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The Relationship Between Patch Spraying Cost and Target Weed Distribution

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1. Introduction

Carroll and Holden (2005) defined a method for quantifying weed distributions using distance transform analysis as a first-step in relating the distribution of weeds in a field to the type and cost of equipment used to spray the field (Carroll and Holden, 2009). The method was developed because in much of Europe, fields are sprayed at a fixed application rate determined by the average weed density of weed patches in the field, despite the fact that some areas of the field are below the economic threshold (ET) for intervention and do not require spraying (Mortensen et al., 1995). Targeted application of herbicides to weed patches, known as patch spraying, has the potential to significantly reduce herbicide use, which has both economic and environmental advantages (Lutman et al., 1998).

Patch spraying of herbicide is only viable if: (i) there is a distinct pattern of within-field variability; (ii) the variability identified can be reliably mapped; (iii) the variability has a known biological or environmental effect once managed; (iv) there is a suitable theoretical means of dealing with the weed that accounts for chemical efficacy and weed reproduction; (v) the mechanical equipment exists that can target the within-field variability in an accurate and precise manner; and (vi) the operation can be undertaken at an acceptable cost and return on investment.

The work of Carroll and Holden (2005, 2009) provides a method of quantifying weed distributions. It is documented that weeds are clustered and can be mapped (Godwin and Miller, 2003), and there is reasonable evidence to suggest that patch spraying can be a theoretically effective management approach that has an agronomic and environmental advantage (Lutman et al., 1998 and Wilkerson et al., 2004). Ford et al. (2011) showed that less herbicide could be used through variable rate application, when comparing a conventional broadcast herbicide sprayer to a variable spray weed sensing sprayer. It is also known that within certain spatial constraints patch spraying can be accurate (Paice et al., 1997), but the question remains as to whether an acceptable cost and return on investment can be achieved. Carroll and Holden (2009) developed generalized relationships between field weed patterns, patch sprayer specifications and the spray quality achieved with the view to use these relationships to specify the most appropriate equipment for a certain field weed pattern based on required spray quality and cost.

The focus of the research presented within this chapter is to define the actual costs associated with using sprayer specifications, derived by analyzing weed distributions, and to compare this cost with that of uniform spraying. Any potential environmental costs or benefits associated with applying excess or precise herbicide amount in whole field or site specific applications are not considered. The analysis was undertaken to quantify the economic benefit of precision agriculture herbicide application technology.

2. Economic thresholds

Some research has been reported on the economic analysis of the benefits of patch spraying. The first requirement of any economic weed control analysis is the allocation of an ET, which is defined as the weed density at which the control cost equals the crop loss value if no control action is taken (Bauer and Mortensen, 1992) or the weed population at which the cost of control is equal to the crop value increase from control of the weeds present (Coble and Mortensen, 1992).

Coble and Mortensen (1992) wrote that the economic return associated with a crop production practice and the sustainability of that practice is of greatest immediate concern to the producer. As both biological and economic effects and costs are considered, an economic threshold offers a method by which profitable and sustainable weed management decisions can be made. The ET can be estimated by:

$$T_e = \frac{C_h + C_a}{YPLH} \tag{1}$$

Where

- T_e = economic threshold
- C_h = herbicide cost
- C_a = application cost
- Y = weed free crop yield
- P = value per unit of crop
- L = proportional loss per unit weed density
- H = proportional reduction in weed density by the herbicide treatment.

Equation 1 reveals that any increase in herbicide or application cost will increase ET with other factors being constant. Increase in crop yield, value, degree of weed control or crop loss per unit weed density will lower ET. Three of the factors involved in ET calculations, herbicide cost, application cost and crop value can be estimated fairly accurately by individual growers. However, other factors including potential crop yield, proportional loss per unit weed density and herbicide efficacy are more difficult to estimate because of the variability associated with weather, weed species composition, weed size and cropping system effects on these variables. The focus of this research is on the application cost (C_a). This consists of depreciating sprayer value, cost of operation (including fuel and maintenance) and labor costs. All costs will relate to the size, segmentation and the control system of the sprayer.

Bauer and Mortensen (1992) discussed the Economic Optimum Threshold (EOT) concept. Economic thresholds generally refer to in-season decisions during a single crop year, and do not include a cost factor associated with possible increases in the soil seedbank due to lack of weed control. However, the term EOT is used to include the impact of seedbank

dynamics on long-term profitability of weed management decisions. Not treating a near threshold weed population may affect whether or not a threshold will be exceeded in subsequent years due to increases in weed seedbank. Weaver (1996) discussed the importance of seed production by threshold density weed populations, emphasizing the importance of seed viability, dormancy and longevity. Long-term weed management programs must consider weed seed production, as well as yield losses to permit accurate cost estimation and to increase the likelihood that the threshold criterion is adopted by producers. Zanin et al. (1993) determined ET for winter wheat weed control using different herbicides or mixtures effective against individual weed species:

- *Avena Sterilis* L. subsp. *Ludoviciana* (Durieu) Nyman = 7 – 12 plants per m².
- *Alopecurus myosuroides* Hudson = 25 – 35 plants per m².
- *Lolium multiflorum* Lam = 25 – 35 plants per m².
- *Bromus sterilis* L. = just under 40 per m².
- *Galium aparine* L. = 2/m².
- *Vicia sativa* L. = 2 – 10 /m².

Within the same species the different values of ET result from the different costs and efficacy of the herbicides.

Black and Dyson (1993) developed a model for calculating the economic benefit of early spraying of herbicides in wheat and barley crops, using data derived from routine herbicide evaluation field experiments. The absolute yield benefit (kg/ha) from controlling a forecast proportion of estimated weed units present when the crop is sprayed at or before the early tillering stage has 3 determinants: the weed-free yield potential of the crop (kg/ha); the number of weeds /m² at spraying; and relative growth stages of weeds and crop at spraying. The weight of evidence from the data used indicates that there is an approximately linear relationship between weed density after spraying and grain yield.

3. Economic simulations

Barroso et al. (2004) simulated the effects of weed spatial pattern and resolution of mapping and spraying on economics of site-specific weed management (SSWM). They concluded that the economic benefits of using SSWM are related to the proportion of the field that is weed-infested, the number of weed patches and the spatial resolution of sampling and spraying technologies. Different combinations of these factors were simulated using parameter values obtained for *Avena sterilis ludoviciana* growing in Spanish winter barley crops. The profitability of SSWM systems increased as the proportion of the field infested decreased and when patch distribution was more concentrated. Positive net returns for SSWM were obtained when the weed-infested area was smaller than 30% with the highest return occurring at a 12 m X 12 m mapping and spraying resolution.

Paice et al. (1998) evaluated patch spraying using a stochastic simulation model incorporating Lloyd's Patchiness Index to quantify the patchiness of the weed distribution and the negative binomial distribution to measure distribution shape. They concluded that the long-term economic benefits of patch spraying are likely to be related to the initial spatial distribution, the demographic characteristics of the weed species and the weed control and crop husbandry practices to which they are subjected and that for a system conforming to their very exact specifications, patch spraying of *Alopecurus myosuroides* Huds

would not be profitable in the long term if the control area was greater than 6m X 6m. The method was not developed for field application and focuses on the agronomic rather than the mechanization aspects of weed control.

The work presented in this chapter, and the preceding papers (Carroll and Holden, 2005, 2009), provides a practical, readily applied method of selecting the most appropriate spray technology for accurate patch spraying based on the weed distribution to be targeted, and to evaluate whether an economic benefit will arise from using the technology in preference to uniform application of herbicide over the whole field.

4. Materials and methods

4.1 Weed maps and pattern quantification

The weed maps used to develop the economic analysis were the same as those used by Carroll and Holden (2005) (all scanned with a resolution of 1 m per pixel and subject to a 2 pixel radius filter after thresholding to remove noise): (i) 23 maps of blackgrass (*Alopecurus myosuroides* Huds.) in cereal fields published in a report for the Home Grown Cereals Authority in the United Kingdom (Lutman et al., 1998) with a critical density of >3 plant/m² and a minimum patch size of 25 m²; (ii) 14 maps of 'scutch grass' (*Elymus repens* L. Gould) delineated by field scouting after harvest from a farm in Ireland located in Co. Kilkenny (52.6 degrees north, 7.1 degrees west) with a critical density of c. 10 plants/m²; (iii) 9 maps delineating blackgrass (*Alopecurus myosuroides* Huds.) in cereals and sugar beet published by Gerhards and Christensen (2003), with a critical density of >5 plants/m²; and (iv) 4 maps published by Barroso et al. (2001) delineating sterile wild oat (*Avena Sterilis*) infestations mapped by 4 different methods: counting panicle contacts, scoring panicle density from the ground, scoring panicle density from a combine and counting seed rain on the ground. 5 plants/m² was defined as the critical density.

The pattern of weeds as shown in each map was quantified by inward (subscript i) and outward (subscript o) distance transform analysis (Carroll and Holden, 2005) and summarised by an exponential association function fitted to the cumulative area probability distribution derived from the transformed image histogram:

$$y = a(b - e^{-c_n x}) \quad (2)$$

where a and b values account for the error of the fitted curve from the data ($1 - ab$ indicates the deviation of the fitted curve from the data), and the c_n parameter represents the steepness of the curve (where n can be inward or outward). Values of c_n were collected for each field and were used to group fields with similar weed distribution patterns (Table 1, Figure 1).

4.2 Required resolution

Carroll and Holden (2009) defined the minimum control requirements for each on the nine weed map classes (Figure 1) in terms of boom segmentation (BS) and control distance (CD) for acceptable patch spraying (based on Spray Quality Index, SQI) for both untreated weed maps (Table 2), and after a dilation and erosion image processing algorithm had been applied to consolidate many small patches into larger patches of lower average weed density (Table 3).

Class	Description	C_i	C_o
1	Widely distributed large patches	< 0.05	< 0.025
2	Large patches closer together than in class 1	< 0.05	$0.025 - 0.1$
3	Large spatially aggregated patches	< 0.05	> 0.1
4	Medium, widely distributed patches	$0.05 - 0.14$	< 0.025
5	Medium patches closer together	$0.05 - 0.14$	$0.025 - 0.1$
6	Spatially aggregated medium sized patches	$0.05 - 0.14$	> 0.1
7	Small, widely distributed patches	> 0.14	< 0.025
8	Small patches closer together	> 0.14	$0.025 - 0.1$
9	Small spatially aggregated patches.	> 0.14	> 0.1

Table 1. Qualitative wed map class descriptions derived from quantified distance transform analysis (Carroll and Holden, 2009)

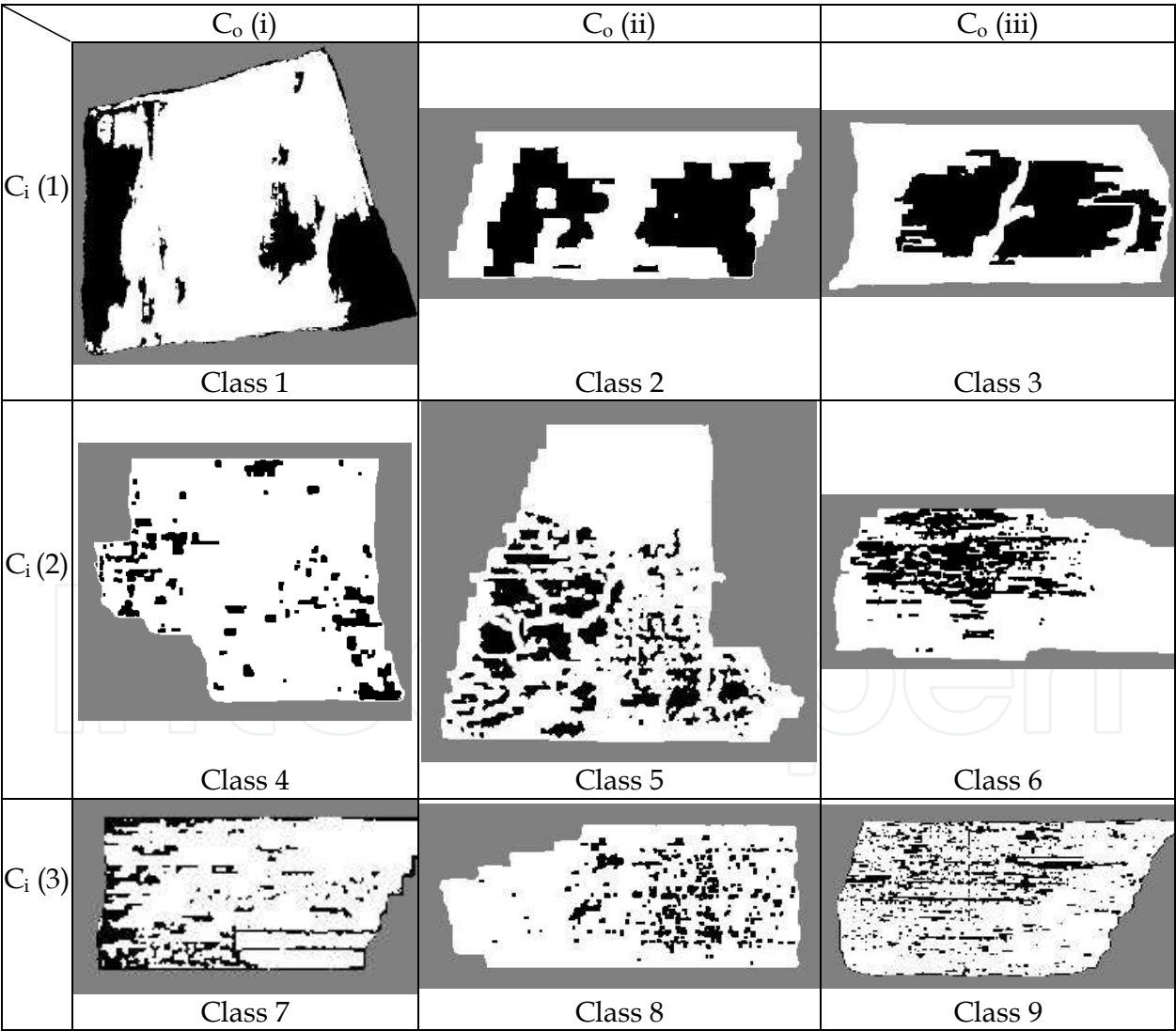


Fig. 1. Example weed maps in each of the 9 classes derived by quantified distance transform analysis.

Class	SQI @ Min Control	SQI @ Max Available Control	Min Requirements for 75% SQI	
	(BS = 30, CD = 20)	(BS = 3, CD = 2)	BS	CD
1	78	97	30	20
2	72	95	30	13
3	80	96	30	20
4	45	91	12	5
5	50	90	12	6
6	60	88	10	6
7	15	80	4	2
8	27	79	3	3
9	25	80	3	3

Table 2. SQIs at different boom segment length (BS, m) and control distance (CD, m) combinations

Class	Average initial weed area (%)	Average weed area after processing (%)	% error induced by processing	Min requirements for 75% SQI (before)		Min requirements for 75% SQI (after)	
				BS (m)	CD (m)	BS (m)	CD (m)
4	13	18	5	12	5	12	5
5	33	41	8	12	6	12	6
6	61	72	11	10	6	10	6
7	9	15	6	4	2	12	6
8	22	34	12	3	3	10	6
9	35	65	30	3	3	10	6

Table 3. Results of weed map erosion and dilation.

No change in the minimum technology requirements was predicted to be needed for Classes 1 to 6 (i.e. large to medium sized patches from widely distributed to spatially aggregated). This was due to the fact that the erosion and dilation process had very little effect in these situations. Only maps in classes 7 to 9 really benefited from this processing because the small weed patches amalgamate and produce maps classified as class 5 or 6. Pre-processing provides a means to specify readily available and relatively inexpensive spraying technology and still make savings in herbicide use compared to uniform spraying (Carroll and Holden, 2005, 2009).

4.3 Calculation of costs

For each of the nine classes, costs were calculated for an assumed model tillage farm of 100ha under winter wheat for three situations: uniform application with cheapest possible combination of sprayer and tractor; patch spraying for 75% SQI with no pre-processing algorithm; and patch spraying for 75% SQI after pre-processing with erosion/dilation algorithm. Total costs were calculated using five sub-sections:

- Sprayer: Manufacturers list prices and data from O’ Mahony (2010) were used to determine the price of sprayers that could satisfy the boom length and control distance

specified in Tables 2 and 3. Average costs per hectare over 10 years were found using ASAE Standard 497.4 as a template.

- Tractor: The size of tractor needed to power each sprayer was determined using ASAE Standards 2002a, EP496.2 (Table 4). List prices for these tractors were found in O' Mahony (2010). Using ASAE Standards 2002b, EP497.4 as a guide, depreciation, repair and maintenance and interest costs were calculated. The costs were then averaged over 10 years to give a cost of tractor use per hectare. Using average values of tractor work schedules (Forristal, 2005), 20% of the tractors yearly work was allocated to spraying. The Hardi Window 3.00 (Drouin, 1989) computer program was used to calculate fuel consumption and hence diesel costs based on tractor and sprayer size, distance to field and distance traveled within the field (Table 5).
- Positioning/Control System (only needed for patch spraying): The costs of a Global Positioning System with the required accuracy (e.g. 1-5 m Carroll and Holden 2009), Geographic Information System to process data and create the various maps required (e.g. ArcView GIS and AgLeader SMS) and control system for patch sprayer operation (e.g. AgLeader Insight) were determined as per manufacturers list price and again allocated per unit area using ASAE Standard 497.4.
- Labor: The Hardi Window 3.00 (Drouin, 1989) computer program was used to calculate the work rates for each type sprayer in ha/hr over the model 100 ha farm (Table 6). This was then converted to a labor cost by multiplying by the Irish national agricultural wage of €7.50/hr and allowing for three herbicide applications per year.
- Herbicide Costs: A herbicide cost of €66/ha for contact herbicide application in winter wheat crops was reported by O' Mahony (2010). There are typically three herbicide applications per year in Irish conditions. The first is a glyphosate spray on stubbled ground post harvest for control of grass weeds including scutch grass (*Elymus repens* L. Gould) and rye grasses (*Lolium perenne* spp.). The second spray (sulfonylureas) is applied post emergence for control of the common grass and broadleaved weeds including chickweed (*Stellaria media* spp.), speedwell (*Veronica arvensis* L.), charlock (*Sinapsis arvensis* L.) and knotgrass (*Paspalum distichum* L.). The third spray (amidosulfuron and Fenoxaprop-P (ethyl)) is applied for control of cleavers (*Galium aparine*) and wild oats (*Avena fatua* L.). For herbicide costs it was assumed that if a non-weed area is not sprayed, this will have no effect on future weed populations.

Total costs were calculated using equation 3.

$$T_c = C_t + C_s + C_r + C_l + C_h \quad (3)$$

Where T_c = total cost

C_t = cost of tractor

C_s = cost of sprayer

C_r = cost of resolution (function of mapping/GPS/control system combination).

C_l = cost of labor

C_h = cost of herbicide

5. Results and discussion

5.1 Uniform application

Costs were calculated under the following headings

1. Sprayer: It was assumed that a simple 15m sprayer with manual valve operation could be used for uniform application of herbicide over the entire 100 ha model farm. This is a fairly typical sprayer used for these operations on Irish farms (Rice, 2005). A typical sprayer of this type has a list price of €12,000 and, allocated over 10 years, gives an average cost per hectare of €20.73. For the largest model available (30m) the extra costs of purchasing the equipment (€49,000) and the larger tractor (€90,000) were not found to be justified in this situation. However for a larger operation economies of scale may lead to larger sprayers being much more economically viable.
2. Tractor: Using the data from ASAE Standard EP496.2 it was determined that a tractor of 45 kW is required to operate this 15 m sprayer. Allowing for adverse field conditions and the use of a slightly larger tractor also used for many other farm operations, it was decided that a 65kW tractor at cost of €40,000 (O’ Mahony, 2010) would be used in this situation to give an allocation of €13.82/ha.

Sprayer Width (m)	PTO Power (kW)	Required Tractor Power (kW)	Actual Tractor Power (kW)
10	24.6	29.6	50
12	29.5	35.6	55
15	36.9	44.5	65
18	44.2	53.4	75
21	51.7	62.2	85
24	59.1	71.1	90
27	66.4	80.1	100
30	73.8	88.9	110

Table 4. PTO and Tractor power requirements for different sprayer boom lengths

The costs were calculated as per {Table 7} and 20% of yearly tractor work was allocated to spraying. Diesel costs at €0.40/l (Table 5) were obtained using Hardi Window 3.00 program, which calculates sprayer use based on tractor and sprayer size, distance from field and distance traveled within the field and found to be €2.80/ha over three applications for this situation.

Boom Length (m)	Tank Size (l)	Tractor size (kW)	Work Rate (ha/hr)	Diesel Cost (€/ha)
10	800	50	4.1	2.97
12	800	55	4.5	2.91
15	1000	65	5.5	2.80
18	1200	75	6.4	2.76
21	1500	85	7.4	2.76
24	1500	90	8.1	2.67
27	2500	100	9.6	2.46
30	2500	110	10.2	2.55

Table 5. Diesel Cost based on different sprayer and tractor combinations.

3. Positioning/control system: for uniform application no mapping, positioning or control systems are used so none of these costs are incurred in this situation.
4. Labor: labor costs were calculated based on a sprayer work rate as shown in Table 6 and the agricultural minimum wage of €7.50 per hour to give a value of €4.09/ha for the 15 m sprayer over the 3 herbicide sprays.
5. Herbicide: From O’ Mahony (2010) a herbicide cost of €66/ha was allocated for the three contact herbicide applications.

Boom Length (m)	Work Rate (ha/hr)	Labor cost (€/hr)	Number of runs	Labor (€/ha)
10	4.1	7.50	3	5.63
12	4.5	7.50	3	5.01
15	5.5	7.50	3	4.09
18	6.4	7.50	3	3.52
21	7.4	7.50	3	3.04
24	8.1	7.50	3	2.81
27	9.6	7.50	3	2.34
30	10.2	7.50	3	2.21

Table 6. Labor costs/ha calculations

5.2 Patch spraying

Costs were calculated under the same headings as for uniform for systems required for 75% SQI and best available technology in Ireland at the current time before and after processing with the erosion/dilation algorithm. At 75% SQI efficacy of spray is at or near 100%.

1. Sprayer: For each group the cost of sprayers with a resolution required for 75% SQI and best available technology (BAT) from table 2 were calculated. For 75% SQI it was found that the sprayer used in the uniform application had the necessary resolution for groups 1 to 3 to give a cost of €20.73/ha. For groups 4 to 6 a 15 m sprayer with control over 3 x 5 m segments and a control distance of less than 6 m was required. A sprayer with this resolution retailed at €15,000 to give a cost/ha of €25.91. For groups 7 to 9 a 15 m sprayer with control over 5 x 3m segments and a control distance less than 3 m was required. A retail price of €17,000 led to an allocation of €29.36/ha over 10 years. After pre-processing the required resolution of the sprayer remained the same for groups 1 to 6 so the same costs were incurred. For groups 7 to 9 the required resolution was decreased so the same sprayer as used for groups 1 to 6 could be used to give a cost of €25.91/ha, a decrease of €3.45/ha.

From table 2 the best available technology has control over 3m boom sections at a control distance of approximately 2m on a 15m boom. A retail price of €19,000 led to an allocation of €32.82/ha over 10 years to each group. Other emerging technologies may in the future lead to a much higher cereal accuracy but as yet are not suited for herbicide application at high resolutions in cereal crops.

2. Tractor: For both 75% and best available technology with and without pre-processing, the 15m boom was used for each group as described above to give a cost of €13.82/ha

using the method as shown in Table 7. The first column shows the amount of depreciation (at 15% cumulative per annum) in each of the 10 years that the tractor is used. The second column shows repair and maintenance costs, which will naturally increase, as the tractor gets older. The 3rd column shows interest on capital expenditure at 5% per annum. The costs were then averaged over 10 years per hectare. Diesel costs came to €2.80/ha.

Year	Depreciation	R&M	Interest	Cost/ha
1	7500	166	2125	97
2	6375	833	1806	90
3	5418	1166	1535	81
4	4605	1666	1305	75
5	3915	3333	1109	83
6	3327	5000	942	92
7	2828	5833	801	94
8	2404	7500	681	105
9	2040	9166	579	117
10	1737	10000	492	122

Table 7. Allocation of costs over 10 years in €/ha for a €50,000 tractor

Group	% weed		Herbicide Cost (€)				
	Before proces- sing	After proces- sing	Uniform	Before processing		After processing	
				75% SQI	B.A.T.	75% SQI	B.A.T.
1	20	20	66	16.50	13.60	16.50	13.60
2	28	28	66	23.10	19.40	23.10	19.40
3	37	37	66	30.53	25.40	30.53	25.40
4	13	18	66	10.73	9.35	14.85	12.95
5	33	41	66	27.73	23.96	33.83	29.77
6	61	72	66	50.33	45.09	59.40	53.22
7	9	15	66	7.43	7.13	12.38	11.88
8	22	34	66	18.15	17.57	28.05	27.15
9	35	65	66	28.88	27.72	53.63	51.48

Table 8. Herbicide cost at different accuracy levels

3.
- GPS/Mapping/Control System: mapping costs of €15/ha for resolution required for 75% SQI and €18/ha for best available technology were allocated (Barroso et al, 2004). The AgLeader Insight system, which provides positioning, control, and analysis components at a retail price of €5,000 was used as the base for the control system. This gave a cost of €9.52/ha. For best available technology a retail price of €6,000 was assumed to give a cost of €11.43/ha over 10 years.

4. Labor: For both 75% SQI and best available technology the 15 m boom gave a work rate of 5.5 ha/hr to give a labor cost of €4.09/ha over the three spray applications from Table 6.
5. Herbicide: Calculated based on average percent weed in each class before and after pre-processing from Carroll and Holden (2009) as shown in table 8. As can be seen for the 75% and best available technology categories the cost of herbicide will depend on the percent weed present in the field.

Once all these costs had been calculated they were collected and combined to give an overall cost for spraying with the three different methods for each group. Examples of 3 groups are shown in Table 9 and the final figures for all groups are shown in Table 10.

Cost	Group 1			Group 5			Group 9		
	Uni-form (€/ha)	At control requirements for (€/ha)		Uni-form (€/ha)	At control requirements for (€/ha)		Uni-form (€/ha)	At control requirements for (€/ha)	
		75%	B.A.T.		75%	B.A.T.		75%	B.A.T.
Sprayer	20.73	20.73	32.82	20.73	25.91	32.82	20.73	29.36	32.82
GPS/ Mapping/ Control System	0	24.52	29.43	0	24.52	29.43	0	24.52	29.43
Tractor	16.62	16.62	16.62	16.62	16.62	16.62	16.62	16.62	16.62
Labor	4.09	4.09	4.09	4.09	4.09	4.09	4.09	4.09	4.09
Herbicide	66	16.50	13.60	66	27.23	23.96	66	28.88	27.7
Total	107.44	82.46	96.56	107.44	98.73	106.92	107.44	103.47	110.68

Table 9. Total cost of uniform versus patch spraying for some sample groups.

Group	Total costs (€/ha) @				
	Uniform Spraying	Before processing		After processing	
		75% SQI	B.A.T.	75% SQI	B.A.T.
1	107.44	82.46	96.56	-	-
2	107.44	89.06	102.36	-	-
3	107.44	96.49	108.36	-	-
4	107.44	81.87	92.31	85.99	95.91
5	107.44	98.73	106.92	104.97	112.73
6	107.44	121.47	128.05	130.54	136.18
7	107.44	82.02	90.09	83.52	94.84
8	107.44	92.74	100.53	99.12	110.11
9	107.44	103.47	110.68	124.77	134.44

Table 10. Total costs at different resolution levels

By analyzing the above data, the cost benefit from patch spraying can be described using the following function.

Cost benefit = $f(\text{group, percent weed, required resolution})$

The required resolution will be determined by the group to which the field is allocated and the resolution cost can be described using the function.

Resolution cost = $f(\text{sprayer, tractor, mapping, positioning, control system})$

It is clear from the above data that patch spraying at 75% SQI would give a reduction in costs in most cases. This reduction is very much related to the percent weed present with a Pearson's Correlation Coefficient of 0.975 ($p < 0.0001$). As percentage weed increases the benefits derived from patch spraying will decrease linearly. In the groups with well spread out weed patches (1,4 and 7) cost benefits of up to €25/ha could be achieved. Even though the costs were greater in group 7 due to the increased resolution of the spraying system a large benefit could still be achieved due to the major reduction in herbicides. Cost benefits are least in the spatially aggregated patch groups due mostly to the fact that in these groups the percent weed is almost always greater than in other groups. The dilation/erosion pre-processing, while reducing the equipment costs in groups 7 to 9 actually led to an increased patch spraying cost in all cases. This was due to the production of more weed pixels by the process and hence an increase in percent weed, which led to greater herbicide costs.

While these results focus only on the sprayers and tractors required for specific use on a model 100 ha winter wheat farm, the data from Tables 4,5 and 6 could be used to allocate costs based on different sized systems.

6. Conclusion

Using the above method it is clear that patch spraying using basic, readily available equipment should be economically advantageous in certain situations. For many of the weed map classes containing medium to large weed patches (1 to 6) there should be economic benefits (up to €25/ha) from patch spraying. Some benefits are also expected in fields with smaller, more aggregated weed patches but at higher weed populations the extra cost of more sophisticated equipment may outweigh the savings from reduced herbicide usage. For patch spraying to become a more attractive option to farmers a cheap, standardized mapping method must be maintained and control systems that can adapt normal sprayers for site specific application must become more readily available and cost effective. If these conditions are met and the methods described by Carroll and Holden (2005, 2009) are used to allocate the correct sprayer to the correct field and weed distribution, patch spraying may be of great economic benefit to a large number of farmers as well as decreasing pesticide introduced into the agro-environment.

7. References

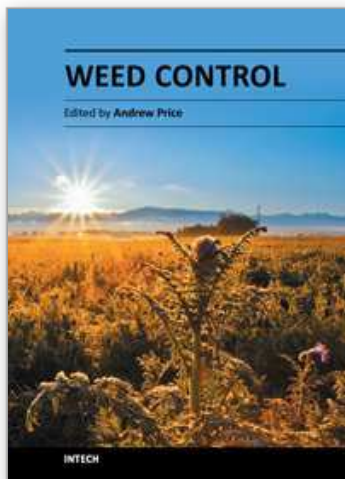
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Weed Control

Edited by Dr. Andrew Price

ISBN 978-953-51-0159-8

Hard cover, 276 pages

Publisher InTech

Published online 29, February, 2012

Published in print edition February, 2012

Crop loss due to weeds has challenged agricultural managers since man began to develop the first farming systems. In the past century, however, much progress has been made to reduce weed interference in crop settings through effective yet mostly non-sustainable weed control strategies. With the commercial introduction of herbicides during the mid-1900's, advancements in chemical weed control tactics have provided efficient suppression of a broad range of weed species for most agricultural practices. Currently, with the necessity to design effective sustainable weed management systems, research has been pushing new frontiers on investigating integrated weed management options including chemical, mechanical as well as cultural practices. Author contributions to Weed Science present significant topics of research that examine a number of options that can be utilized to develop successful and sustainable weed management systems for many areas of crop production

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

John Carroll and Nicholas Holden (2012). The Relationship Between Patch Spraying Cost and Target Weed Distribution, *Weed Control*, Dr. Andrew Price (Ed.), ISBN: 978-953-51-0159-8, InTech, Available from: <http://www.intechopen.com/books/weed-control/the-relationship-between-patch-spraying-cost-and-target-weed-distribution>

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