

Benefits and Limitations of Decision Support Systems (DSS) with a Special Emphasis on Weeds

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Abstract: Decision support systems (DSS) have the potential to support farmers to make the right decisions in weed management. DSSs can select the appropriate herbicides for a given field and suggest the minimum dose rates for an herbicide application that can result in optimum weed control. Given that the adoption of DSSs may lead to decreased herbicide inputs in crop production, their potential for creating eco-friendly and profitable weed management strategies is obvious and desirable for the re-designing of farming systems on a more sustainable basis. Nevertheless, it is difficult to stimulate farmers to use DSSs as it has been noticed that farmers have different expectations of decision-making tools depending on their farming styles and usual practices. The function of DSSs requires accurate assessments of weeds within a field as input data; however, capturing the data can be problematic. The development of future DSSs should target to enhance weed management tactics which are less reliant on herbicides. DSSs should also provide information regarding weed seedbank dynamics in the soil in order to suggest management options not only within a single period but also in a rotational view. More aspects ought to be taken into account and further research is needed in order to optimize the practical use of DSSs for supporting farmers regarding weed management issues in various crops and under various soil and climatic conditions.

Keywords: decision support systems (DSSs); weed management; herbicides; eco-friendly strategies

1. Introduction

Decision support systems (DSS) for agriculture are systems which provide information resources to contribute to farmers' decision making, by integrating various forms of information required for growing crops [1]. Many types of data can be collected, organized and analyzed in order to set crop production strategies which are more environmentally friendly and profitable, as compared to the conventional ones [2]. Expert knowledge, management models, timely and accurate data and continuous feedback after every cultivation period are among the key factors affecting DSSs' effectiveness and are often used to provide farmers with either short- or long-term crop growing decisions [3]. The first step for the function of a DSS designed for use in agriculture includes the collection of data from the environment where the crop is grown. Such data might refer to climatic conditions, crop growth parameters or the presence of pests and weed flora composition and density. Then the incorporated models in the DSS analyze the data and rank a list of suitable treatments for each case. DSS models can include rules, tips, schedules of management, mathematical equations and combinations of decision aids [4]. For instance, one DSS can suggest the use of a fertilizer, rank a list

for pest or weed control treatments or even suggest the integration of both chemical and non-chemical-based practices in favor of crop development and productivity. The type and merely the success of a DSS is determined by the cooperative efforts of a team of experts, the availability of technical and financial resources, the degree of industry organization and farmers' involvement and the demands of crop growers [5].

Weeds are considered to be very competitive and adaptable to a wide range of environments. It has to be noted that weed infestations are the reason for a 5% loss in agricultural production in most developed countries, a 10% loss in less developed countries and a 25% loss in the least developed countries [6]. Moreover, the consumption of herbicides represents approximately half of the total amount of pesticides used every year, with chemical control remaining one of the most effective agronomic practices against weeds. However, important issues have arisen regarding herbicide use such as crop injury, residues in water and soil, toxicity to non-target organisms, concerns for human health and the rapid development of herbicide resistant weed populations [7–11]. Consequently, researchers seek for the development of alternative methods which can decrease herbicide use in weed management. Targeting weed control over a whole crop rotation scheme, through achieving maximum benefits from a combination of both agronomical and chemical control practices, may also help to substantially reduce the overall cost of agricultural production [12]. Herbicide inputs should be reduced and this can be achieved only with integrated weed management systems and, particularly, the successful consideration of the actual weed flora within an individual field along with information regarding not only the interference between crops and weeds but also the soil and climatic conditions of an agricultural area [13]. Therefore, it is crucial to convince farmers to look long-term and focus on the various benefits of such a strategy rather than the risks.

Several authors have introduced models of weed populations in order to determine the economic thresholds for sufficient weed control [14,15]. This issue is at the same time crucial for decision making and complicated since there are many interactions and factors involved. In all cases, attempts to set thresholds for weed control treatments have been made during recent years [16–19]. The majority of these models has been research tools intended to provide information for use by DSSs. Making weed management decisions is often a challenging process, especially due to the involvement of several and various factors, parameters and their interactions. Lately, there has been growing interest in the use of DSSs to make these tools directly accessible by farmers and advisors or consultants. Several DSSs have been designed for weed management in a global range. DSS methodologies can predict the expected yield losses due to competition between weed and crops, identify weed patches within a field and give advice for the optimum dose rates and timing regarding herbicide applications. DSSs can define whether a chemical treatment is necessary and suggest reduced dose rates of herbicides offering feasible options for efficient, economically acceptable weed management with respect to the environment [20]. In Europe, the number of crops where the performance of DSSs has been tested ranges from 1 to 30. The Danish Crop Protection Online-Weeds and the Dutch Minimum Lethal Herbicide Dose [21,22] have been efficiently tested in situ and they provide useful information regarding the composition of weed flora and the abundance of actual weed populations within a field. In Denmark, more than 30 crops and 100 weed species were investigated by means of the DSS “IPMwise” and suggestions for herbicide applications along with recommendations for non-chemical weed control were made [23]. There is clear evidence that herbicide inputs can be decreased in major crops by applying herbicides according to the suggestion of such DSSs [24,25]. Both farmers and advisors can significantly benefit from the use of a DSS for weed control. In particular, farmers can get specific and tailor-made solutions for each field if the weed flora is monitored, and the advisor can make a set of more variable advices with limited time consumption. However, up to now, DSSs have not been widely adopted in weed management and crop protection. The aim of the current study is to evaluate the potential and also present some of the limitations of using decision support systems (DSS) for decision making in weed management.

2. Benefits of Decision Support Systems (DSS) in Weed Management

Both individual and distributed decision making can be supported by knowledge-based systems that facilitate, expand or enhance a manager's ability to work with one or more kinds of knowledge called DSSs [26]. In general, DSSs are now defined as interactive computer-based tools used by decision makers to help answer questions, solve problems and support or refute conclusions. Developing an accurate and effective DSS for weed management has long been recognized as a primary goal for agronomists, land and crop managers and weed scientists [27]. A DSS can be in a simple form, such as a software that indicates the appropriate herbicides recommended for weed specific threshold concepts [28]. More complicated DSSs evaluate herbicide efficacy, the environmental aspect of herbicide treatments and the competitiveness between crops and various weed species, while they may also provide special knowledge on ecosystem diversity and the effects of soil and climatic conditions on the efficacy of herbicide applications [29]. Furthermore, it would be important for DSSs to help farmers identify their most important objectives and develop strategies to achieve them. It is well documented that advanced technology can play a pivotal role in managing important parameters within a field in favor of crop protection and with respect to the sustainability of the agroecosystem [30,31].

In many cases, the adoption of a DSS targets to control both grass and broadleaf weeds simultaneously with one herbicide application instead of two or three. In general, DSSs are promising as an attractive tool designed to support farmers to make the right decisions concerning weed management in important crops. For instance, DSS methodologies have been reported to have achieved comparisons of the densities of all weed species into a common basis and consequently predict possible yield losses for the crop due to weed competition [18]. A functional DSS can also quantify the level of the weed control needed on a field level, select the appropriate herbicides and the required rates for a satisfactory weed control, and also estimate the proportion of the individual herbicides in tank mixtures [24]. Synergistic and antagonistic effects between the mixture components can also be detected [32] and this is among the most important information for farmers. DSSs rank a list of appropriate treatments to farmers and, in many cases, combinations among them in an integrated management context. By selecting a particular herbicidal treatment from the proposed list, information is provided regarding the herbicide cost, application rates, weed densities either before or after treatment and expected yield losses for each case [18]. Moreover, DSSs have been reported to assess the yield losses of important crops such as winter wheat or soybean due to weeds surviving herbicide treatments, while some of them are able to estimate the herbicide residuals in soil water by means of several environmental indices [33]. Factors affecting herbicide efficacy can be also recognized as well as the influence of climatic conditions [34]. DSSs can evaluate weather data and inform the user about their impact on the efficacy of both residual and contact-acting herbicides [35]. DSSs provide knowledge to the farmer regarding the competition among weeds and crops and suggest the most appropriate herbicides against the dominant weed species at the optimum dose rate, application time and method [36]. The impact of the DSS technology on reducing herbicide use by approximately 40%, as compared to reference herbicide treatments, has been well established [25]. Efficient weed control has been recorded at over a 30% decreased herbicide use in cereals by applying herbicides according to the suggestion of a DSS, whereas in sugar beet, the advice from a DSS decreased the herbicide input up to 20% [24]. Moreover, herbicide inputs can be decreased up to 60% in cereals if spraying is carried out according to the collection of site-specific data [37]. Other studies also reported that potential savings in the number of herbicides sprayed to control broadleaf and grass weed species ranged between 60% and 77% [38].

In addition, remote sensing can also play a key role in the development of advanced DSSs since its adoption provides the ability to detect on-time changes in weed flora attributes within a field. The core of site-specific weed management is to identify, analyze and manage site-specific spatial and temporal variability of weed populations within agricultural areas in order to optimize weed management practices and the overall strategy [27]. Therefore, the functionality of DSS methodologies should be enhanced by the timely collection of precise data regarding spatial and temporal attributes within a field [39]. DSSs can take advantage of such information and improve management decision making based on incorporating various data and key parameters observed

within a field at a certain point in time [40]. For instance, outputs from a DSS may be a site-specific map for herbicide applications in a field or a georeferenced map with the probable location of invasive plants or herbicide-resistant biotypes of specific weed species [27]. Farmers can take advantage of the benefits of site-specific weed management and manage to reduce the cost of herbicide inputs with respect to environmental protections as well as to keep their economic risks at the lowest acceptable levels [41]. The data bases of decision support systems usually consist of a large amount of useful information not only by an agronomic or environmental but also economic aspect [12]. Agronomically speaking, knowing the accurate growth stage of the crop and the weeds at a specific time is vital for predicting yield losses due to weed competition. Furthermore, the abundance of weed flora can be quantified, whereas data regarding either soil type or crop growth can be derived from the use of a DSS. Concerning the environmental impact, herbicide ranking is partially dependent on the dose per treatment index and the risk of drift and leaching. Advice is also available about the restrictions on the use of each herbicide. In addition, herbicides are ranked based on cost, reflecting a balance that includes estimated yield losses due to the weeds, expected crop yield and herbicide distribution costs. [36]. In Figure 1, some of the achieved or achievable goals of a weed-based DSS are shown, while future challenges are also presented.

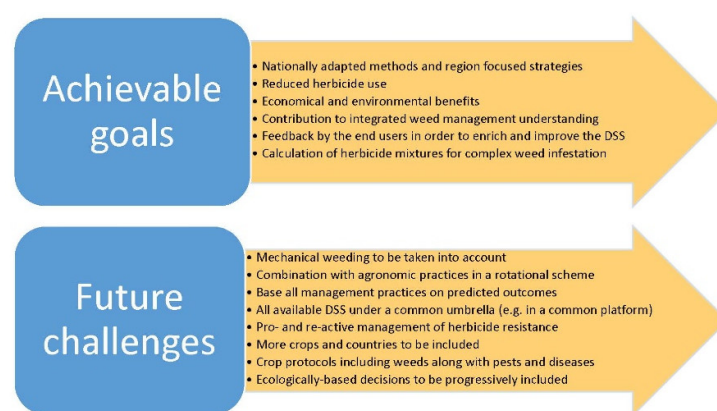


Figure 1. Indicative achievable goals and future challenges of weed-based decision support systems (DSS).

3. Limitations of Decision Supports Systems (DSS) in Weed Management

Despite their prospects, and up to now, DSSs have contributed little to solving practical problems in crop protection under real field conditions due to a series of emerged problems during their adoption and use [42]. As Wilson et al. (2009) have reported, this failure to adopt DSSs may be partially related to gaps in farmers' understanding of the human role in weed dispersal and the tendency to overlook risks associated with management. Rapid advancements in technology render equipment and software obsolete in a short period of time. Even if equipment still performs the desired functions, it might no longer be supported by the company it was purchased from, either due to merging or the company going out of business [43]. Thus, farmers may be frustrated at the rate of change in technology, which can discourage the adoption of the technology as a whole. This is not unusual with new, evolving technologies; however, it has been widely recognized as a major limitation in the adoption of remote sensing and DSSs [44]. In general, it is difficult to convince farmers to use DSSs [45] as it has been shown that producers often have different expectations of decision-making tools depending on their farming styles and the practices that they follow [46]. The gap between the decision-making style required by DSSs and the different types of farmers is recognized, since sometimes a DSS either targets to address problems that are minor or not a priority under real field conditions or fails to solve the most important management issues [47]. This is a consequence of the global trend of researchers concentrating on a single parameter such as a specific weed species, whereas at the same time farmers face challenges regarding broad spectrum weed

management, including the interactions existing between various crops and weed species and also the combined management of either microbial or arthropod pests. From a weed science perspective, research in weed biology and ecology is needed in order to take advantage of new introduced technologies, such as DSSs, to enhance weed management in a global range. Many DSSs have also failed because they do not provide an easy way to capture and store environmental or biological data. Long-term weed management requires a good knowledge of weed growth and interactions between crops and weeds according to ecological and agronomical components, and this is something that is often underestimated by DSS developers [48]. Before adopting the DSS technology, the interference among each crop and various noxious weed species should be assessed because some weed species can be more harmful for a specific crop than others. For instance, *Avena sterilis*, when recorded at a density of 120 panicles per square meter, has been indicated as more harmful for barley crops as compared to the grass species *Phalaris minor* (Retz.), when recorded at a density of 400 panicles per square meter, respectively [49]. Therefore, prioritization within each DSS for the several weeds is crucial for the success of each recommendation and the practical utility of such supporting systems. Due to the fact that weed populations are heterogeneous in composition and distribution, any herbicide application that does not address that heterogeneity has a degree of inefficiency [50]. Furthermore, additional aspects which are often considered important by farmers ought to be taken into account. For instance, aspects like weed propagation, requirements for crop quality with minimum weed seeds in the crop seeding lots, weedy material in machinery and storing systems ought to be taken into consideration in order to avoid misleading predictions of accurate yield losses by the DSS of the next decade.

DSS software and electronic distribution networks are also expensive to develop and maintain. The construction of a DSS often requires enormous amounts of time and financial investment [51], and when this responsibility falls on a single individual or small group, there is often little energy or resources left for the delivery phase. It is well known that complex products delivered without technical support or regular updates may quickly vanish from the marketplace [47]. Consequently, a strong and continuous technical support to the customers, farmers and advisors is rather necessary. In addition, there is a lack of required algorithms which can determine the level of weed control needed in each agricultural area. The present status of studies on yield loss estimations and economic weed control thresholds have recorded the relative instability of such approaches [52]. DSS programs indicate the highest herbicide rates needed for a reported spectrum of weeds. Consequently, the number of weed species which can be efficiently controlled remains limited, whereas at the same time control of other species can be achieved [24]. As previously reported, the need for individual field recordings remains a strong barrier in enhancing DSS technology which might be increased as long as farm sizes are expected to increase within the coming years. The necessary functionality of a DSS requires accurate assessments of weeds within a field as input data. However, the main targets of DSS developers are not always the exact assessments because what they want most are higher weed control levels [25]. The concept of economic thresholds is widely used in DSSs for weed management as well. According to this approach, weeds should be ignored up to a certain level of density, beyond which, weed control should be performed with a standard chemical, mechanical or alternative treatment. However, economic thresholds are related to yield, whose value cannot easily be predicted under real field conditions at the time when herbicides are sprayed [33]. If the expected yield is not estimated correctly, false assessments regarding the economic threshold for herbicide applications will also be made [24].

DSS methodologies can be a useful tool in terms of integrated weed management; however, the limitations regarding their potential still exist. A DSS requires a resource stock of adequate data. Modern computer systems are able to store considerable quantities of data, although capturing the data can be problematic [47]. Since DSSs use imaginary data of the dominant weeds observed in a field in order to show management options, identifying weeds exerts a strong influence in the efficacy of timely herbicide applications as provided by decision support systems. However, identifying grass weed species in cereals or broadleaf weeds in legume or vegetable crops with imaginary data is exceptionally challenging since the similarity between the weed and crop plants is great, especially

during the early growth stages. For instance, noxious Poaceae species such as *A. sterilis*, *L. rigidum*, *Phalaris* ssp. and *Bromus sterilis* were misidentified by the system described in the study by Gonzalez-Andujar et al. (2006) [53]. There are also other obstacles in weed identification and mapping by collecting imaginary data as a consequence of the spectral reflectance or texture between crop and weed canopy and the difficulty to depict large areas in a short time [50]. As previously reported in soybean crops, if the weed density is lower than 10 plants per square meter, some weeds cannot be identified with 1-m pixel images [54]. Distinct weed patches do appear in no-tilled agricultural fields [55,56] and in uncultivated areas [57,58] but only if the weeds are at the seedling stage and at sufficient densities [50]. Difficulties in identifying the composition of a weed patch have also been noticed by other scientists [59]. Moreover, DSSs theoretically process all the available data such as images of the field based on the detected weeds, and thus support the required weed management options. However, the time needed for a precise image acquisition and weed spatial resolution are concerning issues as these can cause delays to the weed management under real field conditions [27]. In general, it can be said that the degree of spatial resolution needed is dependent on the task of interest [60]. Airplane-mounted sensors can provide spatial resolution by varying the flight altitude and provide the convenience of capturing images on demand [61,62]. This resolution could be sufficient for weed detection in some cases (fields, vineyards and orchards), but weed patches should be of high and adequately detectable densities. As a result, aerial imagery could offer a solution regarding image acquisition and weed spatial resolution issues; however, limitations such as either small area coverages or economic burdens might still exist [63].

As mentioned above, the adoption of DSSs can result in a reduced herbicide use [24,25]. However, the development of DSSs should target, in the long-term, to enhance weed management with strategies involving lower reliance on the use of herbicides. This could allow farmers to apply non-chemical weed control practices against noxious weed species such as *L. rigidum*, which is notorious for evolving herbicide resistance patterns in different crops and countries [64,65]. Large reductions in herbicide usage and the replacement of herbicides by non-chemical control methods is feasible and environmentally desirable but is often associated with economic burdens for the farmer and their overall profitability [66]. In addition, the principle of using DSS methodologies for getting feedback of the weed seedbank dynamics into shallow and deep layers of soil has been suggested in a recent study [12], but this version of the specific DSS regarding long-term weed management was not tested. As a result, although DSSs have potential in reducing herbicide inputs within a season, they have a lack of information on weed seedbank dynamics in the soil. Thus, they have not led to the development of long-term weed management decisions. This is a strong challenge, especially since knowledge of seedbank dynamics can promote the adoption of eco-friendly weed management practices such as false or stale seedbeds. The optimization of such agronomic practices through the use of DSSs could be proven to be of high importance since false seedbeds have resulted in sufficient weed control in major arable crops such as rice and barley, although control of weeds was not carried out by herbicide applications [67,68,69]. In Figure 2, some of the crucial points for the further development of weed-based DSSs are shown and ought to be taken into account in future attempts.

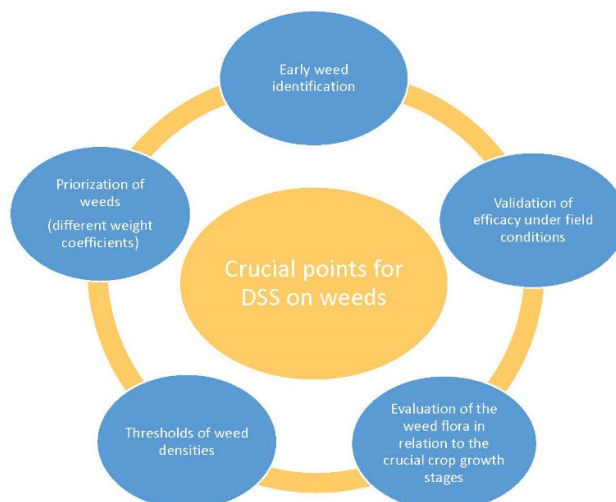


Figure 2. Potentially crucial points for weed-based DSS.

4. Conclusions

Decision support systems (DSS) have the potential of becoming an attractive tool designed to support farmers and advisors to make the right decisions regarding crop and weed management. A functional DSS can evaluate data collected from the crop environment and clarify the level of weed control needed within a field. DSSs can help farmers and advisors to choose the appropriate herbicides for a field and suggest the minimum rates for an herbicide application that can result in optimum weed control without the risk of low efficacy or herbicide resistance. In the case of tank mixtures, the proportion of each component in a mixture can be also estimated. When weed control is carried out according to the information provided by a DSS, this can result in decreased herbicide inputs in crop production. DSSs incorporate models able to assess yield losses for the crop due to competition and select management options which are biologically and economically feasible. Given that the adoption of DSSs can lead to decreased herbicide inputs in crop production, their potential for creating eco-friendly, and of acceptable economic risk, weed management strategies is obvious. On the contrary and despite their potential, DSSs have contributed little to solving practical problems in crop protection under real field conditions due to a series of emerged problems during their adoption by the farmers. The concept of economic thresholds is widely used in DSSs for weed management. However, economic thresholds are related to yield, whose value cannot easily be predicted under real field conditions at the time when herbicides are sprayed. Moreover, a prioritization among the several weeds of a specific field is also necessary. In general, it is difficult to stimulate farmers to use DSSs as it has been noticed that farmers have different expectations of decision-making tools depending on their farming styles. Rapid advancements in technology render equipment and software obsolete in a short period of time. Even if equipment still performs, farmers may be frustrated at the rate of change in technology, which can discourage the adoption of DSSs. The functionality of DSSs requires exact assessments of weeds within a field as input data, although capturing the data can be problematic. The development of DSSs should target to enhance weed management with strategies involving lower reliance on the use of herbicides. Moreover, DSSs should provide information regarding weed seedbank dynamics in the soil in order to suggest weed management options not within a single period but from a rotational and a long-term viewpoint. Further research is needed in order to optimize the practical use of DSSs for supporting farmers regarding their weed management issues in various crops and under various soil and climatic conditions.

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References

1. Adebayo, S.; Ogunti, E.O.; Akingbade, F.K.; Oladimeji, O. A review of decision support system using mobile applications in the provision of day to day information about farm status for improved crop yield. *Per. Eng. Nat. Sci.* **2018**, *6*, 89–99.
2. Agrios, G.N. *Plant pathology*, 5th ed.; Academic Press: New York, USA, 2005.
3. Sonka, S.T.; Bauer, M.E.; Cherry, E.T. *Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management*, National Academy Press: Washington, USA, 1997.
4. Seem, R.C.; and Russo, J.M. 1984. Simple decision aids for practical control of pests. *Plant Dis.* **1984**, *68*, 656–660.
5. Travis, J.W.; Latin, R.X. Development, implementation and adoption of expert systems. *Annu. Rev. Phytopathol.* **1991**, *29*, 343–360.
6. Oerke, E.C.; Dehne, H.W. Safeguarding production-losses in major crops and the role of crop protection. *Crop Prot.* **2004**, *23*, 275–285.
7. Li, Y.; Sun, Z.; Zhuang, X.; Xu, L.; Chen, S.; Li, M. Research progress on microbial herbicides. *Crop Prot.* **2003**, *22*, 247–252.
8. Cox, C. Ten reasons not to use pesticides. *J. Pest. Ref.* **2006**, *26*, 10–12.
9. Meksawat, S.; Pornprom, T. Allelopathic effect of itchgrass (*Rottboellia cochinchinensis*) on seed germination and plant growth. *Weed Biol. Manag.* **2010**, *10*, 16–24.
10. Pot, V.; Benoit, P.; Le Menn, M.; Eklo, O.M.; Sveistrup, T.; Kvaerner, J. Metribuzin transport in undisturbed soil cores under controlled water potential conditions: experiments and modeling to evaluate the risk of leaching in a sandy loam soil profile. *Pest Manag. Sci.* **2011**, *67*, 397–407.
11. Owombo, P.T.; Aregbesola, O.Z.; and Adeloye, K.A. Eco-friendliness of weed management methods in organic farming: the need for extension education. *J. Agric. Sustain.* **2014**, *6*, 179–199.
12. Parsons, D.J.; Benjamin, L.R.; Clarke, J.; Ginsburg, D.; Mayes, A.; Milne, A. E.; Wilkinson, D. J. (2009). Weed Manager—a model-based decision support system for weed management in arable crops. *Comput. Electron. Agric.* **2009**, *65*, 155–167.
13. Sønderkov, M.; Rydahl, P.; Bøjer, O.M.; Jensen, J. E.; Kudsk, P. Crop Protection Online—Weeds: A Case Study for Agricultural Decision Support Systems. In *Real-World Decision Support Systems*, Papathanasiou, J., Ploskas N., Linden I., Eds.; Springer: Cham, Switzerland, Volume 37, 2016; pp. 303–320.
14. Cousens, R.; Doyle, C.J.; Wilson, B.J.; Cussans, G.W. Modelling the economics of controlling *Avena fatua* in winter wheat. *Pestic. Sci.* **1986**, *17*, 1–12.
15. Doyle, C.J.; Cousens, R.; Moss, S.R. A model of the economics of controlling *Alopecurus myosuroides* Huds. in winter wheat. *Crop Prot.* **1986**, *5*, 143–150.
16. Coble, H.D.; Mortensen, D.A. The threshold concept and its application to weed science. *Weed Technol.* **1992**, *6*, 191–195.
17. Berti, A.; Bravin, F.; Zanin, G. 2003. Application of decision-support software for postemergence weed control. *Weed Sci.* **2003**, *51*, 618–627.
18. Nesser, C.; Dille, J.A.; Krishnan, G.; Mortensen, D.A.; Rawlinson, J.T.; Martin, A.R.; Bills, L.B. 2004. WeedSOFT(R): a weed management decision support system. *Weed Sci.* **2004**, *52*, 115–122.
19. Bennett, A.C.; Price, A.J.; Sturgill, M.C.; Buol, G.S.; Wilkerson, G.G. HADSS (TM), pocket HERB (TM), and WebHADSS (TM): decision aids for field crops. *Weed Technol.* **2003**, *17*, 412–420.
20. Been, T.H.; Berti, A.; Evans, N.; Gouache, D.; Gutsche, V.; Jensen, J.; Kapsa, J.; Levay, N.; Munier-Jolain, N.; Nibouche, S.; Raynal, M.; Rydahl, P. Review of new technologies critical to effective implementation of Decision Support Systems (DSS's) and Farm Management Systems (FMS's), Aarhus University: Aarhus, Denmark, 2009.
21. Haage, I.; Bastiaans, L.; Kempenaar, C. Exploring options for improved low dose application based on the MLHD-technology. In *Proceedings of the 12th EWRS Symposium*, Wageningen, Netherlands, 2002; pp. 200–201.
22. Kempenaar, C.; Groeneveld, R.; Uffing, A.; Van Der Weide, R. Y.; Wevers, J. New insights and developments in the MLHD-concept of weed control. In *Proceedings of the 12th EWRS*, Wageningen, Netherlands, 2002; pp. 98–99.

23. Rydahl, P.; Bojer, O.M.; Jørgensen, R.N.; Dyrmann, M.; Andersen, P.; Jensen, N.P.; Sørensen, M. Spatial variability of optimized herbicide mixtures and dosages. In Proceedings of the 14th International Conference on Precision Agriculture. International Society of Precision Agriculture, June 24–27 2018; Montreal, Quebec, Canada, 2018.
24. Rydahl, P. A web-based decision support system for integrated management of weeds in cereals and sugarbeet. *EPPO Bulletin* **2003**, *33*, 455–460.
25. Jørgensen, L.N.; Noe, E.; Langvad, A.M.; Jensen, J.E.; Ørum, J.E.; Rydahl, P. Decision support systems: barriers and farmers' need for support. *EPPO bulletin* **2007**, *37*, 374–377.
26. Holsapple, C.W.; Winston, A.B. *Decision Support Systems: A Knowledge Based Approach*. West Publishing: Eagan, Minnesota, USA, 1996; pp. 1–29.
27. Shaw, D.R. Translation of remote sensing data into weed management decisions. *Weed Sci.* **2005**, *53*, 264–273.
28. Rankins, A.; Shaw, D.R.; Byrd, J.D. HERB and MSUHERB field validation for soybean (*Glycine max*) weed control in Mississippi. *Weed Technol.* **1998**, *12*, 88–96.
29. Cardina, J.; Johnson, G.A.; Sparrow, D.H. The nature and consequence of weed spatial distribution. *Weed Sci.* **1997**, *45*, 364–373.
30. Bongiovanni, R.; Lowenberg-DeBoer, J. Precision agriculture and sustainability. *Precis. Agric.* **2004**, *5*, 359–387.
31. Pedersen, S.M.; Fountas, S.; Blackmore, S.; Gylling, M.; Pedersen, J.L. Adoption and perspectives of precision farming in Denmark. *Acta Agric. Scand. B, Soil Plant Sci.* **2004**, *54*, 2–6.
32. Streibig, J.C.; Kudsk, P.; Jensen, J.E. A general joint action model for herbicide mixtures. *Pest. Sci.* **1998**, *53*, 21–28.
33. Berti, A.; Zanin, G. GESTINF: a decision model for post-emergence weed management in soybean (*Glycine max* (L.) Merr.). *Crop Prot.* **1997**, *16*, 109–116.
34. Rydahl, P. Optimizing mixtures of herbicides within a decision support system. Brighton Crop Protection Conference Weeds, BCPC: Farnham, UK, 1999; pp. 761–766.
35. Bouma, E. *Weather and crop protection*. Roodbont Publishers: Zutphen, Netherlands, 2008.
36. Rossi, V.; Meriggi, P.; Caffi, T.; Giosué, S.; Bettati, T. (2010). A web-based decision support system for managing durum wheat crops. In *Decision Support Systems: Advances in*, Devlin, G., Ed.; Intech, Vukovar, Croatia pp. 1–26.
37. Jensen, H.G.; Jacobsen, L.B.; Pedersen, S.M.; Tavella, E. (2012). Socioeconomic impact of widespread adoption of precision farming and controlled traffic systems in Denmark. *Precis. Agric.* **2012**, *13*, 661–677.
38. Gutjahr, C.; Gerhards, R. (2010). Decision rules for site-specific weed management. In *Precision crop protection—the challenge and use of heterogeneity*, Oerke, E.C., Gerhards, R., Menz G., Sikora R.A., Eds.; Springer: Dordrecht, Netherlands, 2010; pp. 223–239.
39. Kitchen, N.R. Emerging technologies for real-time and integrated agriculture decisions. *Comput. Electron. Agric.* **2008**, *61*, 1–3.
40. Barnes, E.M.; Baker, M.G.; Pinter, P.J.; Jones, D.D. Integration of remote sensing and crop models to provide decision support for precision crop management. In Proceedings of the First International Conference on Geospatial Information in Agriculture and Forestry; Lake Buena Vista, Florida, USA; January 1–3 1998; 1998; Volume 1, pp. 211–213.
41. Heermann, D.F.; Hoeting, J.; Thompson, S.E.; Duke, H.R.; Westfall, D.G.; Buchleiter, G.W.; Westra, P.; Peairs F.B.; Fleming, K. Interdisciplinary irrigated precision farming research. *Precis. Agric.* **2002**, *3*, 47–61.
42. Parker, C.G.; Campion, S.; Kure, H. Improving the uptake of decision support systems in agriculture. In Proceedings of the First European Conference for Information Technology in Agriculture; Copenhagen, Denmark, 15–18 June 1997; Thysen, I., Kristensen, A.R., Eds.; 1997, EFITA, The Royal Veterinary and Agricultural University: Copenhagen, Denmark, 1997; pp. 129–134.
43. Lowenberg-DeBoer, J. Risk management potential of precision farming technologies. *J. Agric. Appl. Econ.* **1999**, *31*, 275–285.
44. Johannsen, C.J.; Carter, P.G.; Morris, D.K.; Ross, K.; Erickson, B. The real applications of remote sensing to agriculture. In Proceedings of the Second International Conference on Geospatial Information in Agriculture and Forestry; Lake Buena Vista, Florida, USA; January 10–12 2000; 2000. Volume 1, pp. 1–5.
45. McCown, R.L. Probing the enigma of the decision support system for farmers: learning from experience and from theory. *Agric. Syst.* **2002**, *74*, 1–10.

46. Noe, E.; Halberg, N. Research experience with tools to involve farmers and local institutions in developing more environmentally friendly practices. In *Environmental Co-operation and Institutional Change*, Hagedorn, K., Ed.; Edward Elgar Publishing: Cheltenham, UK, 2002; pp. 143–161.
47. Magarey, R.D.; Travis, J.W.; Russo, J.M.; Seem, R.C.; Magarey, P.A. Decision support systems: quenching the thirst. *Plant Dis.* **2002**, *86*, 4–14.
48. Le Bourgeois, T.; Jeuffrault, E.; Grard, P.; Carrara, A.; St Pierre, L.R. A new process to identify the weeds of La Réunion Island: the AdvenRun system. In 14th Australian Weeds Conference; Charles Sturt University, Wagga Wagga, Australia; September 2004; 2004, Weed Society of New South Wales.
49. Dhima, K.V.; Eleftherohorinos, I.G.; Vasilakoglou, I.B. Interference between *Avena sterilis*, *Phalaris minor* and five barley cultivars. *Weed Res.* **2000**, *40*, 549–559.
50. Brown, R.B.; Noble, S.D. Site-specific weed management: sensing requirements— what do we need to see? *Weed Sci.* **2005**, *53*, 252–258.
51. Crassweller, R.M.; Travis, J.W.; Heinemann, P.H.; Rajotte, E.G. The actual and potential future use of expert system in horticulture. *Hortic. Technol.* **1993**, *3*, 203–205.
52. Blair, A.M.; Cussans, J.W.; Lutman, P.J.W. A biological framework for developing a weed management support system for weed control in winter wheat: weed competition and time of weed control. Brighton Crop Protection Conference Weeds, BCPC: Farnham, UK, 1999; pp. 753–760.
53. Gonzalez-Andujar, J.L.; Fernandez-Quintanilla, C.; Izquierdo, J.; Urbano, J.M. SIMCE: An expert system for seedling weed identification in cereals. *Comput. Electron. Agric.* **2006**, *54*, 115–123.
54. Medlin, C.R.; Shaw, D.R.; Gerard, P.D.; LaMastus, F.E. Using remote sensing to detect weed infestations in Glycine max. *Weed Sci.* **2000**, *48*, 393–398.
55. Brown, R.B.; Steckler, P.G.A.; Anderson, G.W. Remote sensing for identification of weeds in no-till corn. *Trans. Am. Soc. Agric. Eng.* **1994**, *37*, 297–302.
56. Lamb, D.W.; Weedon, M. Evaluating the accuracy of mapping weeds in fallow fields using airborne digital imaging. *Panicum effusum* in oilseed rape stubble. *Weed Res.* **1998**, *38*, 443–451.
57. Everitt, J.H.; Alaniz, M.A.; Escobar, D.E.; Davis, M.R. Using remote sensing to distinguish common (*Isocoma coronopifolia*) and Drummond goldenweed (*Isocoma drummondii*). *Weed Sci.* **1992**, *40*, 621–628.
58. Williams, A.P.; Hunt, E.R. Estimation of leafy spurge cover from hyperspectral imagery using mixture tuned matched filtering. *Remote Sens. Environ.* **2002**, *82*, 446–456.
59. Bajwa, S.G.; Tian, L.F. Aerial CIR remote sensing for weed density mapping in a soybean field. *Trans. Am. Soc. Agric. Eng.* **2001**, *44*, 1965–1974.
60. Moran, M.S. Inoue, Y.; Barnes, E.M. Opportunities and limitations for image-based remote sensing in precision crop management. *Remote Sens. Environ.* **1997**, *61*, 319–346.
61. Lamb, D.W.; Weedon, M.M.; Rew, L.J. Evaluating the accuracy of mapping weeds in seedling crops using airborne digital imaging: *Avena* spp. in seedling triticale. *Weed Res.* **1999**, *39*, 481–492.
62. Rew, L.J.; Whelan, B.; McBratney, A.B. Does kriging predict weed distributions accurately enough for site-specific weed control? *Weed Res.* **2001**, *41*, 245–263.
63. Moran, M.S. Image-based remote sensing for agricultural management—perspectives of image providers, research scientists and users. In Proceedings of the Second International Conference on Geospatial Information in Agriculture and Forestry; Lake Buena Vista, Florida, USA; January 10–12 2000; **2000**, Volume 1, pp. 23–29.
64. Zangeneh, H.S.; Mohammaddust Chamanabad, H.R.; Zand, E.; Alcantara-de la Cruz, R.; Travlos, I.S.; De Prado, R.; Alebrahim, M.T. Clodinafop-propargyl resistance genes in *Lolium rigidum* Gaud. populations are associated with fitness costs. *Agronomy* **2018**, *8*, 106.
65. Travlos, I.S.; Cheimona, N.; De Prado, R.; Jhala, A.J.; Chachalis, D.; Tani, E. First case of glufosinate-resistant rigid ryegrass (*Lolium rigidum* Gaud.). *Agronomy* **2018**, *8*, 35.
66. Pannell, D.J. Decision support for integrated weed management. In Proceedings of the Third International Weed Science Congress, Foz do Iguaçu, Brazil, 6–11 June 2000; 2000. pp. 6–11.
67. Sindhu, P.V.; Thomas, C.G.; Abraham, C.T. Seed bed manipulations for weed management in wet seeded rice. *Indian J. Weed Sci.* **2010**, *42*, 173–179.
68. Kanatas, P.J.; Travlos, I.S.; Gazoulis, J.; Antonopoulos, N.; Tsekoura, A.; Tataridas, A.; Zannopoulos, S. The combined effects of false seedbed technique, post-emergence chemical control and cultivar on weed management and yield of barley in Greece. *Phytoparasitica* **2020**, *48*, 131–143.

69. Wilson, R.S.; Hooker, N.; Tucker, M.; Lejuene, J.; Doohan, D. Targeting the farmer decision making process: A pathway to increased adoption of integrated weed management. *Crop Prot.* **2009**, *28*, 756–764.



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