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Precision Farming: Barriers of Variable Rate Technology Adoption in Italy

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Abstract: Research dealing with the adoption of various precision agriculture technologies has shown that guidance and recording tools are more widespread than reactive ones (such as variable rate technology), with much lower utilization rates in European case studies. This study aims to analyze the propensity to innovate variable rate technologies among young Italian farmers. A cluster analysis was carried out revealing four groups. The first two groups represent non-adopters who think technological innovation is very complex from a technical point of view, as well as not very accessible as capital-intensive technology. The third and fourth groups represent adopters. The third reports an early level of adoption, still considering the cost of access a major barrier to technology implementation. The fourth, on the other hand, shows a more intensive level and considers the lack of institutional support a major limitation. The cluster with the most intensive adoption is characterized by the youngest age group, the farms with the largest size, and a prevalence of female entrepreneurs. The need for management training in day-to-day business operations upon adoption is detected for all groups. This paper identified relevant drivers and barriers in characterizing the adopting farm of variable rate technologies. Results may offer insights to the policy maker to better calibrate support interventions.

Keywords: variable rate technology; adoption; barriers; precision farming; innovation

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1. Introduction

The introduction of innovative technologies in agriculture has been studied for decades. Formerly, several studies have delved into the topic trying to understand which are the barriers or drivers to technology diffusion [1]; latterly, others have tried to model the adoption and implementation processes themselves [2]. The main purpose of these studies was not only to encourage their diffusion, but also to foster a change in business visions and in the way production activities are organized. This effort can also be seen in the institutional support, which over time has characterized itself as a promoter of technology diffusion and facilitator to close the gap between provider supply and user demand [3]. A paradigmatic consequence of this is the funding policies implemented by global agricultural policies, such as the Farm Bill in the United States (US) and the Common Agricultural Policy (CAP) in the European Union (EU). It is precisely the latter, in its latest programming, 2023–2027, that has paid special attention to the role of innovations as a fundamental tool to achieve the ambitious goal of "producing more, polluting less". In addition, a major chapter has been dedicated to the development of knowledge systems, or better known as Agricultural Knowledge Innovation Systems (AKIS), precisely to foster the diffusion of innovations, linked to economic support measures in rural development plans with the aim of simplifying access to technologies [4].

Among the innovations in agriculture, precision farming (PF) certainly plays an important role. PF originated in the US in the late 1980s and 1990s, then it spread globally. Conceptualized as "Precision Agriculture" or "Site Specific Management", it is also described as "Smart Farming" and "Digital Farming" as it is based on the use of smart technologies in agriculture and digital data management [5]. PF applies principles, technologies, and strategies for differentiated management of internal plot variability, studied considering the interaction between the spatio-temporal component, the type of cultivation, and farm-specific agronomic management [6]. Farming can be compared to a dynamic system, whose qualitative-quantitative production depends on the use of techniques that allow a variable application of inputs according to the actual needs of the crops and the chemical-physical properties of the soil. Underlying the application of PF tools is a preliminary study of both spatial and temporal variability, with the aim of identifying and quantifying the intensity of one or more parameters. In this way, "homogeneous zones" are identified, thanks to which differentiated management is implemented within the plot [7]. The resulting advantages are related to a better optimization of outputs, input rationalization, cost reduction, and environmental benefits [8].

Precision farming encompasses the use of numerous technologies that have spread to different parts of the world with varying degrees of use. Studies that have attempted to measure the take-up rate of different technologies in different countries tend to show that the adoption is higher for guidance (such as Global Navigation Satellite systems) or recording technologies (such as soil and yield mapping), rather than reacting ones (such as variable rate nutrients, seeding, and pesticides) [9,10]. Furthermore, many studies [10,11] confirmed that, on average, North American farms are more likely to use VRT than European farms.

Based on an extensive review of literature, our study aims to investigate the adoption of variable rate technologies (VRT) in Italy, for which, according to our study, there is a lack of research. In particular, the aim of this study is to characterize drivers and barriers of the adoption of VRT in Italy.

2. Theoretical Background

Variable rate application is a technology that finds application in agricultural operations, from tillage to harvesting. VRT "allows precise seeding, optimization on planting density and improved application rate efficiency of herbicides, pesticides and nutrients, resulting in cost reduction and reducing environmental impact" [12] (p. 13). Other applications are recorded in the field of weed control treatments, gypsum/lime application, and irrigation [13–15]. VRT represents the idea of precision agriculture well, by managing primary production based on the needs of the soil, the land, and the crops that are grown. VRT can be map- or sensor-based [15]. VRT based on the use of prescription maps (produced before the operations) varies the amount of product to be distributed according to the information in the prescription maps, which are the result of data from different acquisition systems (e.g., yield map, agronomic indices, satellite images, meteorological data, soil sampling, etc.). The other VRT methodology uses "on-the-go" sensors, which detect in real time during the operation the chemical characteristics of the soil and the phenological state of the crop. These data are sent to the reprocessing unit from which feedback is given to the actuator on the amount of input to be spread. Distribution therefore takes place by homogeneous zones, each of which corresponds to a precise dose: the on-board computer controls the actuator (hydraulic or electric), which will modulate the opening damper or the volumetric regulation system based on the different management zone [16].

Even though there are no global assessments of VRT use rates in the literature, Finger et al. [10] and Maloku [11] confirmed that, on average, North American farms are more likely to use VRT than European farms. In North America, on average the rate of use is 17% greater than in Europe, according to Nowak [17]. In the European market, Germany, Denmark, and the Netherlands were first countries interested to use this technology [18], while the Mediterranean countries have only recently begun to see the introduction of these instruments. Delving into the literature, most studies have been conducted in America.

In the United States [19,20], VRT utilization rates hardly exceed 40%. Other studies, although residual, have been conducted in Florida, Alabama [21], and Kansas [22], where higher utilization rates are also recorded. Some studies have been carried out in the UK with utilization rates from 8% [23] to 16% [24], even based on the different variable rate application (fertilization, seeding, etc.) for different production orientations [25]. Other studies have been conducted in Australia, with variable rate technology utilization rates averaging 20% [15] or higher [26]. In Europe, we find studies conducted in Germany, Sweden, France, the Netherlands, Belgium, and Denmark [11]. Reichardt and Jürgens [27] reported during 2001–2006 that approximately one out of five PF adopters used VRT in Germany. In Denmark, the rate of VRT use across studies ranges from 7% to 37% [26–28].

According to Nowak [17], the variable rate application has grown at a slower rate compared to other PF technologies. Sunding and Zilberman [29] state that there is a significant latency between the introduction of an innovative technology into the market and its widespread use by farmers, so its adoption is not immediate. Several types of barriers to the adoption and diffusion of technological innovations have been cited [30], some of which focused on VRT [13–15].

The first barrier is economic and can be attributed to the high initial costs and subsequent training and tool implementation costs that end-users should bear [31,32]. Indeed, studies identified larger operators as more willing to adopt VRT given their capacity to absorb costs [33,34]. However, researchers [1,26,35] also showed a positive association between farm profits and VRT adoption, also underlined possibilities to reduce costs (i.e., when adopting VRT together with soil mapping).

In addition to economic barriers, there remain socio-economic, organizational, institutional, behavioral barriers [36,37]. Innovation can be influenced by socio-economic factors such as the user's age, education level, gender, and degree of information [38,39]. Younger, better-educated, more knowledgeable about the costs and benefits of PF, and more optimistic farmers were more likely to utilize VRT [16].

Furthermore, the business organization and work intensity could not be compatible with the application of new technologies [40]. Limits to VRTs adoption have been technical issues related to equipment and software, access to services, and lack of compatibility of equipment with existing farming operations [15,31].

The institutional context itself can influence these choices. Literature describes physical barriers related to the agroecological context in which the new technology might operate. In fact, different VRT adoption rates can be identified based on the different agro-meteorological characteristics of an area [15,41], as well as on the basis of the type of cultivation [33]. Cultural barriers (i.e., habits, consumer choices, market uncertainty) [42,43], as well as limited institutional support [44] have been identified. Subsidies, as well as more indirect interventions such as information support can lead to increased adoption of VRT [1,34]. For example, Evans et al. [14] confirmed the importance of economic incentives to motivate growers to move to higher levels of variable rate irrigation adoption.

Vecchio et al. [37,39] also describe barriers related to the cognitive sphere, emphasizing the importance of the farmer's perception, which is now no longer linked only to risk appetite or the expected benefits of technologies. Indeed, it is with the term "perceived complexity" that these authors encapsulate the most influential barriers in the adoption process. Other authors recall how the farmer's perception in fact produces a positive or negative attitude towards adoption [45], which is often shaped by the socio-economic characteristics of the individual [46] and the social systems in which the technology operates. In this sense, more research to understand group behavior and collective action is required [44,47].

Table A1 (see Appendix A) reports some of the most highlighted studies in literature on VRT adoption.

This paper aims to understand whether there are conformations of farms that are more likely to adopt such VRT, through the study of farm types. The purpose is to identify the most common barriers and drivers and characterize the profile of the "adopting farm" in order to provide insights to the policy maker to better calibrate support interventions for PF diffusion.

3. Materials and Methods

3.1. Data Collection

The study was conducted through the administration of a questionnaire to young farmers (under 40 years old) at a conference held in Bologna in October 2022 dedicated to precision farming. The conference was organized in collaboration with the largest representative organization of farmers at an Italian and European level, and therefore the representation of the population that took part is guaranteed. However, the choice of respondents was random and participation in the survey was voluntary (after reading a consent form). This questionnaire is part of research conducted by the University of Bologna, at the School of Agriculture and Veterinary Medicine, in collaboration with Coldiretti and is aimed at investigating the main determinants of access to VRT. The survey carried out aimed to take a snapshot of several farm realities in Italy. The questionnaire was designed to provide a sufficiently broad overview of the various farms analyzed.

The survey consisted of two thematic sections, as follows:

- Section 1. Demographic and personal characterization: dedicated to investigating the socio-structural characteristics of the farms.
- Section 2. VRT adoption: in particular, it investigated obstacles to innovation adoption, the automation/innovation ratio, training needs, and attitude towards sustainable intensification.

Before the administration, a pilot test was carried out to improve interview questions. A total of 205 questionnaires were collected, of which, however, only 174 were deemed sufficiently complete and thus usable for analysis purposes from different regions represented in Figure 1. The distribution of interviewed farms is representative of the Italian farm distribution, according to the last census of Istat [48].

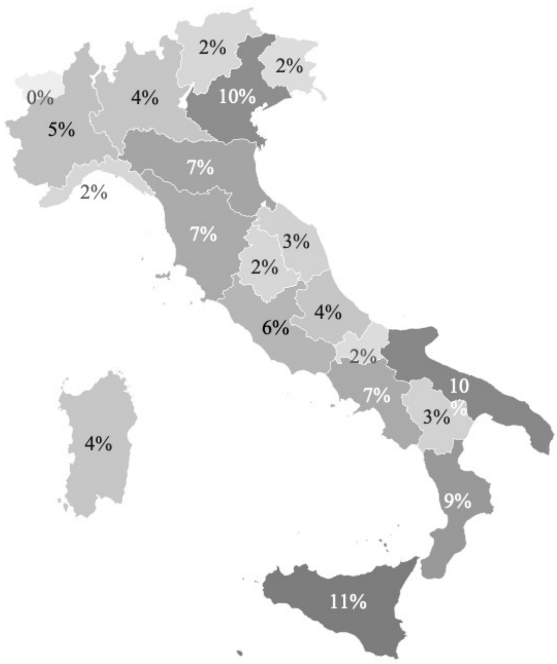

Figure 1. Geographical representation.

The sample was selected using non-probability sampling approaches, namely convenience sampling techniques [49].

The need stems from having identified companies that were familiar with VRT technology to have answers based at least on awareness of the technology's existence. This allows for opinions based on knowledge or experience to identify drivers and barriers from informed individuals [2]. Then, data analysis was performed.

The research process is reported in Figure 2.

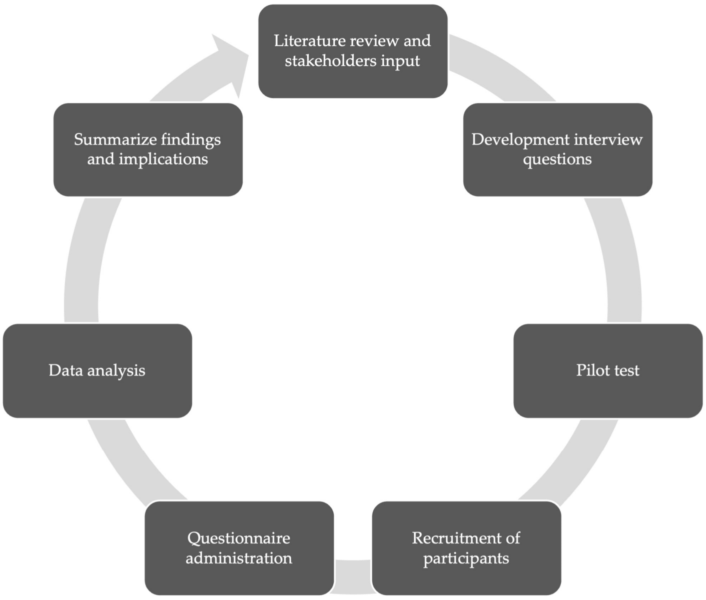

Figure 2. Research process.

3.2. Data Analysis

The analysis is divided into two parts: a first descriptive part and a secondary part in which a cluster analysis was applied to identify different farm types. The first part of the analysis is descriptive in nature as it provides information about the characteristics of the entrepreneur and the farm. The cluster analysis represents the second part. This analysis is used to compress a set of multivariate statistical units within classes that are not defined a priori, with the goal of reducing the complexity of the original information while preserving its significant components and forming groups that are as homogeneous within themselves as possible while being as heterogeneous with respect to the characteristics measured. In other words, the goal of the analysis is to minimize the logical distance inside each group while increasing the gap between groups using similarity/dissimilarity measurements. To classify the groups, a two-step cluster analysis is used. The distance metric is log-likelihood [50], and the automatic clustering criterion is the Akaike Information Criterion (AIC) [51]. This Information Criterion compares the model's probability distribution f to the actual distribution g. The equation describes it:

This is example (1) of an equation:

$$\mathrm{AIC} = 2k - 2\ln(L), \quad (1)$$

where k is the number of statistical model parameters and L is the maximum value of the likelihood function of the estimated model. Clustering factors include the following variables (Table 1).

Table 1. Active variables of the cluster analysis.

Variable	Type
Gender	Binary
Age	Qualitative (1 = ≤24 years, 2 = 25–28 years, 3 = 29–33 years, ≥4 = 34 years)
UAA (Utilized Agricultural Area)	Quantitative

Table 1. *Cont.*

Variable	Type
Work intensity	Quantitative
Business diversification	Binary (Yes = at least 2 different crops, No = specialized)
Obstacles	Qualitative (1 = initial cost, 2 = farm size, 3 = human capital, 4 = institutional barriers)
Automation-employment ratio	Qualitative
Using VRT	Qualitative (1 = Already in use, 2 = No, but I intend to proceed in this direction, 3 = No, I don't want)
Training	Qualitative (1 = relational, 2 = management, 3 = technical and managerial)
Sustainable intensification	Qualitative (1 = Not oriented; 2 = Non-adopter, but oriented; 3 = adopter of sustainable strategies)

The cluster analysis was carried out using SPSS v28.

4. Results

As shown in Table 2, the sample consists of 78% of male respondents and 22% of female respondents. This is in line with the national figure in which an average of 28% of Italian farms are headed by a female holder [48]. The average UAA of the sample is 27 ha with an average labor intensity of 13 days per hectare of Utilized Agricultural Area (UAA). With regard to age, 28.2% of the respondents are in the ≤24 years group, 24.7% 25–28 years, 24.1% 29–33 years, 23% ≥34 years. The most common productive orientations are fruit and vegetables (31%), followed by arable crops (17%), wine (16%), livestock (14%), and olive (11%).

Table 2. Descriptive analysis.

Variable	Descriptive Analysis
Gender	78% male, 22% female
Age	28.2% of the respondents are in the ≤24 years, 24.7% 25–28 years, 24.1% 29–33 years, 23% ≥34 years
UAA	27 hectares on average
Work intensity	13 days/hectare on average
Main production	31% fruit and vegetables, 17% arable crops, 16% wine, 14% livestock farming, 11% olive, 5% agriculture-related activities, 4% floriculture, other 2%

The cluster analysis identified four typological groups (Table 3), which are relevant to assess the propensity to use variable rate technologies for the present study. The variables used for the purposes of the analysis are both the structural variables of the sample and those specific to the PF.

Table 3. Cluster analysis of the sample.

Variable	CL 1 (33.1%)—Potential Adopter of VRT	CL2 (22.1%) Sustainable Farm and Future VRT Adopter	CL 3 (31.6%) Early Adopter	CL 4 (13.2%) Adopter
Gender	Male majority (86.7%)	Male majority (86.7%)	Male majority (81.4%)	Female majority (51%)
Age (years)	≥34	29–33	25–28	≤24
UAA (ha)	21.11	35.67	8.36	52.75

Table 3. *Cont.*

Variable	CL 1 (33.1%)—Potential Adopter of VRT	CL2 (22.1%) Sustainable Farm and Future VRT Adopter	CL 3 (31.6%) Early Adopter	CL 4 (13.2%) Adopter
Work intensity (days/ha)	11.9	8.11	19.92	10.56
Business diversification	present	present	absent	present
Obstacles	Cost of access	Cost of access	Cost of access and farm size	Institutional (regulations, absence of institutional support, low local diffusion of technologies, etc.)
Automation-employment ratio	Reduced manual labor, increased skills	Reduced manual labor, increased skills	Technology will improve productivity while keeping factors of production the same	Technology will improve productivity while keeping factors of production the same
Using VRT	No, but he intends to proceed in this direction	No, but he intends to proceed in this direction	Already in use	Already in use
Training	Management and technical	relational, management, technical and managerial	Relational, management and managerial	Management
Sustainable intensification	Willingness to proceed in this direction	Implementing actions	Implementing actions	Implementing actions

Cluster 1 (CL1) has a size of 33.1% and almost the entire sample includes men (86.7%) aged ≥34 years. About land tenure, it emerges that the most frequent category within CL1 was that of a farm size of 21.11 hectares UAA. From the analysis of the first farm production, it emerges that the CL1 respondents are for the most part involved in fruit and vegetable production and have a second production. The analysis shows that farmers dedicate an average of 11.9 working days per hectare of UAA to these activities. This value is referred to as the "labor intensity index", which is an indicator of the time spent in agriculture, commensurate with the total UAA and production orientation. It is calculated by dividing the total number of working days performed on the farm, whether by family members, the holder, or third parties, by the total UAA. As pointed out by De Rose [52], this indicator is very important as it allows us to distinguish the areas where manual labor continues to be an important component of the production process in agriculture from the areas where it has been more widely supported by automation. This cluster, aware that new technologies can contribute to a greater efficiency in the use of resources and a reduction in the impact on the environment, expresses the intention to move towards the direction of sustainable intensification. For these reasons, CL1 best represents the type of "Potential adopter of VRT", the group's identifying name. To substantiate this, they would like in the future to take part in the process of sustainable transition that agriculture is undergoing. In this context, we move on to assess the effects of such innovations on business cost management, labor, and agricultural employment. The members of this group agree that in the face of new changes and innovations in agriculture, technology will lead to a reduction of manual labor on the farm and induce the reconversion of some professional skills. In fact, it is a common idea among those interviewed that this technological evolution would lead to the emergence of new specialized and skilled professionals in PF which describes them as bringing new business functions and value to the farm. To adapt to this evolutionary process, they manifest important training needs from a technical and managerial point of view, as this is the only way they will be able to fully understand and exploit the benefits of these technologies. In CL1, the cost of access to PF techniques is confirmed as an obstacle,

while small farm size, institutional barriers (i.e., regulations, lack of subsidies), and human capital are not considered as such.

Cluster 2 (CL2) is less numerous (size 22.1%), brings together farmers aged between 29 and 33, and shows a male prevalence of 86.7%. The type of farm that stands out as the most frequent in the cluster is a mixed one and recognizes arable crops as the primary production. This is confirmed by the high surface area of 35.67 hectares. Labor intensity was 8 average days per hectare. CL2 believes in the potential of PF technologies but does not apply VRT principles. This group also confirms itself as a potential adopter, but with an additional requirement. Indeed, it is already oriented towards the issue of sustainable intensification in agriculture, which is why it is called "Sustainable farm and future VRT adopter". The CL2 already embraces the choice of sustainability in agriculture and plans to move towards the use of VRT. Faced with the effects of technological developments, this group believes that there will be an erosion of agricultural employment in favor of the rise of new professionals and new skills. To realize this transition, it is essential to promote training processes, and in particular the CL2 expresses the desire to update and improve the management and managerial side of the business, as well as the technical and relational side with the various actors in the supply chain. Counteracting the strong propensity to innovate of this group are the high costs of access, which prevent most of the cluster's respondents from benefiting from these techniques.

Cluster 3 (CL3) has a size of 31.6% and a male prevalence of 81.4%, with an age between 25 and 28 years. As far as land structure is concerned, the smallest farm type is noted as it is characterized by 8 hectares of UAA. The most frequent production within CL3 was fruit and vegetables and there is no business diversification. The labor intensity is 19.92 average days per hectare of UAA. The CL3 believes that technology will enable them to improve productivity while keeping the factors of production the same, in fact they are already oriented towards a more innovative and sustainable agriculture. This group represents VRT users. To carry out an effective innovation process on the farm, they need relational, managerial, and management training. Moreover, in CL3, both the cost of access and the small size of the farm are confirmed as obstacles. For all these reasons, they have been referred to as "early adopters", a term used in the literature to define companies and users at an initial state of use [53]. CL3 represents users of these technologies, but probably there is not yet a full application of these, partly due to the characteristics of the group itself, partly due to the current agricultural context that struggles to integrate small businesses into the sector's innovation process.

Cluster 4 (CL4) has a size of 13.2% and is the most heterogeneous group. In fact, 51% of the sample is made up of females and the most frequently detected age group is ≤24. The farm type most present within CL4 was mixed-oriented, with primary production being linked to arable farming. Consistent with primary production, labor intensity was 10.5 average days per hectare, which, as Colotti et al. [54] reported, is in line with the national average of 19.6. It is probably linked to an agricultural context where manual labor is already integrated with automation techniques. This is confirmed by the fact that they are users of variable rate technologies. For this reason, the type that best defines the cluster is that of "Adopter". CL4 is already oriented towards following a process of sustainable intensification of the sector. Faced with the effects of technological developments, this cluster believes that new technologies will improve productivity while keeping the factors of production, such as labor itself, unchanged. Regarding this, they state that they have no training needs, neither of a technical nor managerial or relational nature, but that they need management training in order to be able to fully exploit technology in the governance of a large farm. While training does not appear to be a major obstacle to the use of these technologies, the institutional one does, which certainly involves a gradual but necessary adaptation of farms in the face of new legislative processes in the field of innovation. Among institutional barriers, they recognized the low diffusion of VRT in their geographical area, and lack of economic support to undertake technical transition. The presence of fewer barriers and the overcoming of the economic barrier could point to a more intensive level of technology use within this group.

5. Discussion

From the results produced by the cluster analysis, socio-demographic factors have a strong influence on whether variable rate techniques are adopted; in particular age, for which two groups can be distinguished: CL1 is the group of those inclined to use VRT, with a more mature sample, while CL4 represents the users, with a younger one. These results are in line with the literature, in which it is underlined that younger farmers have been described as major adopters of VRT [16]. Although the questionnaire was administered to a very young public, this parameter proved to be very discriminating, and it was the youngest who turned out to be the greatest users of these techniques. As far as gender is concerned, on which the research evidence is lacking for PF and VRT adoption, it is interesting to note that the largest sample of women fell into CL4, which represents the group of more intensive adopters of the analysis. The others showed a strong male predominance. According to the previous literature review there is no clear evidence about the influence exerted by gender on the propensity to adopt VRT.

Also discriminating is the farm surface area and to a lesser extent the labor intensity applied to it. As far as farm size is concerned, it is a major obstacle for CL3, consistent with their actual size, which is the smallest among groups (8.36 hectares). In contrast, CL4 represents the highest farm size (52.75 hectares). This relation for VRT adoption studies has been confirmed by Hanson et al. [33] and Townsend and Noble [34]. Contextualizing our values, it is important to emphasize that in the Italian context, the average UAA is 8 [52].

The first three groups, or more generally those who have not adopted or represent early adopters, report the cost of access to VRT as an obstacle, especially for small farms, as the literature i.e., [33] also highlighted. The lowest values of labor intensity are shown in CL4, which in relation to the large farm size, suggests a strong presence of new innovative technologies that have supported everyday practices in the production process. This index of labor intensity, however, is linked to context specifics, as Vecchio et al. [37] reported and in this case to the production order of the respective groups, which are characterizing. The inclined (CL1 and CL2) and the users (CL3 and CL4), can also be distinguished by their thoughts on the automation-employment relationship: the former's view is that manual labor will be reduced in favor of an increase in more skilled professionals, the latter's view is already more focused on the role of technology that will improve productivity and keep the factors of production unchanged. The risk of reducing farmers' employment with the introduction of PF tools was highlighted by Jochinke et al. [55]. Thus, a very positive approach towards the innovation process emerges, already rooted in the user groups, who have already oriented themselves and adapted all factors of production to the change.

The variable "training" proved to be characteristic for all groups. There is a strong lack of technical and management training for all groups, as studies such as Pederson et al. [31] reported, except the CL4, where only the latter is lacking.

Furthermore, clusters also showed different perceptions about barriers related to VRT adoption. The cost of access to technologies is reported by the first three clusters as a limitation to the application of these techniques, as many studies reported [34]. Farm size represents a major obstacle for CL3; in contrast, in CL4, the obstacles arise in relation to regulatory processes or lack of institutional support, considered as limiting the integration in the innovation process in agriculture. The absence of institutional support has been well highlighted in VRT adoption studies [14,44].

6. Conclusions

This work explored the topic of PF, and specifically the adoption of VRT, which aims to "do the right thing, at the right time, at the right place" [56]. The use of PF, which undoubtedly concerns the application of a series of innovative technologies, leads to a series of benefits of an economic nature, a reduction in environmental impact and farmers, who receive considerable support in business management [57,58].

PF is often associated with VRT, as it is one of the first adopted among technologies by many farmers, but at a slower pace. In fact, its uptake now rarely exceeds 20% among different studies, especially in European countries. Some causes are to be found in the low mechanization of European farming systems (especially for SMEs), in the initial costs, and in the complexity to understand uptake benefits [9].

This paper could contribute to enriching this research field. The cluster analysis shed light on the major trends and needs in relation to the willingness of Italian young farmers to adopt VRT. In particular, the study reinforces some of the barriers already noted in the literature, such as those related to the need to receive training, those linked to compatibility with the farm workforce and the cost of access to technology. Furthermore, it highlights the role that female entrepreneurship could play in the dissemination of these technologies, on which the literature is still very deficient.

This study supports the need to investigate beyond the causes of low adoption of these technologies, given that European strategies themselves, as well as the scientific community, e.g., [59], manifest the need to incentivize the diffusion of climate smart technologies among farmers. In this sense, a greater adoption of VRT could help farmers to cope with the effects of climate change through timely monitoring of the real needs of plants and soil. Furthermore, from the present work emerges the need for a policy intervention at different levels to favor the technological transition with a view to the sustainability of Italian farms. In some cases, as suggested by Masi et al. [60], it will be necessary to facilitate training and to exploit information flows, encouraging the creation of professionals specialized in supporting farms. Promoting the diffusion of technologies to expand the market and make them accessible also to small and medium size farms is another political challenge that arises in order to achieve the European objectives in the field of sustainability.

The limitations of the study relate to the fact that it focuses on the adoption of only one precision farming technology, and it is focused on a very young sample of farmers. Furthermore, being a study aimed at defining farm typologies, the focus was on all those characteristics that define the farm, leaving out the external context, such as the effect of institutional policies (such as rural development policies) which may have favored the introduction of innovative technologies through economic support. In order to develop a more complete study, future developments should indagate other aspects: (i) the influence exerted by different context-related factors in the multistage process of VRT adoption; (ii) understand which could be the best strategies and the most suitable tools to adopt to achieve sustainable transition; (iii) policy effects, as well as those one of public and private partnerships for the diffusion of innovation in the Italian territory should be considered.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Studies dealing with VRT adoption.

Authors	Title	Journal	Focus
Hanson et al., [33]	The adoption and usage of precision agriculture technologies in North Dakota	Technology in Society	This paper explores the adoption of automatic section control, Global Positioning Systems and autosteer, satellite imagery, variable rate nitrogen application, and variable rate seeding by farm operators in North Dakota.
Townsend and Noble, [34]	Variable rate precision farming and advisory services in Scotland: Supporting responsible digital innovation?	Sociologia Ruralis	This study explored the role of advisors in supporting the adoption of variable rate precision farming in Scotland.
Nowak, [17]	Precision Agriculture: Where do We Stand? A Review of the Adoption of Precision Agriculture Technologies on Field Crops Farms in Developed Countries	Agricultural Research	This review provides a start of art of adoption of PF technologies in developed countries, including variable rate application (soil mapping, variate rate fertilizing, and variable rate seeding).
Erickson et al., [61]	Precision Agriculture dealership survey	/	The work involves a survey of crop input dealers on precision agriculture technologies in the US, who were asked questions about how they use PF within their business, what products and services they offer their customers, adoption, and constraints.
Griffin and Traywick, [62]	The Role of Variable Rate Technology in Fertilizer Usage	Journal of Applied Farm Economics	Study highlights barriers to adoption of VRT for fertilization, exploring new opportunities for market expansion.
Maloku, [11]	Adoption of precision farming technologies: USA and EU situation	SEA practical application of science	Review case studies reporting the adoption rate of VRT in USA and EU.
Ofori et al., [63]	Duration analyses of precision agriculture technology adoption: what's influencing farmers' time-to-adoption decisions?	Agricultural Finance Review	Over 300 Kansas companies were monitored from 2002 to 2018 to study the relationship between PF technology adoption factors (global navigation satellite system, yield monitors, variable rate fertility, soil sampling, automated guidance and section control, light bar) and time to adoption.

Table A1. *Cont.*

Authors	Title	Journal	Focus
Finger et al., [10]	Precision Farming at the Nexus of Agricultural Production and the Environment	Annual Review of Resource Economics	This article studies the economics of PF, as well as its adoption and spread, and its implications on the environment, from the point of view of both farmers and policy network.
Miller et al., [64]	Farm adoption of embodied knowledge and information intensive precision agriculture technology bundles	Precision Agriculture	The study predicts the chances of embedded knowledge technologies, information-intensive technology bundles, and variable rate technologies being adopted throughout time.
Bramley and Ouzman, [65]	Farmer attitudes to the use of sensors and automation in fertilizer decision-making: nitrogen fertilization in the Australian grains sector	Precision Agriculture	This study assesses the Australian cereal growers' attitudes towards yield monitors, remote and proximal crop sensing, high resolution soil sensing, soil moisture sensing, and digital elevation models for the nitrogen fertilizer management in Australia.
Medici et al., [66]	Environmental benefits of precision agriculture adoption	Economia Agro-Alimentare	This review brings together studies that deal with the environmental benefits of adopting PF solutions in order to raise awareness among farmers.
Lowenberg-DeBoer and Erickson, [9]	Setting the record straight on precision agriculture adoption.	Agronomy Journal	The analysis found that adoption rates for PF equipment range greatly, with guidance technologies becoming common practice in most mechanized agricultural systems around the world and VRT fertilizer behind in most cropping systems.
Thompson et al., [67]	Farmer perceptions of precision agriculture technology benefits	Journal of Agricultural and Applied Economics,	This research deepens the perception about PF (in terms of perceived benefits) of variable rate fertilizer application, precision soil sampling, guidance and autosteer, and yield monitoring.
Barnes et al., [1]	Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers.	Land Use Policy	This study empirically examines the adoption of automatic guidance and variable rate nitrogen technologies in European agricultural systems.

Table A1. *Cont.*

Authors	Title	Journal	Focus
Zhou et al., [41]	Precision farming adoption trends in the Southern U.S.	Journal of Cotton Science	The study focuses on US Southern cotton producers; the objective was to evaluate the temporal trends and geographical patterns of the adoption of PF technologies (information gathering, the global positioning system, variable rate, and automatic section control technologies).
Schimmelpfennig and Ebel, [35]	Sequential adoption and cost savings from precision agriculture.	J. Agric. Resour. Econ.	The study determined whether and when VRT contributes to extra manufacturing cost savings.
Schimmelpfennig, 2016 [26]	Farm profits and adoption of precision agriculture. Economic Information Bulletin No 80. Economic Research Service (ERS), United States Department of Agriculture (USDA).	/	In this report, the factors influencing PF technology (GPS computer mapping, guidance system, and VRT) adoption rates and the impact of adoption on profits are studied.
Evans et al., [14]	Adoption of site-specific variable rate sprinkler irrigation systems	Irrigation Science	This paper provides a historical overview of the commercial evolution of variable rate irrigation technology and some of the barriers to adoption.
Robertson et al., [15]	Adoption of variable rate fertiliser application in the Australian grains industry: status, issues and prospects	Precision Agriculture	This paper deals with the extent of VRT adoption for fertilizer for grain industry in Australia.
Kotsiri et al., [20]	Farmers' Perceptions about Spatial Yield Variability and Precision Farming Technology Adoption: An Empirical Study of Cotton Production in 12 Southeastern States	/	The purpose of this paper is to investigate how cotton farmers' perceptions of spatial yield variability influence their decision to use precision farming technologies.
Reichardt & Jürgens, [27]	Adoption and future perspective of precision farming in Germany: results of several surveys among different agricultural target groups	Precision Agriculture	The report tracks how PF approaches have penetrated the German market over time and geography. Farmers were asked about their experiences using PF technology, as well as their perspectives and challenges with it.
Larson et al., [16]	Factors affecting farmer adoption of remotely sensed imagery for precision management in cotton production.	Precision Agriculture	This paper studied decisions made by cotton farmers in USA who used remotely sensed imagery for VRT application inputs, analyzing factors influencing adoption.

Table A1. *Cont.*

Authors	Title	Journal	Focus
Torbett et al., [13]	Perceived importance of precision farming technologies in improving phosphorus and potassium efficiency in cotton production.	Precision Agriculture	This study identifies factors influencing farmers' perceptions of the importance of PF technologies in improving the efficiency of variable rate applications of phosphorous and potassium fertilizers. The analysis was conducted in the south-east regions of USA.
Roberts et al., [68]	Adoption of site-specific information and variable-rate technologies in cotton precision farming.	Journal of Agricultural and Applied Economics	The analysis identified the determinants of the adoption of site-specific technologies by cotton farmers in the south-east of USA.
Surjandari and Batte, [69]	Adoption of variable rate technology	Makara Journal of Technology,	The study investigates how producer and field characteristics may differently influence the decision to adopt the variable rate for fertilizer application for grain production in Ohio.
Isik and Khanna, [70]	Uncertainty and spatial variability: incentives for variable rate technology adoption in agriculture.	Risk, Decision and Policy	The incentives for using a technology that provides information about geographical variability in nutrient availability and enables variable rate fertilizer delivery are examined in this study. It investigates the effects of uncertainty regarding the technology's accuracy on input application and adoption decisions.
Khanna, [71]	Sequential adoption of site-specific technologies and its implications for nitrogen productivity: A double selectivity model	American Journal of Agricultural Economics	This paper analyzes the sequential decision to adopt site-specific technologies (soil testing and variable rate technology), and the impact of adoption on nitrogen productivity.
Pedersen et al., [31]	Adoption and perspectives of precision farming in Denmark.	Acta Agriculturae Scandinavica, Section B-Soil & Plant Science	This paper addresses bottlenecks of adoption, in terms of profitability and environmental impact and use of PF tools in Denmark. Among the PF tools: yield and soil mapping, variable rate fertilizer application, variable rate lime application, variable rate spraying application, variable rate manure application, variable rate seed application, weed mapping, and electromagnetic monitoring.

Table A1. *Cont.*

Authors	Title	Journal	Focus
Fountas et al., [28]	Farmer experience with precision agriculture in Denmark and the US Eastern Corn Belt.	Precision Agriculture	The study investigates the experience of using PF equipment and software, data management, the value of data for decision-making, changes in management strategies, preferred services and information, and the next expected step in PF implementation. The study included farmers from Denmark and the United States' Eastern Corn Belt. Among PF tools: Yield mapping, soil sampling with GPS, electromagnetic monitoring, variable rate manure/fertilizer/seed/lime/pesticide applications, weed mapping, variable tillage applications, and remote sensing applications.

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