PROSPECTS FOR SITE SPECIFIC WEED MANAGEMENT

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Abstract. Research on Site Specific Weed Management (SSWM) started in the late 80`s. Since that moment, considerable research has been conducted on different aspects of SSWM, from fundamental studies on the spatial ecology of weeds to the applied development and testing of new technologies for weed detection and site-specific control. Despite the relatively good knowledge available, there has been little practical uptake of these technologies. In this work we explore some of the reasons for this limited uptake.

Keywords: Weeds, spatial ecology, weed sensing, precision equipment and economy

1 Introduction

McBratney et al. (2005), in their prospective paper on Precision Agriculture, stated "The natural tendency of scientists to assume that what they consider to be a good product of research will be enthusiastically embraced by potential users has proved to be naive". This statement probably explains some of the frustrations of researchers involved in Site Specific Weed Management (SSWM). Up to now, adoption of this concept in practice has been rather low. Looking for explanations for this fact researchers tend to focus on scientific and technological questions: Is our knowledge on the spatial ecology of weeds not good enough to support SSWM practices? Do we have inadequate tools for a precise and reliable detection and suppression of weeds? Certainly, we should consider these questions critically. But we should also consider other factors: economic profitability, sustainability, environmental aspects, social values, etc. In the following sections we have tried to review some of these aspects.

2 Scientific and technological aspects

2.1 The concept

Perhaps we should start by asking ourselves a very basic question: is the concept of SSWM scientifically sound? The basic hypothesis beyond the SSWM concept is based on three major facts: a) weed populations are irregularly distributed within crop fields; b) the advent of new sensors and geospatial technologies (GPS, GIS) make possible to detect and map weed patches; and c) the development of advanced agricultural machinery has opened the possibility of careful tailoring weed management to fit the different conditions found in each field. During the last three decades numerous studies have described the spatial distribution of weeds in different crops and have proved weed heterogeneity (Christensen et al., 2009). Simultaneously, various technologies have been developed and field-tested to detect weed patches (Christensen et al., 2009). Finally, various chemical and physical tools have been devised to control weeds only where, and when, they really represent a serious threat (Christensen et al., 2009). Consequently, evidences accumulated during this period confirm these three facts and support the soundness of the SSWM concept.

2.2 Perceived risks

In spite of the fact that we have an extensive knowledge on the spatial ecology of weeds and on the technologies to control them, numerous farmers are reluctant to use SSWM systems due to the perceived risks of increasing weed populations. This perception is based on the hypothesis that field areas that are not sprayed (due to undetected or low-density weed populations) may act as sources of new weed seeds that reinfest the field. Although available experimental evidences do not support this hypothesis (Ritter & Gerhards, 2008), farmers do not rely too much on punctual scientific results. Their personal experience tells them that climatic and cropping variation, as well as various unpredictable factors, may cause patches to `wax and wane´ in different years. Unless we can reduce this uncertainty, risk-adverse farmers will not uptake these practices.

2.3 Uncertain forecasts

Up to now, most site specific systems are based on the weed mapping approach. As we will describe in the following section, various procedures have been devised to map weed patches based on data collected at weed flowering time or at harvest time (Peña-Barragan et al, 2007; Andujar et al., 2011). Obviously, this information is of no use in the current year. However, if we were able to predict weed infestation in one year based on its presence in the previous year, this information could be used to predict the location of the major weed patches. Although weed patches of several important weed species have proved to be relatively stable (Colbach et al. 2000) our knowledge of the spatial dynamics of most weeds is not good enough to make reliable predictions.

According to Pierce & Nowak (1999) prospects for precision management increase as the degree of spatial dependence increases, but the degree of difficulty in achieving precision management increases with temporal variance. In the specific case of SSWM we can hypothesize that weeds with high spatial dependence and low temporal variance (e.g., perennials, species with highly persistent seed banks) will be more easily managed precisely than those with large temporal variance (e.g. highly dispersed, non persistent seed banks). However, this hypothesis has not being tested yet.

2.4 Weed detection

Regarding weed detection technologies, there is a variety of options available, ranging from generation of weed maps from satellite images to real-time sensors located in the sprayer.

Remote sensing from satellites or from aircrafts can provide accurate weed maps of various weed species when the images are obtained at late weed phenological stages (when discrimination between the crop and the weed is easiest) (Lopez-Granados, 2011). However, as we just mentioned, these late-season maps may have a limited use for weed management. In order to be used for in-season weed control decision making purposes it is necessary to detect weeds at early growth stages. Unfortunately, remote sensing discrimination of weeds at early stages presents much greater difficulties than mapping them at late stages. Gray et al. (2008), working with a complex of six weed species in a soybean crop, reported that weed detection was not obtained until 8 to 10 weeks after emergence, which is unacceptable in production agriculture. They concluded that more refined imagery acquisition with higher spatial and/or spectral resolution and more sophisticated analyses need to be further explored for this technology to be used early-season. Similar conclusions have been reached by other researchers (Lamb and Brown, 2001; Lopez-Granados, 2011). Furthermore, the use of satellite and airborne methods is strongly dependent on sky cloudiness. This is a major limitation due to the relatively short time window available for weed detection and subsequent control actions (e.g., herbicide spraying).

All these limitations might be now overcome using the new generation of small unmanned aerial vehicles (UAV). UAV can operate at low altitudes and capture images at very high spatial resolutions. Moreover, UAV can work with great flexibility at critical moments, independently of the cloud cover. Various research lines are currently active on the use of UAV technology for weed detection, with very promising results (Rasmussen et al, 2013; Torres-Sanchez et al., 2013).

Weed detection from the ground can also be undertaken at various times and from different types of vehicles. Probably, the simplest method consists in visual mapping from a tractor or a quad-bike vehicle at early stages of growth or from a combine at harvest time. Obviously, weed detection at harvest time has the same drawbacks mentioned previously for aerial detection. These visual systems have been tested for different weed species, proving that this is a reliable and commercially feasible method (Andujar et al., 2011). Although this is a viable option, it has some important limitations due to its low precision and its dependence on man labor.

Automated weed detection has been a subject of considerable research in recent years. Probably, the most widely tested systems (and the only ones that have been commercialized up to now) are those based on the use of optoelectronic sensors. These systems can be used for both, on-line spraying and weed mapping (Felton, 1992; Biller, 1998; Brown and Noble, 2005; Andujar et al., 2011). The major drawback of this technology is its lack of discrimination (between crops and weeds and between weed species). In order to solve this problem, various researchers have used bi-spectral video cameras combined with image analysis software that discriminate between species (Gerhards & Christensen, 2003, Oebel & Gerhards 2006, Weis and Sokefeld, 2010). These techniques are able to differentiate between cereal and other crops and numerous weed species and have been extensively tested for mapping purposes. However, this system still needs improvements. Recent studies show that crop and weed overlapping leaves complicate considerably species identification and counts (Keller et al. 2014). Although these techniques have potentials to be used in real-time systems, no commercial products are still available.

The selection of the weed detection procedure to be used in each case will depend on the critical densities ("thresholds") to be detected. Various experimental and simulation studies have shown that the proportion of the field area requiring herbicide treatment is highly dependent on the threshold used (Longchamps et al., 2014). Since threshold levels are generally very low (e.g. <5 weeds/m^2 or < 0.10% weed cover) and weeds have very small sizes, it is likely that most of the aerial and many of the ground detection methods will provide unreliable results.

The intended resolution of patch spraying and the cost-effectiveness of each procedure are also important factors to be considered. Spraying resolution may range from relatively large areas (e.g. applying different herbicides, or not herbicides at all, to different sections of the field with standard sprayers) to micro-spraying (e.g. applying different products and rates to individual plants with highly accurate spraying nozzles) (Christensen et al., 2009). In the first case, a relatively crude weed mapping procedure may be adequate whereas in the second case real-time detection with sophisticated sensors may be required. Probably, the cost-effectiveness of these two detection / spraying options will be much different. If we, as researchers, only focus our attention on the development of sophisticated detection technology we may miss opportunities to develop less sophisticated but more cost-effective SSWM strategies that might be adopted by a wider range of growers (Wiles, 2005).

2.5 Weed control actuation

At its simplest, precision weed control implement may consist of an automated weed detection system mounted on the front of a tractor or a self propelled sprayer identifying the weeds and passing the information to a decision algorithm that controls the spraying system. Some sprayers have been developed for treatment of weed patches by selective control of small sections of the spray boom. Herbicide dosages are mostly regulated by the pressure in the hydraulic system and standard nozzles. The patch sprayer developed by Gerhards & Oebel (2006) has a spraying system that delivers the treatments based on a GIS that contains three treatment maps.

Gerhards & Oebel (2006) conducted a series of whole-field experiments in different crops and fields with the patch sprayer over four years. The three tanks contained different herbicides to control annual grass weeds, annual broad-leaved weeds and perennial weeds. The results of the experiments showed an average of 60% herbicide savings when spraying annual broad-leaved weeds and up to 90% when spraying annual grass weeds.

Another category of precision sprayers is the direct injection sprayers that can apply different herbicides and dosage, e.g. using maps of weed species occurrence to control a series of nozzles, a boom section or the whole boom. Some companies have developed direct injection systems that inject concentrated pesticide solutions into a water stream. Injection pumps have mostly been placed in front of the carrier pump. Consequently, a reaction time of several seconds was required until the pesticide mixture reached the nozzles.

The above mentioned precision sprayers fit to patch spraying. A higher resolution requires another spraying system. Lee et al. (1999) and Lund et al. (2010) developed weed-sensing system and a highly accurate spraying apparatus to control weeds among crop plants.

In recent years, so-called intelligent intra-row cultivator has been developed for intra-row weed control in transplanted row crops. They have camera vision systems that identifies crop plants and mechanical devices that cultivate the inter row spaces (Tillett et al., 2008). Even if they have been adopted in agriculture, there is hardly any scientific documentation on their efficiency (Rasmussen et al., 2012). Practical experiences show that crop identification and positioning works out well in transplanted crops. Intra-row weed control in direct sown crops (e.g. sugar beet) has not yet benefitted from site specific automation. Experiments have been carried out with rotation tines guided by RTK-GPS relative to geo-referenced sugar beets, but crop damages were too high due to lack of precision and inappropriate actuators (Rasmussen et al., 2012).

A first attempt has been carried out to optimize the aggressiveness of post-emergence weed harrowing in cereals by using a harrow equipped with bi-spectral cameras, which detect crop leaf cover, weed cover and soil density (Rueda-Ayala et al. 2013). It is, however, too early to evaluate the system including decision algorithms, which were completely new and not previously tested.

3 Socioeconomic aspects

3.1 Adoption

The adoption of SSWM among farmers has so far been modest. A farm survey from 2001 found that the adoption of site specific pesticide application among early precision farming adopters (farmers that already use yield mapping systems) was 10 % among Danish and UK farmers but only 2 % among farmers in Nebraska (US) (Pedersen et al. 2001). Another survey shows that variable rate pesticide application (mainly herbicides) was used by 3.95 %, 2.72 % and 1.28 % in Germany, Denmark and Finland respectively (Lawson et. al 2011).

Although several studies indicate that SSWM and variable application of herbicides can reduce the use of herbicides between 10-90 % depending on the crop and weed pressure and distribution (e.g. Timmermann 2003; Gerhards and Oebel 2006) farmers are still reluctant to adopt the systems due to relatively high cost of weed mapping (Pedersen et. al. 2004). Gathering information manually is a high-cost operation (relative to the inexpensive herbicides) and it is time consuming to interpret maps. Autonomous weed detection systems are relatively costly to develop, since these systems require heavy computer capacity in order to make reliable pictures and to process and compare many digital images while the farm vehicle is "on the go". Because of these facts, lack of affordable weed detection procedures is regarded by many farmers as a major barrier for SSWM adoption. In spite of that, research on the profitability of SSWM has focused too much on the reduced costs of herbicide use, but ignored significant information costs for scouting, making treatment maps, and patch herbicide application (Swinton 2005).

3.2 Potential benefits

A recent study (Ørum et al. 2012) indicates that the potential savings of herbicides from site specific weeding in winter wheat will depend on the weed control timing and the weed types and pressure. As an example, about 11 % of the Danish area with winter wheat only needs a basic application of herbicides in the autumn. In this area it is not likely that variable rate application will enable the farmer to reduce dose or costs because this treatment is given at a very early growth stage. The later the treatment the better the weed observations; but, at the same time, treatments conducted at later growth stages require higher herbicide dosage to control weeds. In a Danish context, broad-spectra herbicides applied in winter cereals are often preferred. Several weed species like *Elymus repens, Cirsium arvense, Artemisia vulgaris, Galium aparine, Polygonum convolvulus, Stellaria media, Viola arvensis, Apera spica-venti, Alopecurus myosuroides, Poa annua, Poa trivialis, Polygonum convolvulus,* and *Lolium perenne* are often treated late autumn or in spring having a potential for variable precision application based on real-time monitoring. Ørum et al (2012) showed that supplemental spring treatments of competitive grass weeds like *Poa annua*, *Apera spica-venti* and *Alopecurus myosuroides* are relevant for 32%, 32% and 5% of the winter cereal fields in Denmark. If, hypothetically, most of the spring applications could be saved due to variable precision application, approximately 30 € per ha could be saved in the fields actually treated in the spring. In most cases, however, the different weed species are not just located in one and the same corner of the field. For that reason, the potential savings are likely to be smaller: between 10 and 30 € per ha for winter cereals treated in the spring, or 5 € per ha on average for Danish Agriculture. This saving leaves a potential to cover the cost of mapping and investment in precision implements.

Although the direct benefit from variable rate herbicide application at the farm level seems to be modest, the adoption of SSWM may provide a welfare economic benefit and a net surplus to the society due to an overall reduction of herbicide contamination of the environment and energy use for mechanical weeding. The socioeconomic impact of widespread adoption of precision farming in Denmark was assessed by Jensen et. al. (2011). In this analysis, it was assumed that site specific herbicide application is reduced with 40-60 % and implemented on major crops on the larger farms in Denmark (300 ha and above) which is equivalent to 15,5 % of the arable land. Under these assumptions it may be possible to reduce the pesticide use between 2.5 % and 3.8 % at a national level.

3.3 Decision models

In order to fully assess the economic and environmental potential of site specific weed management it is necessary to integrate site-specific information about weed species composition and density, knowledge about crop-weed competition, the effect on crop yield and quality and the species-specific efficacies of possible control methods. The effect of soil conditions, crop husbandry and machinery are also variables that have significant influences in the emergence, competition and propagation of different weed species, and are therefore also important for decision making. The infinite combination of biological variables with the range of efficacies of all possible control methods generates a need for decision models that optimises economic goals and meets environmental constraints (Christensen et al. 2003, Asif et al. 2013).

3.4 Consultants and service providers

One of the reasons for the low adoption of site specific application is the high demand for management time that farmers cannot afford (Smith 2002). In addition, a relatively high education is required for applying new technological advances. Incompatibility between various technologies and a lack of common standards between companies that develop farm equipment introduce additional barriers for large scale adoption of these technologies (Pedersen 2004). Better compatibility of hardware and software, and ease of use, should increase the potential for the average producer – those not so fascinated by the technology.

In this regard, agricultural consultants and agricultural services companies may have an important role to play in the implementation and adoption of SSWM. The adoption of the GPS-systems, including application maps, yield maps and collecting data for analysis will presumably move work load from the field and into the office or to the local advisor. The use of these service providers may also be intensified if a broader commercialization of UAV (Unmanned Aerial vehicles) with cameras for remote sensing develops in the near future. The ideal solution would be that site-specific herbicide application is conducted in combination with other variable rate treatment procedures to reduce the cost of implementing GPS systems, mapping and sensor systems.

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