved in the study.

AUTHOR CONTRIBUTIONS

Funding acquisition and supervision for Italy: RFa; WP leader of Selection of sustainable diversified cropping systems: MDG-L; task leader of data mining: RFr; task leader of mathematical calculation of the aptitude of each proposed alternative: JC; conceptualization: MDG-L, JC, CDB, and RFr; research design, methodology: MDG-L, JC, and DM-G; literature review: CDB, RFr, and EB; investigation: JC, MDG-L, DM-G, CDB, RFa, and RFr; survey adaptation and translation: CDB and RFr; data curation: DM-G; statistical analysis: JC and DM-G; multi-criteria analysis MDG-L; socio-economic and policy evaluation: EB; original draft writing: CDB, MDG-L, RFr, DM-G, and JC; writing review and editing: CDB, RFr, EB, and RFa. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.861225/full#supplementary-material

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