DISSERTATION

SPATIAL DYNAMICS OF WEEDS IN IRRIGATED CORN

Submitted by

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ABSTRACT

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Weeds are rarely distributed uniformly across agricultural fields, and are commonly aggregated into clusters leaving large areas weed-free. This spatial distribution suggests substantial reductions in herbicide use are possible if herbicides could be applied only to where weeds exist, a concept known as precision weed control. This concept has the potential to reduce environmental pressures and reduce costs from herbicide applications. However, the benefits of precision weed control can only be realized if accurate weed maps can be generated in a cost effective manner. This paper examines several aspects of the spatial dynamics of weeds in irrigated corn fields in eastern Colorado in an attempt to facilitate methodology development for creating useful weed maps and ultimately the realization of the benefits from precision weed control: Sampling strategy comparison, correlations of weeds with soil properties and management zones, and the relationship between herbicide dissipation and management zones as well as nitrogen application rates.

Weeds were sampled within a 0.27 m^2 quadrat at points designated by both "grid" (semi-random within regular grid cells) and "cluster" (small-scale groupings of samples randomly within large grid cells) strategies. Both mapping strategies have strengths and weaknesses, but for the most part seem to generate similar information in both summary statistics and spatial modeling, although the grid strategy appeared less accurate at small

spatial scales. The cluster sampling strategy was less time and labor intensive, even when more samples were taken with the cluster sampling strategy. However, for the purpose of generating a map for precision weed control, neither map had enough detailed spatial information to be practical as a stand-alone guide for precision weed control.

Weed sampling and/or mapping may be more efficient if consistent correlations between weed occurrence and site variables that are relatively temporally and spatially stable and/or easy to map can be established. Soil characteristics often vary across fields and can influence the presence, absence, and density of weeds. Management zones are areas within a field having similar soil traits that are categorized into low, medium, and high crop producing regions, and may also have some relationship with weeds that could be used to streamline weed mapping efforts. Management zones were delineated by means of examination of digital aerial photographs and separation of pixel groups into high, medium, and low productivity zones using average albedo values. Weeds were sampled within a 0.27 m^2 quadrat, again using both cluster and grid sampling methods similar to those described above with some exceptions: The cluster samples were spatially coincident with soil sampling points in order to examine correlations between soil characteristics and weed density. The grid sample points were grouped by their spatial designation within the established management zones. Several significant correlations with soil properties were discovered, as well as statistical differences between weed densities within management zones. However, the statistical significances were not consistent between sites within a sampling year or between years within a site. Weeds have an intimate relationship with soil characteristics, but the degree to which soil properties designate if and how many weeds occur at specific sites can be influenced by a

variety of factors and may fluctuate widely, in both time and space. The use of management zones is still a promising concept for the future of precision agriculture, but delineation methods developed for variable nutrient application (as used here) is likely not be suitable for classifying weed density or occurrence zones.

One of the factors that may significantly affect the spatial distribution and density of weeds in agriculture is variability in the dissipation rates of applied herbicides. This variability can be caused by soil conditions and, potentially, nitrogen application rate when available as a substitute for microbial degradation of herbicides. In this study, the influence of soil variables was examined by using management zones, as described above, as large areas with soil traits similar within and distinct between zones. Within each management zone, three levels of nitrogen application (0, 50, and 200 lbs./ac.) were applied. An application of a tank mixture of atrazine and metolachlor was applied throughout the study site at 1.63 and 1.26 lbs. ai./acre, respectively, and application variability was measured with filter papers at the time of application. Within each management zone/nitrogen application combination, three repetitions of soil samples were taken at each of 8 time points after herbicide application (0, 9, 19, 29, 40, 54, 68, and 99 days after application [DAT]) and separated into 0-6 inch and 6-12 inch depths. Extraction and analysis of herbicides from filter papers and were run with blanks and quality control standards to assess accuracy and contamination. Disassociation coefficients (Kd) were also generated for atrazine and metolachlor with field soils collected from sites throughout the study area with known variability in conductivity values (conductivity is one of the factors used in the delineation of management zones). High levels of variability were evident throughout much of the data, with the exception of

Kd values which were relatively constant throughout the field samples. The dissipation curves observed in this study were not typical, most notably due to the increase in residue levels starting at 40 DAT, peaking at 54 DAT to levels near or above those seen at 1 DAT, then dropping again at 68 DAT through 99 DAT. Standards, blanks, and self-assurance tests indicated little error in recovery of herbicides from the samples. Statistical differences between management zones and nitrogen treatments were few and inconsistent at any given time point.

Many factors likely contribute to the spatial distribution of weeds in agricultural fields, and it is possible that the majority of them are highly stochastic processes that are difficult to model. A greater understanding of the dynamics influencing the spatial patterns of weeds will facilitate more efficient mapping and management processes.

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CHAPTER 1

A Comparison of Two Discrete Sampling Strategies for the Creation of Weed Maps

INTRODUCTION

Weeds are rarely distributed uniformly across agricultural fields, and are commonly aggregated into clusters leaving large areas weed-free (Marshall, 1988, 1989; Thornton et al., 1990; Wilson and Brain, 1990; Wiles et al., 1992; Mortensen et al., 1993; Chancellor and Goronea, 1994; Brown et al., 1994; Donald, 1994; Cardina et al., 1995; Rew and Cussans, 1995; Johnson et al., 1995, 1996; Gerhards et al., 1997, 2000; Christensen and Heisel, 1998; Mortensen et al., 1998; Dammer et al., 1999; Dielman and Mortensen, 1999; Dielman et al., 2000; Gonzalez-Andujar and Saavedra, 2003; Jurado-Exposito et al., 2003). This has been found to be especially true for grass species (Marshall, 1988; Wilson and Brain, 1990) and perennial weeds (Donald, 1994). Studies have attributed the cause of weed patchiness to one or several factors. These factors can include mechanisms of seed dispersal and vegetative reproduction, the spatial variation of soil conditions required for initiating germination and promoting growth, and the absence of various germination and growth deterrents (van Groenendael, 1988; Donald, 1994; Zanin et al., 1998).

The aggregated spatial distribution of weeds indicates two things for precision control efforts. First, contiguous weed-free areas exist in fields and substantial reductions in herbicide use are possible. Secondly, it complicates the sampling strategies and modeling that are necessary in order to create useful maps for the implementation of site-specific (precision) weed control; the application of herbicides only where weeds exist and at a rate that will generate the most economical return. If precision weed control is to become a viable management strategy, practical sampling strategies must be formulated.

A legitimate sampling plan must produce information that is at least equal-to, if not more valuable than the costs of sampling efforts. The value of the information gathered from a weed map depends largely on the particular site conditions. The major economic benefit growers will gain from site specific weed control comes from the reduction in herbicide application costs, which is directly related to the amount of weed-free areas which is, of course, highly variable. While not all fields will be extensively weed-free, it can be assumed the majority of agricultural fields would see significant cost savings if site-specific herbicide application were implemented. However, the cost-benefit needs to be examined closely to incorporate potential reductions in economic gain due to weed-map inaccuracies, or associated input costs necessary to attain sufficient map accuracy.

If a weed map does not accurately correspond to actual field populations, costs savings will decline. In the case of simple on/off patch spraying, weed map errors designating weed occurrences in weed-free areas lower the savings gained from reduction of herbicide application. Conversely, if there are areas of the map designated as weed-free that actually contain weeds, yields may be reduced and the soil seed bank may be

recharged. Similarly, with variable rate applications, misidentified areas of weed occurrence as well as density may result in over and under application of herbicides to weed patches that could prevent effective control or waste resources.

The degree to which either of these map inaccuracies will affect cost savings will depend on several factors. These include the value of the crop, the competitiveness of weed species present, the efficacy and cost of the particular herbicide or herbicides being used, and the overall infestation level. These will vary from site to site, but will be of little consequence if the weed map is highly inaccurate. The accuracy of the weed map is a major determinant of cost benefits of site-specific weed control.

Estimates of sampling costs to generate weed maps are not often addressed in the literature. Swinton (2005) estimated weed sampling costs at roughly \$14 ha^{-1}, which were inferred from soil sampling costs used for precision fertilizer application. Wiles and Schweizer (1999) determined that the cost of weed sampling is dependent upon the number of weeds and different weed species present, and can vary from \$0.02 $quadrat^{-1}$ to \$1.14 $quadrat^{-1}$ based on a labor cost of \$8.50 h^{-1}. Neither of these studies gives a good indication as to how much a useful weed map would cost to create. Regardless of these estimates, it is likely that costs for suitable sampling will vary by site. Although the industry may eventually set definitive cost ranges for sampling processes in the future, it is likely that the most efficient strategy will vary as will the associated costs.

Discrete sampling strategies need to involve the unit (quadrat) size and shape, number of units to be sampled, where and when samples are to be placed, and what information is to be gathered. Use of any discrete sampling strategy alone is generally not a cost effective method to create weed maps. However, the information is valuable

and could be used in conjunction with other sampling data to provide a cost effective map. The objectives of this study are to compare two large-scale discrete sampling strategies and evaluate the spatial properties of weeds they generate. This study does not attempt to assess the relative accuracy of the two methods, but to compare the distribution and density data generated from each strategy in light of the resources they require to produce. The value of small scale spatial information for generating accurate weed maps will also be discussed.

MATERIALS AND METHODS

All data were collected from irrigated corn fields in Eastern Colorado in 2002. Site 1 was the northern half of a pivot in Yuma County, site 4 was in Weld County, and site 5 was the eastern half of a pivot in Morgan County. Grid sampling and cluster sampling techniques were used at approximately the same time (+/- 1 to 3 days) in all sites in order to directly compare the two sampling strategies.

Two different discrete sampling methods were implemented at each site: Grid and cluster sampling. For both methods, weeds were counted by species within 0.18 m by 1.5 m (0.27 m^2) quadrats. Sampling positions were located using a Trimble AG-114 GPS receiver coupled with a pen-top computer using MapInfo software. All samples were taken between the second and fourth leaf growth stages.

For grid sampling, a 30 m square grid was digitized over an aerial image of the field in a GIS. Sampling points were placed within digitized grid cells in a semi-random fashion; randomly at each crop row sampled, but identical in placement along each individual row

within a linear set of pixels in the direction of the crop rows (see Figure 1.1 for clarification). This was done to minimize movement across rows to facilitate time constraints and reduce crop damage from traversing between sampling points.

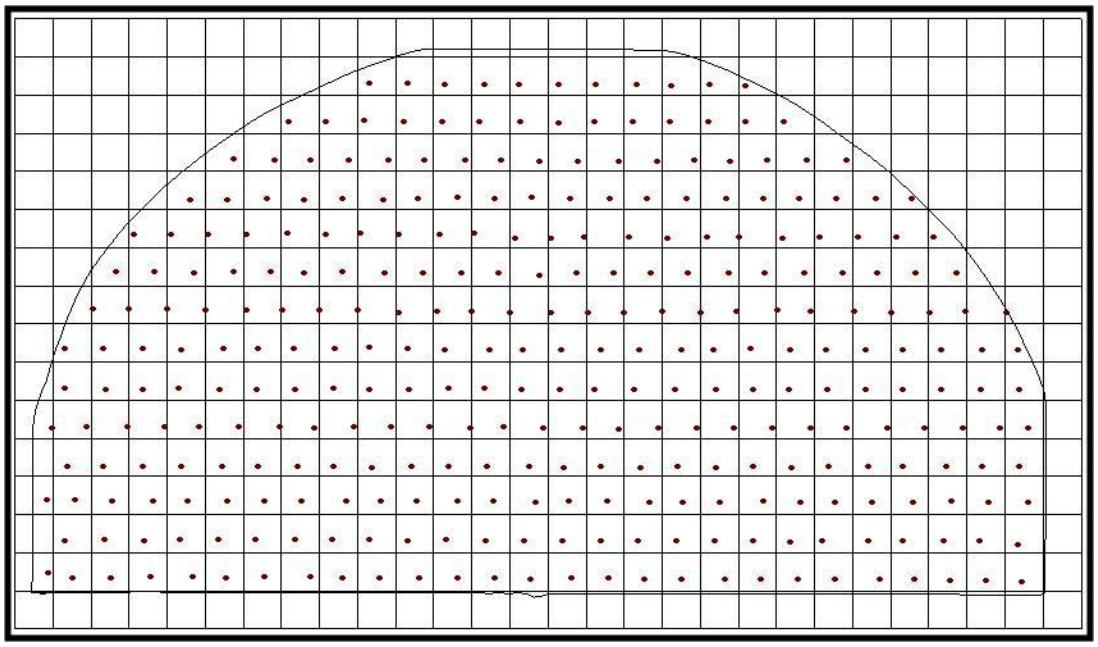

Figure 1.1. Grid sampling strategy showing grid pixels (boxes) and sampling locations (dots). Note that rows run east to west (horizontal in figure) and sample points have identical placement in this direction, but are random from north to south (vertically).

Cluster sampling utilized small-scale clusters of samples at points randomly placed within a larger square digitized grid. Two different grid sizes and cluster arrangements were used: At the larger sites (sites 1 and 5), a grid size of 1 ha was used and quadrats were placed in a 3 by 3 square grid with approximately 3 m spacing within the cluser at each sampling point. At the smaller site (site 4), each cluster was randomly placed within a 0.4 ha cell with each cluster consisting of 5 samples in a cross pattern spaced approximately 3 m apart. The different sampling sizes, intensity, and spacing were used in order to complete the sampling of each site in roughly one day with the

maximum number of samples possible for the purposes of generating the most accurate weed map possible. However, these differences make comparisons between sites unrealistic, and therefore the analysis of the two sampling methods is performed on a site by site basis only.

Summary statistics were generated for each site, sampling strategy, and weed species/category (dicots, monocots, annuals, and perennials).

Sampling effort was determined by examining the total distance traveled for each sampling strategy and man-hours taken to complete sampling. The distance traveled was calculated from digital measurements of the GPS plotted data points. Although the distance traveled in some cases could have been reduced by choosing alternate sampling routes, the estimates given are from the actual route taken during sampling that was deemed most appropriate in the field. Man hours were estimates of time taken for sampling only, and did not take into account set up time, planning stages, or travel.

The Moran's I test was run in order to determine if data had significant spatial autocorrelation. This statistic evaluates the degree of spatial relatedness within the data, or the extent to which neighboring spatial units, set by a spatial weights matrix, influence particular variables. Data that did not exhibit significant spatial autocorrelation were deemed to have a lack of spatial structure and could not be confidently interpolated.

For data that yielded significant spatial autocorrelation, a semi-variogram model was fit. Gaussian, exponential, and spherical models were examined for goodness of fit by AICC values. Nugget, range, and sill values were estimated from models with the best fit. These values, which describe the extent and nature of the spatial properties of

weed populations, were compared qualitatively across sampling strategies as a measure of performance.

RESULTS

A summary of sampling strategies is presented in Table 1.1. Sampling sites ranged from 20.6 to 28.7 ha, and were sampled between May 20th and June 13th, 2002. The total number of quadrats counted ranged from 231 to 317 for grid sampling and from 225 to 261 for cluster sampling.

Table 1.1. Summary of sampling strategies.

Site	Sampling strategy	Field size (ha)	Date sampled	Pixel size (ha)	Clusters	N
1	Grid	28.7	20-May	0.09	-	317
1	Cluster	28.7	23-May	1	29	261
4	Grid	20.6	12-Jun	0.09	-	231
4	Cluster	20.6	13-Jun	0.4	51	255
5	Grid	25.7	4-Jun	0.09	-	281
5	Cluster	25.7	6-Jun	1	25	225

Weed species and density summary statistics on a quadrat basis for the grid sampling strategy are presented in Table 1.2 and for cluster sampling in Table 1.3. Weed species detected by each of the sampling strategies was not always equal. Canada thistle (*Cirsium arvense*) was not detected by the grid sampling strategy in sites 1 and 4, but was picked up by the cluster strategy in both cases. The presence of velvetleaf (*Abutilon theophrasti*) at site 1 and puncturevine (*Tribulus terrestris*) at site 4 was detected with

grid sampling, whereas neither was found with the cluster sampling method at these sites. All other weed species were detected with both sampling strategies.

Differences in average weed densities between sampling methods ranged from 0 to 1.09 weeds/quadrat. All median values were 0 weeds/quadrat at sites 1 and 4, and were either 0 or 1 weeds/quadrat at site 5. Coefficients of dispersion (C.D., ratio of variance to the mean) were all higher in the cluster sampling data than the grid sampling data at site 1 with the exception of velvetleaf (*Abutilon theophrasti*). At site 4, half of the C.D. values were higher in grid sampling and the other half higher in cluster sampling. All C.D. values were higher in grid sampling than cluster sampling at site 5. Skewness and kurtosis values were positive for all sites, weed species, and sampling strategies.

The sampling effort for each strategy is summarized in Table 1.4. At all sites the cluster sampling strategy required less distance to be covered and fewer man-hours to complete in comparison to the grid sampling strategy. At site 1 the distance traveled for cluster sampling was approximately 25% of that required for grid sampling, and travel distances for cluster sampling at sites 4 and 5 were 52% and 66% less than grid travel distances, respectively. Man-hours required for cluster sampling were 38%, 53%, and 36% of that necessary to complete the grid sampling strategy for sites 1, 4, and 5, respectively.

The results of the spatial autocorrelation test (Moran's I) for the pooled weed categories (monocots/dicots, annuals/perennials, total weeds) are presented in Table 1.5. The Moran's I statistic was significant at alpha <0.05 in all cases with the exception of perennial weeds in the cluster sampling strategy data for sites 1 and 4 and the grid sampling strategy data for site 5. The Moran's I test was not run on perennials or annuals

at site 1 grid sampling because there were no perennial weeds detected in the observations at this site with the grid sampling method.

Table 1.2. Weed species summary statistics for grid sampling.

Site	Weed species or category	Mean	Median	SD	CV	% quadrats infested	Skew	Kurt
1	ABUTH	0.03	0	0.40	12.82	1.26	16.42	281.58
1	CIRAR	0.00	0	0.00	-	0.00	-	-
1	KCHSC	0.13	0	0.63	5.02	5.05	5.82	35.68
1	SETVE	0.47	0	1.63	3.48	17.67	6.05	44.68
1	Dicots	0.16	0	0.75	4.73	6.31	5.94	39.26
1	Monocots	0.47	0	1.63	3.48	17.67	6.05	44.68
1	Annuals	0.62	0	1.88	3.00	21.14	4.71	26.71
1	Perennials	0.00	0	0.00	-	0.00	-	-
1	All weeds	0.62	0	1.88	3.00	21.14	4.71	26.71
4	ABUTH	0.01	0	0.09	10.72	0.87	10.68	112.96
4	AMARE	0.01	0	0.15	11.31	0.87	12.19	155.59
4	CIRAR	0.00	0	0.00	-	0.00	-	-
4	CONAR	0.02	0	0.16	9.27	1.30	10.26	113.20
4	ECHCG	0.07	0	0.29	3.98	6.49	4.28	19.43
4	EPHGL	0.01	0	0.09	10.72	0.87	10.68	112.96
4	HELAN	0.66	0	2.81	4.28	24.68	7.49	60.82
4	KCHSC	0.20	0	0.45	2.23	18.18	2.16	4.02
4	SASKR	>0.01	0	0.07	15.20	0.43	15.20	231.00
4	TRBTE	0.01	0	0.09	10.72	0.87	10.68	112.96
4	Dicots	0.92	0	2.83	3.06	43.72	7.13	56.93
4	Monocots	0.07	0	0.29	3.98	6.49	4.28	19.43
4	Annuals	0.98	0	2.84	2.90	45.45	7.01	55.57
4	Perennials	0.02	0	0.16	9.27	1.30	10.26	113.20
4	All weeds	1.00	0	2.84	2.85	46.32	6.99	55.39
5	ABUTH	0.01	0	0.18	16.76	0.36	16.76	281.00
5	AMARE	2.82	2	3.05	1.08	75.80	1.72	3.66
5	CIRAR	0.02	0	0.25	13.81	0.71	15.53	249.45
5	ECHCG	0.66	0	2.20	3.35	18.51	5.47	36.17
5	HELAN	0.05	0	0.34	6.35	3.20	8.10	76.90
5	KCHSC	0.67	0	1.23	1.84	36.65	2.98	11.92
5	SASKR	1.34	1	1.66	1.24	60.50	2.57	12.86
5	SOLRS	0.15	0	0.56	3.63	10.32	5.21	33.31
5	TRBTE	0.44	0	2.20	4.98	9.25	7.08	55.51
5	Dicots	5.50	4	4.67	0.85	95.73	1.79	5.02
5	Monocots	0.66	0	2.20	3.35	18.51	5.47	36.17
5	Annuals	6.14	5	5.32	0.87	96.09	1.71	3.85
5	Perennials	0.02	0	0.25	13.81	0.71	15.53	249.45
5	All weeds	6.16	5	5.37	0.87	96.09	1.74	3.94

Table 1.3. Weed species summary statistics for cluster sampling.

Site	Weed species or category	Mean	Median	SD	CV	% quadrats infested	Skew	Kurt
1	ABUTH	>0.01	0	0.06	1596.87	0.39	15.97	255.00
1	CIRAR	0.01	0	0.09	1126.93	0.78	11.22	124.97
1	KCHSC	0.14	0	0.83	587.81	5.10	8.52	86.57
1	SETVE	0.56	0	2.12	380.26	18.04	6.49	51.50
1	Dicots	0.15	0	0.83	545.87	6.27	8.34	83.98
1	Monocots	0.56	0	2.12	380.26	18.04	6.49	51.50
1	Annuals	0.70	0	2.61	371.50	21.57	5.99	39.41
1	Perennials	0.01	0	0.09	1126.93	0.78	11.22	124.97
1	All weeds	0.71	0	2.61	367.31	22.35	5.99	39.38
4	ABUTH	0.00	0	0.00	-	0.00	-	-
4	AMARE	>0.01	0	0.06	15.97	0.39	15.97	255.00
4	CIRAR	0.01	0	0.09	11.27	0.78	11.22	124.97
4	CONAR	0.01	0	0.19	15.97	0.39	15.97	255.00
4	ECHCG	0.02	0	0.15	6.45	2.35	6.32	38.29
4	EPHGL	0.01	0	0.13	15.97	0.39	15.97	255.00
4	HELAN	0.27	0	1.01	3.76	13.44	6.68	57.43
4	KCHSC	0.22	0	0.72	3.20	13.73	4.76	28.01
4	SASKR	>0.01	0	0.06	15.97	0.39	15.97	255.00
4	TRBTE	0.00	0	0.00	-	0.00	-	-
4	Dicots	0.53	0	1.23	2.33	27.45	4.18	24.81
4	Monocots	0.01	0	0.12	8.49	1.37	8.38	68.55
4	Annuals	0.51	0	1.21	2.39	26.67	4.33	26.45
4	Perennials	0.02	0	0.21	10.57	1.18	12.65	173.66
4	All weeds	0.55	0	1.23	2.24	29.41	4.10	24.27
5	ABUTH	0.02	0	0.14	730.27	1.85	7.21	50.60
5	AMARE	2.07	2	2.14	103.16	72.84	1.41	1.78
5	CIRAR	0.01	0	0.08	1272.79	0.62	12.73	162.00
5	ECHCG	1.75	1	2.47	140.74	53.09	1.88	4.00
5	HELAN	0.13	0	0.46	355.95	9.26	4.31	20.64
5	KCHSC	0.43	0	0.88	204.53	27.78	3.13	13.46
5	SASKR	1.12	1	1.48	131.53	58.02	2.71	12.74
5	SOLRS	0.18	0	0.56	310.71	11.11	3.34	10.95
5	TRBTE	0.62	0	1.47	236.50	22.22	2.63	6.24
5	Dicots	4.59	4	3.52	76.72	91.98	0.98	0.76
5	Monocots	1.75	1	2.47	140.74	53.09	1.88	4.00
5	Annuals	6.33	6	4.38	69.17	94.44	0.90	0.90
5	Perennials	0.01	0	0.08	1272.79	0.62	12.73	162.00
5	All weeds	6.34	6	4.38	0.69	94.44	0.90	0.90

Table 1.4. Sampling effort by site and strategy.

Site	Sampling strategy	Distance traveled (m)	Approximate man-hours
1	Grid	9555	16
1	Cluster	2406	6
4	Grid	6989	15
4	Cluster	3342	8
5	Grid	5277	14
5	Cluster	1815	5

Table 1.5. Moran's I p-values for pooled weed categories by site and sampling strategy.

Site	Weed category	----------p-value----------	
		Cluster sampling	Grid sampling
1	Dicots	0.00	0.00
1	Monocots	0.00	0.00
1	Annuals	0.00	-
1	Perennials	0.84	-
1	All weeds	0.00	0.00
4	Dicots	0.00	0.00
4	Monocots	0.00	0.00
4	Annuals	0.04	0.00
4	Perennials	0.40	0.02
4	All weeds	0.00	0.00
5	Dicots	0.00	0.00
5	Monocots	0.00	0.00
5	Annuals	0.00	0.00
5	Perennials	0.04	0.14
5	All weeds	0.00	0.00

Statistics from spatial modeling of the pooled weed categories is presented in Tables 1.6-1.10. Semi-variogram models that most often fit the data best were the Gaussian and spherical model, in almost equal proportions. The exponential model was only used twice, and for the cluster sampling in both cases. In two instances, the monocot data had both spherical and exponential models with identical AICC values as

well as nugget, sill, and range values (denoted gau/sph in Tables 1.6-1.10). Sill and range values were often higher for grid sampling than for cluster sampling. In three cases both values were lower for grid sampling than for cluster, one of which is only by 0.01, which could be considered negligible. Nugget values were sporadic and did not seem to have trends associated with sampling strategy.

Table 1.6. Spatial modeling statistics for pooled dicots by site/sampling method.

Site	Strategy	Model	Nugget	Sill	Range	Alpha	S.E.	AICC
1	Cluster	gau	0.00	0.53	3.61	0.00	0.72	7.66
1	Grid	gau	0.00	0.52	23.38	0.00	0.72	-17.05
4	Cluster	gau	0.33	1.26	81.13	0.26	1.12	33.17
4	Grid	sph	0.07	11.71	103.41	0.01	3.42	83.95
5	Cluster	sph	0.1104	5.15	1.67	0.02	2.27	32.37
5	Grid	sph	0.90	16.74	45.49	0.05	4.09	77.04

Table 1.7. Spatial modeling statistics for pooled monocots by site/sampling method.

Site	Strategy	Model	Nugget	Sill	Range	Alpha	S.E.	AICC
1	Cluster	gau/sph	0.00	1.73	0.51	0.00	1.32	7.62
1	Grid	gau	0.00	1.91	4.95	0.00	1.38	31.81
4	Cluster	gau/sph	0.01	0.03	0.63	0.38	0.17	-37.99
4	Grid	sph	0.00	0.09	37.55	37.55	0.00	0.30
5	Cluster	sph	0.69	5.28	9.08	0.13	2.30	36.74
5	Grid	gau	0.02	3.33	30.66	0.01	1.82	43.70

Table 1.8. Spatial modeling statistics for pooled annuals by site/sampling method.

Site	Strategy	Model	Nugget	Sill	Range	Alpha	S.E.	AICC
1	Cluster	gau	0.00	2.23	0.64	0.00	1.49	57.84
1	Grid	-	-	-	-	-	-	-
4	Cluster	sph	0.26	0.97	2.98	0.27	0.98	-164.70
4	Grid	gau	0.00	10.84	47.57	0.00	3.29	88.72
5	Cluster	gau	0.08	10.40	2.26	0.01	3.22	39.34
5	Grid	sph	1.34	22.12	63.55	0.06	4.70	83.59

Table 1.9. Spatial modeling statistics for pooled perennials by site/sampling method.

Site	Strategy	Model	Nugget	Sill	Range	Alpha	S.E.	AICC
1	Cluster	-	-	-	-	-	-	-
1	Grid	-	-	-	-	-	-	-
4	Cluster	-	-	-	-	-	-	-
4	Grid	gau	0.00	0.03	37.69	0.00	0.16	-79.49
5	Cluster	sph	0.00	0.00	0.87	0.00	0.07	-31.20
5	Grid	-	-	-	-	-	-	-

Table 1.10. Spatial modeling statistics for pooled total weed by site/sampling method.

Site	Strategy	Model	Nugget	Sill	Range	Alpha	S.E.	AICC
1	Cluster	exp	0.00	2.38	2.26	0.00	1.24	58.10
1	Grid	sph	1.97	4.15	578.81	0.47	2.04	14.41
4	Cluster	exp	0.34	1.27	81.87	0.27	1.13	33.55
4	Grid	gau	0.00	11.30	63.59	0.00	3.36	83.59
5	Cluster	sph	1.10	11.50	5.24	0.10	3.39	75.00
5	Grid	sph	2.11	22.63	51.73	0.09	4.76	89.22

DISCUSSION

Both mapping strategies have strengths and weaknesses, but for the most part seem to generate similar information. The most striking difference between the two sampling strategies is in the distance traveled and man-hours taken to complete the sampling. Cluster sampling is obviously less time and labor intensive than grid sampling, even when more samples are taken with the cluster strategy as seen at site 4. This would suggest that cluster sampling is a superior sampling strategy provided the information obtained is similar between the two strategies.

This implication is supported by the fact that both sampling strategies showed a high degree of similarity in summary statistics. The major difference seen in the

summary statistics between the two strategies is in the distribution of the data (C.D., skewness and kurtosis values), with the cluster data generally showing a greater extent of weed patch aggregation. This does not, however, give an indication of which strategy has the advantage in this matter as far as accuracy. In field-scale studies such as this, it is rarely feasible to generate census data and small scale studies may not accurately represent field-wide spatial information.

One of the unexpected outcomes in comparing the two strategies was in the weed species found. It is important for growers to know what species are present in their fields in order to plan appropriate management strategies, and sampling strategies that fail to recognize all weed species preset could be detrimental. Across all of the study sites, two species were detected in grid sampling but not in the cluster sampling, and three species were detected in the cluster sampling but not in grid sampling. This may be indicative of flaws in both strategies as far as sampling intensity, but in comparison both strategies were roughly equal in their limitations in detecting all weed species within a particular site.

When present in reasonable densities, all weeds showed significant spatial autocorrelation. Rare weeds (perennials in this study) were not often seen in patches but more as individual plants scattered throughout the field, representing more of a random spatial nature that make prediction of unknown occurrences of these species (interpolation) from known locations difficult. This distribution and density cause these species to be more difficult to detect in continuous sampling strategies as well. This phenomenon may present a serious problem to weed map generation in a more general

sense, as isolated “pioneer” weeds could be the most important to detect in order to implement effective management strategies.

For those weeds that did exhibit significant spatial autocorrelation, the semi-variograms were generally sufficient in modeling their spatial nature. The higher range and sill values seen with the grid sampled data indicate that this strategy is better in capturing large scale spatial trends. In fitting a semi-variogram model to the grid sampled data, it was necessary to fit the models over larger lag distances because small lag distances did not exist. In contrast, the cluster sampled data had many points at small lag distances with relatively few large lag distances. Consequently, semi-variogram models had better fit at a smaller scale with cluster data and at a larger scale with the grid data. While the grid sampled data generated larger range and sill values, the models may not accurately represent small-scale spatial variability.

It should be mentioned that fitting semi-variogram models to spatial data is more an art form than a pure statistical procedure. Trial and error is the only way to determine the parameters and thus specific model to be used. While all models did end up with a significant fit to the data, it was highly time consuming, tedious, and required a detailed knowledge of the site. This may deter the use of spatial modeling in weed mapping for precision weed control as it could lower the cost benefit to growers.

For the purpose of generating a map for precision weed control, neither map had enough detailed spatial information to be practical as a stand-alone guide for precision weed control. While the cluster sampling strategy yielded detailed small scale spatial information, it failed in estimating large scale trends. The opposite was true for the grid sampling strategy, indicating that a combination of the two would be ideal even though it

would likely involve an extremely high number of sampling points and associated costs to conduct such a sampling strategy. Further exploration of the accuracy of weed maps using various sampling methods could be conducted with simulated weed populations. However, such research should be accompanied by a feasibility assessment for conducting such sampling strategies in field settings in order to demonstrate real-world applicability and cost-benefit analyses.

Estimating costs associated with discrete sampling is difficult without a set market for such services. Even so, it is unlikely that growers would be willing to invest in high density sampling for large fields. This would suggest that discrete sampling alone is not sufficient for creating cost-efficient weed maps. Although the quantitative information generated from discrete sampling is useful, it may be more practical to use it to supplement other continuous data, such as remote sensing.

Time and effort necessary to complete the grid sampling was high in comparison to cluster sampling, even when more samples are taken with the cluster strategy than the grid strategy, as with site 4. This study indicates that the differences in the information generated from either strategy are subtle. Thus, if discrete sampling is to be integrated into a mapping strategy, cluster sampling or a hybrid of the two strategies may be the best approach. Grouping samples at a small spatial scale is a more efficient layout for collecting discrete data, but without a moderate to high density of clusters per given area the ability to generate spatial information from discrete sampling alone is limited.

Future studies using simulated spatial data sets and sampling methods may serve to develop more efficient strategies for precision weed control maps. However, the most

efficient strategy may depend on the actual density and distribution of weeds at specific sites, which cannot be ascertained prior to the development of a sampling strategy.

CHAPTER 2

Relating Weed Densities and Occurrence to Soil Characteristics and Management Zones

INTRODUCTION

Site-specific application of herbicides to areas only where weeds exist (or are present in sufficient density to justify the cost of application) is possible only if a map of where weeds exist, both spatially and temporally, is available. Many sampling strategies have been investigated, but to date there has not been a sampling strategy devised that can produce weed maps with suitable temporal and spatial accuracy for site-specific herbicide application while remaining economical enough to retain the cost benefits possible through targeted application. However, there are ways to improve weed mapping efficiencies.

Some weed populations have been observed to be spatially stable over time (Wilson and Brain, 1991; Rew and Cussans, 1995; Gerhards et al., 1996; Walter, 1996; Gerhards et al., 1997, 2000; Hausler and Nordmeyer, 1999; Williams et al., 1999; Goudy et al., 2001). Temporal and spatial constancy can reduce sampling costs because sampling information can be used over several years, either alone or as a guide to direct

future sampling strategies, thus stretching the value of an intensive initial sampling process.

Another way in which weed mapping efficiency can be improved is by taking advantage of correlations between weed populations and field properties that are more easily assessed at a field-wide scale and at a relatively low cost. Soil characteristics such as type, texture, water holding capacity, and availability of nutrients often vary across fields and can influence the presence, absence, and density of weeds (Andraesen et al., 1991; Dale et al., 1992; Brown et al., 1994; Hausler and Nordmeyer, 1995; Walter et al., 1997; Nordmeyer and Dunker, 1999; Dieleman et al., 2000). However, there are few consistencies between studies indicating they may be a location and/or time dependent phenomenon. The use of soil property maps to streamline mapping strategies requires further research, and must be investigated on a site specific basis.

A novel approach to improving the efficiency of weed mapping processes involves the delineation of management zones. Khosla et al. (2002) investigated the use of management zones to increase applied nutrient efficiencies. Management zones were defined as areas within a field having similar soil traits, and are categorized into low, medium, and high crop producing regions. Decision processes for delineating these zones involves primarily soil information such as reflectance from remotely-sensed imagery, but can utilize farmer's knowledge, topography, and yield data as well. Khosla et al. (2002) found that these zones have a high potential for increasing nutrient input efficiencies by varying the input across zones instead of applying a constant rate over the entire field.

The concept of management zones may have implications for weed control, as weeds are influenced by many of the same factors as crop species. Conversely, because the zones are theoretically designated to areas of similar crop yield, weed competitive pressure may influence management zone delineation. If there is a significant relationship between management zones and weed populations, the zones could be used to structure weed map sampling strategies, or even site-specific herbicide applications if the relationship is strong enough. This would effectively reduce the expense of weed mapping and increase the value of management zone delineation costs.

The objectives of this study were to examine correlations between soil properties and weed species abundance, and to investigate the relationship between weed populations and management zones.

MATERIALS AND METHODS

All data were collected from irrigated continuous-corn fields in Eastern Colorado. Mature weeds and weed seedlings were counted by species within a 0.18 m by 1.5 m (0.27 m^2) quadrat. Sample point coordinates were plotted using a Trimble AG-114 differential global positioning system receiver coupled with a pen-top computer equipped with a geographic information system.

Quadrat sampling points were pre-determined in all site-years using a stratified random or cluster technique. Specific strategies were altered between years to accommodate sampling times and evolving objectives. Grid sampling was performed at all sites in 2001 and 2002. Sampling points were placed within digitized grid cells in a

semi-random fashion; randomly at each crop row sampled, but identical in placement along each individual row within a linear set of pixels in the direction of the crop rows (see Figure 2.1 for clarification). This was done in order to minimize movement across crop rows to facilitate time constraints and reduce crop damage from sampling.

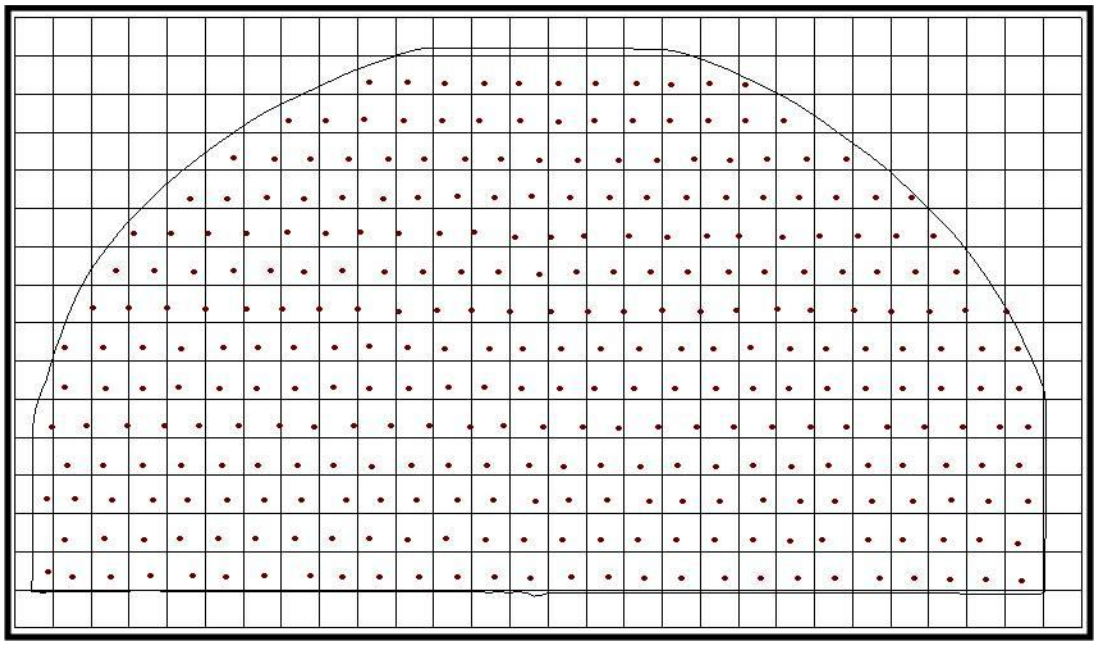

Figure 2.1. Grid sampling strategy showing grid pixels (boxes) and sampling locations (dots). Note that rows run east to west (horizontal in figure) and sample points have identical placement in this direction, but are random from north to south (vertically).

Cluster sampling was performed at all sites in 2002 and 2003. However, for this portion of the study, cluster sampling data are presented only for site 4 in 2002 and site 1 in 2003, as the positioning for these site/years sample locations were coincident with the locations in which soil sampling was conducted in order to examine correlations between weed densities and soil properties. For both sampling strategies, the general proximity of target locations was found using the GPS unit and actual quadrat coordinates were recorded. Site and sampling strategy summary information are presented in Table 2.1.

Table 2.1: Site and sampling summary 2001 to 2003.

Year	Site	Field size (ha)	Sampling strategy	Grid pixel (m^2)	Sample date	Total samples
2001	1	53.4	Grid	1335	8/9	351
2001	2	18.5	Grid	1335	7/3	159
2001	3	69.3	Grid	1335	8/2	500
2002	1	28.7	Grid	900	5/20	317
2002	4	20.6	Grid	900	6/12	231
2002	4	20.6	Cluster	10117	6/13	255
2002	5	25.7	Grid	900	6/4	281
2003	1	28.7	Cluster	4047	6/9	370

Data collection in 2001 was conducted at three sites across the eastern plains of Colorado. Site 1 is 53.4 hectares in Yuma County, site 2 is 18.5 hectares in Weld County, and site 3 is 69.3 hectares in Morgan County. Sampling was performed mid-season when the crop was at the 15^{th} leaf growth stage. Grid size was 36.5 m by 36.5 m (0.13 ha).

The northern half of site 1 (28.7 hectares) was sampled in 2002, as well as new sites in Northern Weld county (20.6 hectares, site 4) and Eastern Morgan county (25.7 hectares, site 5). All field sampling in 2002 was performed during the early part of the growing season between the second and fourth leaf growth stages. Grid sampling was performed on all sites, and cluster sampling was conducted at site 4. Grid pixels in 2002 were 30 m by 30 m (0.09 ha) and sample locations were placed in the same fashion as 2001 samples. Cluster sampling involved five samples in a cross pattern spaced approximately 2.5 m apart. Clusters were placed within 100 m by 100 m (1 ha) grid pixels that coincided with soil sample site positions.

Due to severe drought conditions, only the Northern half of site 1 was sampled in 2003 using the cluster sampling strategy. The technique used was identical to the method used in 2002 and again coincided with soil sample locations.

Management zones were delineated by means of examination of digital aerial photographs and separation of pixel groups into high, medium, and low productivity zones ousing average albedo values. Low albedo areas were designated as high management zones, as dark hues are assumed to represent higher organic matter levels, higher water holding capacity, lower salinities, higher nutrient availability, and hence higher production potential. Conversely, high albedo areas were designated as low management zones, because lighter hues are assumed to represent lower organic matter levels, lower water holding capacity, higher salinities, lower nutrient availability, and thus lower production potential. Intermediate albedos were designated as medium management zones.

Summary statistics were generated from individual site-year data, including soil properties, weed species and category (dicots, monocots, annuals, perennials, and total weeds) counts from cluster sampling, and weed species and category counts by management zone from grid sampling.

Spearman rank correlation coefficients were generated to examine the basic nature and degree of correlations between soil properties and weed densities. These coefficients are similar to Pearson product moment correlation coefficients in terms of proportion of variability accounted for. The difference is that Spearman's are computed from ranks and thus work for non-normally distributed data.

Statistical analysis of differences in weed species/category presence and density were analyzed with contingency table and multiple-response permutation procedures (MRPP), respectively. Grid sampled data were used exclusively in these tests in order to minimize the influence of sampling method and allow comparisons between years and

sites, facilitating analyses of the stability of correlations over time and their general versus site-specific nature. MRPP analysis is a non-parametric procedure that examines Euclidian distances between and within groups against a theoretical distribution generated from multiple (10,000) permutations. Contingency tables plot observed and expected frequencies of categorical (zero or non-zero) data. A chi-square test was used to determine statistical significance in contingency tables. All tests were evaluated at alpha = 0.05 and 0.01; MRPP tests were evaluated using adjusted alpha at 0.05 for multiple comparisons (Abdi, 2007).

RESULTS

Weed count summary statistics for 2001 are shown in Tables 2.2a and 2.2b. The 2001 sample data contained eight species at site 1, ten at site 2, and three at site 3. Only one perennial weed species was found at site 1 (Canada thistle, *Cirsium arvense*), and no perennial species were found at sites 2 and 3. Both monocotyledonous (monocots) and dicotyledonous weeds (hereafter monocots and dicots, respectively) were found in all fields.

Table 2.2a: Weed species and category summary statistics, grid sampling 2001.

Site	Weed species of category	Mean				Median				SD				CD			
		Field	Management zone			Field	Management zone			Field	Management zone			Field	Management zone		
			Low	Med	High		Low	Med	High		Low	Med	High		Low	Med	High
1	ABUTH	0.43	0.17	0.69	0.31	0	0	0	0	1.3	0.7	1.5	0.8	3.9	2.7	3.1	2.2
1	AMARE	0.04	0.06	0.04	0.04	0	0	0	0	0.2	0.3	0.4	0.2	1.3	1.4	3.3	1.3
1	CCHIN	0.05	-	0.12	0.01	0	-	0	0	0.4	-	0.6	0.1	3.3	-	3.6	1.0
1	CIRAR	0.02	-	0.04	0.04	0	-	0	0	0.3	-	0.4	0.5	6.0	-	3.7	6.0
1	ECHCG	0.27	0.16	0.30	0.31	0	0	0	0	1.6	0.7	1.4	2.1	9.8	3.5	6.5	14.3
1	KCHSC	0.00	0.01	-	-	0	0	-	-	0.1	0.1	-	-	1.0	1.0	-	-
1	SETVE	4.37	6.56	4.67	2.94	0	1	0	0	12.9	15.1	14.2	10.2	38.2	34.9	43.2	35.1
1	TRBTE	0.02	0.07	-	0.01	0	0	-	0	0.3	0.7	-	0.1	5.3	6.0	-	1.0
1	Dicots	0.51	0.32	0.70	0.46	0	0	0	0	1.4	1.0	1.5	1.5	3.8	3.1	3.1	4.9
1	Monocots	4.69	6.72	5.08	3.26	0	1	0	0	13.0	15.1	14.2	10.3	35.8	33.8	39.5	32.7
1	Annuals	1.15	7.04	5.79	3.68	1	2	1	0	6.4	15.3	15.1	10.7	35.7	33.1	39.3	31.2
1	Perennials	0.02	6.56	4.67	2.94	0	1	0	0	12.9	15.1	14.2	10.2	-	34.9	43.2	35.1
1	All weeds	5.20	7.04	5.79	3.69	1	2	1	0	13.5	15.3	15.1	10.7	34.9	33.1	39.3	30.9
2	ABUTH	3.00	4.76	2.00	2.14	0	1	0	1	7.2	10.6	5.0	3.1	17.1	23.5	12.4	4.6
2	AMARE	2.48	2.53	2.05	2.92	1	1	1	2	4.3	5.5	3.4	3.8	7.5	11.8	5.5	5.0
2	CHEAL	0.03	0.09	-	-	0	0	-	-	0.3	0.5	-	-	2.6	2.6	-	-
2	ECHCG	0.06	0.11	0.05	0.02	0	0	0	0	0.4	0.5	0.4	0.1	2.4	2.3	3.0	1.0
2	HELAN	0.25	0.40	0.15	0.20	0	0	0	0	0.7	0.9	0.4	0.5	1.7	2.1	1.1	1.2
2	KCHSC	0.09	0.05	0.22	-	0	0	0	-	0.5	0.3	0.9	-	3.1	1.6	3.3	-
2	SASKR	1.60	1.04	0.45	0.67	0	0	0	0	3.8	4.5	1.6	1.4	8.9	19.6	5.9	2.9
2	SOLSA	0.02	-	0.02	0.04	0	-	0	0	0.1	-	0.1	0.2	1.0	-	1.0	1.0
2	TRBTE	0.45	0.47	0.42	0.47	0	0	0	0	2.1	1.8	1.4	3.0	9.9	6.6	4.7	19.2
2	XANST	0.01	-	0.02	0.02	0	-	0	0	0.1	-	0.1	0.1	1.0	-	1.0	1.0
2	Dicots	7.07	9.35	5.33	3.24	3	4	3	0	12.9	19.2	6.8	6.7	23.5	39.5	8.8	13.8
2	Monocots	0.06	0.11	0.05	0.02	0	0	0	0	0.4	0.5	0.4	0.1	2.4	2.3	3.0	1.0
2	Annuals	7.13	9.45	5.38	6.49	3	4	3	3	12.9	19.2	6.8	8.4	23.4	39.1	8.7	11.0
2	Perennials	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	All weeds	7.13	9.45	5.38	6.49	3	4	3	3	12.9	19.2	6.8	8.4	23.4	39.1	8.7	11.0
3	AMARE	1.53	1.11	1.66	1.74	0	0	0	0	3.6	4.0	3.2	3.8	8.3	14.2	6.0	8.1
3	CCHIN	0.17	0.11	0.08	0.41	0	0	0	0	1.1	0.7	0.6	1.8	6.5	4.9	4.7	7.6
3	ECHCG	0.12	-	0.17	0.17	0	-	0	0	1.6	-	2.2	0.9	20.5	-	28.7	4.9
3	SOLSA	3.12	3.59	3.19	2.47	1	1	1	1	5.1	6.4	5.0	3.2	8.3	11.3	7.9	4.2
3	Dicots	4.65	4.70	4.84	4.21	3	2	3	3	6.3	7.9	5.9	5.2	8.6	13.1	7.2	6.4
3	Monocots	0.29	0.11	0.25	0.59	0	0	0	0	2.0	0.7	2.3	2.2	13.2	4.9	20.6	8.5
3	Annuals	4.94	4.81	5.09	4.79	3	2	3	3	6.6	7.8	6.2	5.7	8.7	12.7	7.5	6.7
3	Perennials	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	All weeds	4.94	4.81	5.09	4.79	3	2	3	3	6.6	7.8	6.2	5.7	8.7	12.7	7.5	6.7

Table 2.2b: Weed species and category summary statistics, grid sampling 2001 continued.

Site	Weed species of category	-----% quadrats infested-----				---------Skewness----------				----------Kurtosis----------			
		Field	Management zone			Field	Management zone			Field	Management zone		
			Low	Med	High		Low	Med	High		Low	Med	High
1	ABUTH	36.5	53.1	33.9	29.5	5.4	5.3	2.7	4.3	40.4	32.2	7.6	22.5
1	AMARE	19.4	8.6	28.9	17.4	6.5	5.2	9.6	6.3	45.8	28.5	94.3	43.4
1	CCHIN	6.8	4.9	5.0	9.4	9.4	-	5.7	8.5	91.1	-	31.5	71.9
1	CIRAR	1.7	0.0	3.3	1.3	18.7	-	10.1	12.2	351.0	-	101.7	149.0
1	ECHCG	3.1	4.9	1.7	3.4	11.2	5.0	5.1	11.2	156.2	26.4	27.0	131.8
1	KCHSC	0.6	1.2	0.0	0.7	18.7	9.0	-	-	351.0	81.0	-	-
1	SETVE	0.3	0.0	0.0	0.7	4.7	3.6	4.6	6.0	25.1	13.7	25.0	42.5
1	TRBTE	0.3	1.2	0.0	0.0	18.1	9.0	-	12.2	332.3	81.0	-	149.0
1	Dicots	22.2	14.8	29.8	20.1	4.7	4.1	2.7	6.2	30.7	18.6	7.2	48.2
1	Monocots	43.3	56.8	40.5	38.3	4.6	3.6	4.6	5.7	24.5	13.7	24.7	39.0
1	Annuals	51.6	59.3	52.9	46.3	9.9	3.6	4.5	5.3	116.9	13.5	24.1	33.8
1	Perennials	0.3	0.0	0.0	0.7	4.7	3.6	4.6	6.0	25.1	13.7	25.0	42.5
1	All weeds	51.6	59.3	52.9	46.3	4.5	3.6	4.5	5.3	23.6	13.5	24.1	33.8
2	ABUTH	47.2	50.9	40.0	51.0	4.6	3.3	4.9	2.0	25.5	11.7	28.8	4.6
2	AMARE	62.3	60.0	50.9	77.6	4.7	5.3	2.1	3.4	31.5	33.9	3.8	15.5
2	CHEAL	22.6	27.3	14.5	26.5	9.3	5.4	-	-	89.2	29.4	-	-
2	ECHCG	10.7	14.5	10.9	6.1	6.7	4.9	7.4	7.0	46.4	25.0	55.0	49.0
2	HELAN	17.6	23.6	12.7	16.3	3.8	3.2	2.9	2.5	19.3	12.0	8.5	5.7
2	KCHSC	3.8	3.6	7.3	0.0	6.8	5.9	4.4	-	51.5	35.8	20.3	-
2	SASKR	3.1	5.5	1.8	2.0	5.7	6.9	4.6	2.3	44.5	49.3	21.3	4.7
2	SOLSA	1.3	3.6	0.0	0.0	7.1	-	7.4	4.8	49.6	-	55.0	21.8
2	TRBTE	1.9	0.0	1.8	4.1	7.2	5.0	3.4	7.0	60.9	26.4	10.7	48.5
2	XANST	1.3	0.0	1.8	2.0	8.8	-	7.4	7.0	76.9	-	55.0	49.0
2	Dicots	84.9	85.5	76.4	93.9	6.5	5.2	2.2	4.9	57.1	31.6	5.8	34.0
2	Monocots	3.1	5.5	1.8	2.0	6.7	4.9	7.4	7.0	46.4	25.0	55.0	49.0
2	Annuals	84.9	85.5	76.4	93.9	6.5	5.1	2.2	4.2	56.4	31.4	5.7	22.8
2	Perennials	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-
2	All weeds	84.9	85.5	76.4	93.9	6.5	5.1	2.2	4.2	56.4	31.4	5.7	22.8
3	AMARE	62.7	62.6	61.7	64.7	5.3	7.9	2.9	4.8	42.1	72.8	10.7	32.1
3	CCHIN	40.3	30.5	42.7	46.6	7.6	8.0	10.3	4.8	63.3	69.5	118.6	24.0
3	ECHCG	4.0	3.1	3.1	6.9	19.3	-	15.0	5.9	395.4	-	224.9	35.8
3	SOLSA	2.3	0.0	2.6	4.3	3.4	3.6	2.8	1.8	15.9	15.7	9.5	3.8
3	Dicots	76.6	74.8	75.8	80.2	2.7	3.2	1.8	2.5	10.0	11.6	3.9	9.2
3	Monocots	5.9	3.1	5.7	9.5	11.8	8.0	13.5	4.6	173.0	69.5	192.4	23.6
3	Annuals	78.9	77.1	78.0	82.8	2.6	3.2	1.9	2.2	8.9	11.6	4.4	6.7
3	Perennials	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-
3	All weeds	78.9	77.1	78.0	82.8	2.6	3.2	1.9	2.2	8.9	11.6	4.4	6.7

Field means in 2001 ranged from less than 0.01 to 7.13 weeds/quadrat. Median values across entire sites were mostly 0 weeds/quadrat. Only seven species or categories of species had densities greater than zero and ranged from 1 to 3 weeds/quadrat. Standard deviations varied from 0.1 to 13.5, and coefficients of dispersion from 0.98 to 38.2. The percentage of quadrats that were infested with at least one weed ranged from 0

% to 84.9 %. The lowest non-zero value was 0.3 %. All skewness and kurtosis values were positive, and varied from 2.6 to 19.3, and 8.9 to 395.4, respectively.

The low productivity management zones in 2001 had mean values ranging from 0.01 to 9.45 weeds/quadrat, medians from 0 to 4 weeds/quadrat, and standard deviations from 0.1 to 19.2. Coefficients of dispersion in the low zone varied between 1 and 39.5; all values were greater than 1 with the exception of kochia (*Kochia scoparia*) at site 1. The proportion of infested quadrats ranged from 0 % to 85.5 %, and skewness and kurtosis values were all positive and between 3.2 and 9.0, and 11.6 and 81.0, respectively.

Medium productivity management zones had mean values ranging from 0.02 to 5.79 weeds/quadrat in 2001. The medians for this zone varied from 0 to 3 weeds/quadrat, and standard deviations varied from 0.1 to 15.1. Coefficients of dispersion varied from 1 to 43.24; all values were greater than 1 with the exception of three species at site 2 (annual sunflower [*Helianthus annuus*], hairy nightshade [*Solanum sarrachoides*], and common cocklebur [*Xanthium strumarium*]). Quadrats infested varied between 0 % and 76.4 %, and skewness and kurtosis values were between 1.9 and 10.1, and 3.8 and 101.7, respectively.

The high management zone had means ranging from 0.01 to 6.49 weeds/quadrat, medians from 0 to 3 weeds/quadrat, and standard deviations from 0.1 to 10.7 in 2001. Coefficients of dispersion were between 0.98 and 35.1; all values were greater than one with the exception of one species in site 1 (puncturevine [*Tribulus terrestris*]), and monocots and three species in site 2 (barnyardgrass [*Echinochloa crus-galli*], hairy nightshade, and common cocklebur). Percent infested quadrats ranged from 0 % to 93.9

%, and skewness and kurtosis values varied between 1.8 and 12.2, and 2.8 and 149.0, respectively.

Weed count summary statistics for 2002 are presented in Tables 2.3a and 2.3b. Only three species were found at site 1 and nine at both sites 4 and 5 in 2002. Perennial weeds were found only at sites 4 and 5 (field bindweed [*Convolvulus arvensis*] and Canada thistle, respectively). Monocot and dicot weed species were found at all sites.

Table 2.3a: Weed species and category summary statistics, grid sampling 2002.

Site	Weed species of category	Mean				Median				SD				CD			
		Management zone				Management zone				Management zone				Management zone			
		Field	Low	Med	High	Field	Low	Med	High	Field	Low	Med	High	Field	Low	Med	High
1	ABUTH	0.03	0.07	0.01	-	0	0	0	-	0.4	0.6	0.1	-	5.2	5.6	1.0	-
1	Dicots	0.16	0.28	0.09	0.03	0	0	0	0	0.7	1.0	0.5	0.2	3.5	3.6	3.3	2.0
1	KCHSC	0.13	0.21	0.08	0.03	0	0	0	0	0.6	0.8	0.5	0.2	3.2	3.1	3.6	2.0
1	Monocots	0.47	0.45	0.50	0.46	0	0	0	0	1.6	1.2	2.2	1.4	5.7	3.0	9.4	4.4
1	SETVE	0.47	0.45	0.50	0.46	0	0	0	0	1.6	1.2	2.2	1.4	5.7	3.0	9.4	4.4
1	Annuals	0.62	0.72	0.59	0.49	0	0	0	0	1.9	1.8	2.2	1.4	5.6	4.2	8.6	4.2
1	Perennials	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	All weeds	0.62	0.72	0.59	0.49	0	0	0	0	1.9	1.8	2.2	1.4	5.6	4.2	8.6	4.2
4	ABUTH	0.01	-	0.01	0.02	0	-	0	0	0.1	-	0.1	0.1	-	-	1.0	1.0
4	AMARE	0.01	0.02	0.01	-	0	0	0	-	0.1	0.2	0.1	-	1.7	2.0	1.0	-
4	CONAR	0.02	0.04	-	-	0	0	-	-	0.2	0.3	-	-	1.5	1.5	-	-
4	ECHCG	0.07	0.06	0.02	0.20	0	0	0	0	0.3	0.3	0.1	0.5	1.2	1.4	1.0	1.0
4	EPHGL	0.01	0.02	-	-	0	0	-	-	0.1	0.1	-	-	1.0	1.0	-	-
4	HELAN	0.66	1.16	0.35	0.33	0	0	0	0	2.8	4.3	1.1	0.5	12.0	16.3	3.3	0.8
4	KCHSC	0.20	0.15	0.23	0.27	0	0	0	0	0.5	0.4	0.5	0.5	1.0	1.2	1.0	0.9
4	SASKR	0.00	0.01	-	-	0	0	-	-	0.1	0.1	-	-	1.0	1.0	-	-
4	TRBTE	0.01	-	-	0.04	0	-	-	0	0.1	-	-	0.2	-	-	-	1.0
4	Dicots	0.92	1.40	0.60	0.65	0	0	0	1	2.8	4.3	1.1	0.6	8.7	13.5	2.2	0.6
4	Monocots	0.07	0.06	0.02	0.20	0	0	0	0	0.3	0.3	0.1	0.5	1.2	1.4	1.0	1.0
4	Annuals	0.98	1.42	0.62	0.86	0	0	0	1	2.8	4.3	1.2	0.8	8.2	13.4	2.2	0.8
4	Perennials	0.02	0.04	-	-	0	0	-	-	0.2	0.3	-	-	1.5	1.5	-	-
4	All weeds	1.00	1.46	0.62	0.86	0	0	0	1	2.8	4.3	1.2	0.8	8.1	12.9	2.2	0.8
5	ABUTH	0.01	-	-	0.04	0	-	-	0	0.2	-	-	0.3	-	-	-	3.0
5	AMARE	2.82	4.09	2.47	3.19	2	3	2	2	3.0	3.6	2.6	3.6	3.3	3.2	2.7	4.1
5	CIRAR	0.02	-	-	0.06	0	-	-	0	0.2	-	-	0.4	-	-	-	3.4
5	ECHCG	0.66	1.52	0.40	0.94	0	0	0	0	2.2	2.7	1.8	2.8	7.4	4.7	7.6	8.1
5	HELAN	0.05	-	0.03	0.12	0	-	0	0	0.3	-	0.2	0.5	-	-	1.4	2.5
5	KCHSC	0.67	0.35	0.63	0.84	0	0	0	0	1.2	0.6	1.1	1.6	2.3	0.9	1.8	3.2
5	SASKR	1.34	0.70	1.35	1.49	1	0	1	1	1.7	1.0	1.8	1.4	2.1	1.4	2.5	1.2
5	SOLRS	0.15	0.17	0.08	0.29	0	0	0	0	0.6	0.5	0.3	0.8	2.0	1.4	1.5	2.3
5	TRBTE	0.44	-	0.26	0.93	0	-	0	0	2.2	-	1.8	3.1	-	-	12.0	10.0
5	Dicots	5.50	5.30	4.82	6.95	4	5	4	5	4.7	3.4	4.1	5.7	4.0	2.2	3.5	4.7
5	Monocots	0.66	1.52	0.40	0.94	0	0	0	0	2.2	2.7	1.8	2.8	7.4	4.7	7.6	8.1
5	Annuals	6.14	6.83	5.22	7.84	5	7	4	6	5.3	4.3	4.5	6.6	4.6	2.8	3.8	5.6
5	Perennials	0.02	-	-	0.06	0	-	-	0	0.2	-	-	0.4	-	-	-	3.4
5	All weeds	6.16	6.83	5.22	7.89	5	7	4	6	5.4	4.3	4.5	6.7	4.7	2.8	3.8	5.8

Table 2.3b: Weed species and category summary statistics, grid sampling 2002, continued.

Site	Weed species of category	-----% quadrats infested-----				---------Skewness----------				----------Kurtosis----------			
		Management zone				Management zone				Management zone			
		Field	Low	Med	High	Field	Low	Med	High	Field	Low	Med	High
1	ABUTH	17.7	21.7	14.4	14.7	16.4	11.1	10.5	-	281.6	127.3	111.0	-
1	KCHSC	5.0	8.7	2.7	1.5	5.8	4.4	7.8	8.2	35.7	19.2	65.2	68.0
1	SETVE	1.3	2.2	0.9	0.0	6.1	4.2	6.0	3.8	44.7	23.0	37.3	15.2
1	Dicots	6.3	10.9	3.6	1.5	5.9	4.5	7.5	8.2	39.3	21.8	61.4	68.0
1	Monocots	17.7	21.7	14.4	14.7	6.1	4.2	6.0	3.8	44.7	23.0	37.3	15.2
1	Annuals	21.1	27.5	16.2	16.2	4.7	3.4	5.4	3.7	26.7	12.9	31.5	14.3
1	Perennials	0.0	0.0	0.0	0.0	-	-	-	-	-	-	-	-
1	All weeds	21.1	27.5	16.2	16.2	4.7	3.4	5.4	3.7	26.7	12.9	31.5	14.3
4	ABUTH	24.7	24.7	21.5	30.6	10.7	-	9.6	7.0	113.0	-	93.0	49.0
4	AMARE	18.2	12.4	20.4	24.5	12.2	9.4	9.6	-	155.6	89.0	93.0	-
4	CONAR	6.5	4.5	2.2	18.4	10.3	6.3	-	-	113.2	42.2	-	-
4	ECHCG	1.3	3.4	0.0	0.0	4.3	5.4	6.7	2.2	19.4	31.7	43.9	4.3
4	EPHGL	0.9	1.1	1.1	0.0	10.7	6.6	-	-	113.0	41.9	-	-
4	HELAN	0.9	2.2	0.0	0.0	7.5	4.9	6.1	1.2	60.8	24.8	45.5	0.5
4	KCHSC	0.9	0.0	0.0	4.1	2.2	3.0	2.0	1.6	4.0	8.6	3.1	1.9
4	SASKR	0.9	0.0	1.1	2.0	15.2	9.4	-	-	231.0	89.0	-	-
4	TRBTE	0.4	1.1	0.0	0.0	10.7	-	-	4.8	113.0	-	-	21.8
4	Dicots	43.7	39.3	40.9	57.1	7.1	4.8	4.7	0.4	56.9	23.6	31.5	-0.6
4	Monocots	6.5	4.5	2.2	18.4	4.3	5.4	6.7	2.2	19.4	31.7	43.9	4.3
4	Annuals	45.5	40.4	40.9	63.3	7.0	4.8	4.5	0.8	55.6	23.6	29.2	0.2
4	Perennials	1.3	3.4	0.0	0.0	10.3	6.3	-	-	113.2	42.2	-	-
4	All weeds	46.3	42.7	40.9	63.3	7.0	4.8	4.5	0.8	55.4	23.5	29.2	0.2
5	ABUTH	75.8	73.9	74.0	80.0	16.8	-	-	9.2	281.0	-	-	85.0
5	AMARE	60.5	43.5	55.5	75.3	1.7	0.6	1.3	2.0	3.7	-0.6	1.3	4.6
5	CIRAR	36.7	30.4	37.6	36.5	15.5	-	-	8.5	249.4	-	-	75.1
5	ECHCG	18.5	43.5	13.9	21.2	5.5	2.2	8.7	4.0	36.2	4.1	92.5	17.6
5	HELAN	9.3	0.0	7.5	15.3	8.1	-	7.7	5.5	76.9	-	64.3	34.0
5	KCHSC	10.3	13.0	6.4	17.6	3.0	1.5	2.3	2.9	11.9	1.4	6.3	9.5
5	SASKR	3.2	0.0	2.3	5.9	2.6	1.3	2.8	1.2	12.9	0.9	13.3	2.1
5	SOLRS	0.7	0.0	0.0	2.4	5.2	3.0	5.4	3.9	33.3	8.9	34.8	17.1
5	TRBTE	0.4	0.0	0.0	1.2	7.1	-	11.1	4.1	55.5	-	135.2	17.1
5	Dicots	95.7	95.7	94.2	98.8	1.8	0.2	2.3	1.2	5.0	-1.0	11.0	0.8
5	Monocots	18.5	43.5	13.9	21.2	5.5	2.2	8.7	4.0	36.2	4.1	92.5	17.6
5	Annuals	96.1	95.7	94.2	100.0	1.7	0.3	2.1	1.2	3.9	-0.5	8.2	0.8
5	Perennials	0.7	0.0	0.0	2.4	15.5	-	-	8.5	249.4	-	-	8.5
5	All weeds	96.1	95.7	94.2	100.0	1.7	0.3	2.1	1.3	3.9	-0.5	8.2	0.9

Field means in 2002 ranged from 0.01 to 6.16 weeds/quadrat. Medians were again mostly 0 weeds/quadrat, with 5 species or pooled weed categories of non-zero value from 1 to 5 weeds/quadrat. Standard deviations were also generally lower in 2002, and varied from 0.1 to 5.4. Coefficients of dispersion at site 5 ranged from 0.99 to 38.2. Percent infested quadrats ranged from 0% to 96.1%, the lowest non-zero value being

0.4%. Skewness and kurtosis values were again all positive and varied from 1.7 to 16.8 and 3.7 to 281.6, respectively.

The low productivity management zones in 2002 had mean values ranging from 0.01 to 6.83 weeds/quadrat, medians from 0 to 7 weeds/quadrat, and standard deviations from 0.1 to 4.3. The C.D. was close to 1 for ridgeseed spurge (*Euphorbia glyptosperma*) and Russian thisle (*Salsola krali*) at site 4 and for kochia (*Kochia scoparia*) at site 5. All other C.D.s in the low zone varied between 1.2 and 16.3 in 2002. The proportion of infested quadrats ranged from 0 % to 94.7 %, and skewness values were all positive and between 0.2 and 11.1. Redroot pigweed (*Amaranthus retroflexus*), dicots, and annuals at site 5 had kurtosis values less than zero; all others were positive and ranged from 0.9 to 127.3.

Medium productivity management zones had mean values ranging from 0.01 to 5.22 weeds/quadrat in 2002. The medians for this zone varied from 0 to 4 weeds/quadrat and standard deviations varied from 0.1 to 4.5. The C.D. for velvetleaf (*Abutilon theophrasti*) at sites 1 and 4, as well as redroot pigweed, barnyardgrass, kochia, and monocots were close to 1. All other C.D.s in the medium zone ranged from 1.2 to 12 in 2002. Quadrats infested varied between 0% and 94.2%, and skewness and kurtosis values were between 1.3 and 11.1, and 1.3 and 135.2, respectively.

The high management zone had means ranging from 0.02 to 7.89 weeds/quadrat, medians from 0 to 6 weeds/quadrat, and standard deviations from 0.8 to 16.8 in 2002. Coefficients of dispersion were close to 1 at site 4 for velvetleaf, barnyardgrass, and puncturevine. Site 4 had C.D.s less than to 1 for annual sunflower, kochia, dicots, annuals, and total weeds (annuals and total weeds were the same counts for site 5 in the

high zone, 2002, as all weeds detected were annuals). All other C.D.s were between 1.2 and 10. Percent infested quadrats ranged from 0% to 100%, and skewness values varied between 0.4 and 9.2. Dicots at site 4 had a negative kurtosis value (-0.6), while all other values were positive and ranged from 0.2 to 85.0.

Cluster sample summary statistics for sites 4 and 1 are presented in Table 2.4. Cluster sampling in 2002 (site 4) revealed eight different weed species, including species of all categories. The cluster sample data included Canada thistle spp., which were not detected with grid sampling performed the previous day, but did not include puncturevine or velvetleaf species, which were detected with the grid sample. Field means for the cluster sample were markedly lower than the grid sample, ranging from less than 0.01 to 0.55 weeds/quadrat. Medians were all zero weeds/quadrat, and standard deviations varied from 0.1 to 1.2. Coefficients of dispersion were all greater than 1, with the exception of barnyardgrass, Canada thistle, redroot pigweed, and Russian thistle at site 4, all of which were close to 1. Skewness and kurtosis values were all positive and varied from 4.1 to 16.0 and 28.0 to 225.0, respectively.

Table 2.4: Weed species and category summary statistics, cluster sampling 2002 and 2003.

Year	Site	Weed species or category	Mean	Median	SD	CD	% quadrats infested	Skew	Kurt
2002	4	HELAN	0.27	0	1.0	3.8	13.4	6.7	57.4
2002	4	KCHSC	0.22	0	0.7	2.3	13.7	4.8	28.0
2002	4	ECHCG	0.02	0	0.2	1.0	2.4	6.3	38.3
2002	4	CONAR	0.01	0	0.2	3.0	0.4	16.0	255.0
2002	4	CIRAR	0.01	0	0.1	1.0	0.8	11.2	125.0
2002	4	EPHGL	0.01	0	0.1	2.0	0.4	16.0	255.0
2002	4	AMARE	0.00	0	0.1	1.0	0.4	16.0	255.0
2002	4	SASKR	0.00	0	0.1	1.0	0.4	16.0	255.0
2002	4	Dicots	0.53	0	1.2	2.9	27.5	4.2	24.8
2002	4	Monocots	0.01	0	0.1	1.0	1.4	8.4	68.6
2002	4	Annuals	0.51	0	1.2	2.9	26.7	4.3	26.5
2002	4	Perennials	0.02	0	0.2	2.2	1.2	12.7	173.7
2002	4	All weeds	0.55	0	1.2	2.7	29.4	4.1	24.3
2003	1	KCHSC	0.97	0	3.0	9.6	23.8	4.7	24.0
2003	1	SETVE	0.70	0	2.3	7.7	17.3	5.3	34.6
2003	1	ABUTH	0.08	0	0.5	3.7	3.2	8.4	74.9
2003	1	CIRAR	0.06	0	0.4	2.3	3.0	7.4	61.2
2003	1	AMARE	0.02	0	0.2	2.5	1.4	13.0	190.5
2003	1	SASKR	0.02	0	0.2	1.3	1.6	9.1	92.5
2003	1	Dicots	1.15	0	3.2	8.7	30.0	4.4	21.3
2003	1	Monocots	0.70	0	2.3	7.7	17.3	5.3	34.6
2003	1	Annuals	1.79	0	3.9	8.3	38.4	3.2	11.6
2003	1	Perennials	0.06	0	0.4	2.3	3.0	7.4	61.2
2003	1	All weeds	1.85	0	4.0	8.5	38.6	3.1	10.8

The cluster sample from site 1, 2003 included six different weed species representing all weed categories. Field means ranged from 0.02 to 1.85 weeds/quadrat. Medians were all 0 weeds/quadrat, and standard deviation values varied from 0.2 to 4.0. Coefficients of dispersion ranged from 1.3 to 9.6. Skewness and kurtosis values varied from 3.1 to 13.0 and 10.8 to 190.5, respectively.

Soil variable summary statistics are shown in Tables 2.5 and 2.6. Table 2.5 contains statistics for 30 soil variables; Table 2.6 contains only 28 variables due to the unavailability of soil EC data at site 1. Site 1 had slightly coarser soil texture, somewhat higher average organic matter, and lower average pH than site 4. Coefficients of dispersion for site 4 ranged from 0.001 to 38.1, and from 0.02 to 261 at site 1.

Table 2.5: Soil variable summary statistics, site 4 2002.

Variable	Unit	Mean	Median	Min	Max	SD	CD
Sand	%	61.9	62.0	46.0	73.2	5.72	0.53
Silt	%	19.4	19.2	11.2	27.2	3.53	0.64
Clay	%	18.7	18.8	10.8	26.8	3.54	0.67
OM	%	1.27	1.20	0.90	1.80	0.19	0.03
pH	-	8.11	8.10	7.90	8.40	0.11	0.001
N	ppm	20.2	20.0	9.00	34.0	5.47	1.48
N2	ppm	12.4	10.0	4.00	34.0	7.17	4.16
N3	ppm	9.06	8.00	2.00	33.0	6.33	4.42
N4	ppm	8.39	7.00	1.00	20.0	5.67	3.83
AM	ppm	4.70	4.36	3.15	9.89	1.41	0.42
AM2	ppm	3.87	3.72	2.36	7.10	0.95	0.23
AM3	ppm	2.21	2.20	0.82	3.66	0.71	0.23
AM4	ppm	3.62	3.66	2.09	5.50	0.71	0.14
P (Bray)	ppm	38.9	37.0	13.0	70.0	13.13	4.43
B	ppm	1.27	1.2	0.90	1.60	0.21	0.03
K	ppm	339	316	220	965	114	38.1
MG	ppm	519	503	383	680	73.3	10.4
CA	ppm	3367	3361	2479	3860	263	20.6
S	ppm	46.5	43.0	18.0	165	24.7	13.1
ZN	ppm	2.33	2.30	1.50	3.20	0.43	0.08
MN	ppm	3.43	3.30	2.10	8.50	0.96	0.27
CU	ppm	1.74	1.70	1.30	2.50	0.32	0.06
FE	ppm	9.95	9.60	5.80	33.40	4.18	1.76
CEC	cmol(+)/k	22.4	22.5	17.3	26.3	1.81	0.15
%K	%	3.89	3.70	2.50	10.50	1.28	0.42
%MG	%	19.2	19.3	15.9	23.0	1.66	0.14
%CA	%	75.1	74.9	70.9	78.5	2.04	0.06
%NA	%	1.83	1.80	1.30	2.70	0.28	0.04
ECS	mmho/m	25.5	22.7	13.2	45.5	8.22	2.65
ECD	mmho/m	7.07	6.54	3.15	12.33	2.19	0.68

Table 2.6: Soil variable summary statistics, site 1 2003.

Variable	Unit	Mean	Median	Min	Max	SD	CD
Sand	%	55.6	54.4	36.4	78.4	9.72	1.70
Silt	%	27.4	28.8	8.80	42.8	7.12	1.85
Clay	%	17.0	16.8	8.80	26.8	4.17	1.02
OM	%	1.58	1.60	0.90	2.50	0.28	0.05
pH	-	7.61	7.70	6.10	8.30	0.55	0.04
N	ppm	9.56	9.00	5.00	19.0	2.93	0.90
N2	ppm	5.53	3.00	1.00	38.0	6.77	8.28
N3	ppm	8.82	3.00	1.00	220	27.7	87.0
N4	ppm	8.26	3.00	1.00	142	23.0	63.9
AM	ppm	2.79	2.60	1.00	10.8	1.31	0.62
AM2	ppm	4.80	4.88	2.83	7.26	1.04	0.22
AM3	ppm	2.34	2.26	1.07	4.88	0.75	0.24
AM4	ppm	6.02	5.96	4.60	8.24	0.83	0.11
P (Bray)	ppm	18.0	17.0	2.00	58.0	10.60	6.24
B	ppm	0.79	0.80	0.50	1.10	0.14	0.02
K	ppm	522	527	313	679	86.2	14.2
MG	ppm	297	292	182	533	64.9	14.2
CA	ppm	3042	3010	1446	4604	893	262
S	ppm	6.82	7.00	3.00	11.0	1.74	0.45
ZN	ppm	1.67	1.70	0.40	2.70	0.50	0.15
MN	ppm	4.48	3.40	1.50	12.9	2.86	1.83
CU	ppm	0.75	0.70	0.50	1.30	0.16	0.03
FE	ppm	10.8	7.40	3.60	50.6	8.00	5.95
CEC	cmol(+)/k	19.3	19.7	10.5	28.9	4.63	1.11
%K	%	7.21	7.10	4.50	10.8	1.56	0.34
%MG	%	13.4	13.5	7.90	21.1	3.51	0.92
%CA	%	77.9	78.3	47.9	86.4	6.47	0.54
%NA	%	0.92	0.80	0.50	1.90	0.34	0.13

Spearman correlation coefficients between soil properties and weed species or category are presented in Tables 2.7 and 2.8. Over both sites, coefficients ranged from moderately high (0.59) to nonexistent (<0.01) in both positive and negative directions.

Table 2.7: Spearman correlation coefficients for soil variables and weed counts, site 4 2002.

Soil variable	Spearman correlation coefficient												
	Weed species or category												
	HELAN	KCHSC	ECHCG	CONAR	CIRAR	EPHGL	AMARE	SASKR	Annuals	Perrenials	Dicots	Monocots	All weeds
%Sand	0.24	-0.03	-0.22	-0.21	-0.23	-0.23	-0.05	-0.21	-0.27	-0.32 *	-0.02	-0.22	-0.11
%Silt	-0.09	-0.10	0.24	0.20	-0.01	0.23	0.15	0.20	0.13	0.12	-0.03	0.24	0.03
%Clay	-0.31 *	0.04	0.15	0.19	0.25	0.19	-0.10	0.19	0.24	0.32 *	0.00	0.15	0.09
%OM	0.09	-0.01	0.29 *	-0.03	0.15	0.08	0.13	-0.03	0.21	0.10	0.07	0.29 *	0.20
pH	0.06	0.13	-0.01	-0.16	0.06	-0.16	0.14	-0.16	0.07	-0.05	0.11	-0.01	0.13
N1	-0.04	0.06	0.14	-0.11	-0.10	0.20	-0.07	-0.11	0.15	-0.15	0.04	0.14	0.08
N2	-0.31 *	0.10	-0.21	-0.13	-0.17	-0.09	-0.04	-0.13	-0.02	-0.22	-0.35 *	-0.21	-0.41 †
N3	-0.10	-0.09	-0.32 *	-0.18	-0.30 *	-0.18	0.12	-0.18	-0.27	-0.35 *	-0.32 *	-0.32 *	-0.41 †
N4	-0.06	0.06	-0.27	-	-0.30	-	-	-	-0.01	-0.30	0.03	-0.27	-0.04
AM1	-0.03	-0.10	-0.21	0.01	-0.14	-0.08	-0.13	0.01	-0.16	-0.11	-0.14	-0.21	-0.16
AM2	0.06	-0.12	-0.02	-0.01	0.03	0.00	0.21	-0.01	-0.03	0.02	-0.08	-0.02	-0.02
AM3	0.43 †	-0.07	-0.10	0.13	0.09	-0.04	0.02	0.13	-0.06	0.16	0.41 †	-0.10	0.39 †
AM4	0.17	0.01	-0.26	-	0.07	-	-	-	-0.18	0.07	0.10	-0.26	-0.08
B	-0.04	0.08	0.26	0.22	0.14	-0.11	0.09	0.22	0.25	0.25	0.01	0.26	0.12
Ca	-0.19	0.06	0.16	0.21	0.25	0.18	-0.13	0.21	0.27	0.33 *	0.07	0.16	0.16
Cu	0.16	0.23	0.26	-0.18	0.04	-0.11	0.12	-0.18	0.31 *	-0.08	0.20	0.26	0.31 *
Fe	-0.03	-0.02	0.03	-0.21	0.02	0.02	0.20	-0.21	0.01	-0.11	-0.20	0.03	-0.17
K	-0.21	-0.10	0.06	-0.13	0.02	-0.14	0.03	-0.13	-0.13	-0.07	-0.39 †	0.06	-0.39 †
Mg	-0.09	0.02	0.32 *	0.15	0.24	0.17	0.05	0.15	0.29 *	0.29 *	0.06	0.32 *	0.18
Mn	-0.16	0.04	0.19	-0.10	0.13	-0.07	-0.03	-0.10	0.11	0.05	-0.17	0.19	-0.10
Na	-0.19	0.07	0.32 *	0.08	0.11	0.17	-0.01	0.08	0.26	0.14	-0.05	0.32 *	0.02
P	-0.01	-0.20	-0.14	-0.23	-0.09	-0.13	0.16	-0.23	-0.28 *	-0.21	-0.37 †	-0.14	-0.40 †
S	-0.14	-0.18	-0.33 *	0.23	-0.22	0.20	0.14	0.23	-0.18	-0.03	-0.20	-0.33 *	-0.30 *
Salt	-0.18	-0.07	-0.06	0.23	-0.09	0.22	0.08	0.23	0.04	0.07	-0.12	-0.06	-0.14
Zn	0.21	0.04	0.25	-0.22	-0.04	-0.01	0.10	-0.22	0.15	-0.17	0.12	0.25	0.22
CEC	-0.19	0.03	0.26	0.21	0.24	0.19	-0.08	0.21	0.29 *	0.32 *	0.03	0.26	0.15
%K	-0.13	-0.12	-0.05	-0.19	-0.13	-0.19	0.07	-0.19	-0.24	-0.22	-0.38 †	-0.05	-0.42 †
%Mg	0.01	-0.04	0.31 *	0.09	0.19	0.14	0.12	0.09	0.21	0.21	0.02	0.31 *	0.13
%Ca	0.08	0.07	-0.24	0.03	-0.10	-0.02	-0.11	0.03	-0.08	-0.06	0.18	-0.24	0.10
%Na	-0.04	0.03	0.16	-0.08	-0.07	0.12	0.04	-0.08	0.07	-0.10	-0.07	0.16	-0.09
ECS	0.13	0.21	-0.05	0.11	-0.14	-0.11	-0.02	0.11	0.11	-0.05	0.29 *	-0.05	0.22
ECD	0.04	0.20	0.17	0.17	-0.03	0.10	0.07	0.17	0.28 *	0.08	0.28 *	0.17	0.31 *

* denotes significance at alpha = 0.05.
† denotes significance at alpha = 0.01.

Table 2.8: Spearman's correlation coefficients for soil variables and weed counts, site 1 2003.

Soil variable	Spearman correlation coefficient										
	Weed species or category										
	KCHSC	SETVE	ABUTH	CIRAR	AMARE	SASKR	Annuals	Perrenials	Dicots	Monocots	All weeds
%Sand	0.12	0.01	-0.01	-0.05	-0.02	-0.10	0.11	-	0.06	0.01	0.11
%Silt	-0.12	0.00	0.00	0.01	-0.02	0.14	-0.10	-	-0.06	0.00	-0.10
%Clay	-0.12	-0.04	0.06	0.10	0.04	0.00	-0.11	-	-0.07	-0.04	-0.11
%OM	-0.17	-0.07	0.00	0.05	0.20	0.07	-0.16	-	-0.11	-0.07	-0.16
pH	0.58 †	0.09	0.13	-0.25 *	-0.14	-0.08	0.43 †	-	0.45 †	0.09	0.43 †
N1	0.07	-0.02	0.19	0.18	0.04	0.05	0.17	-	0.19	-0.02	0.17
N2	-0.10	0.12	0.07	0.07	0.11	0.09	0.10	-	0.03	0.12	0.10
N3	0.02	0.27 *	0.21	0.23	0.15	0.18	0.23 *	-	0.18	0.27 *	0.23 *
N4	-0.08	0.22	0.25 *	0.24 *	0.20	0.23 *	0.17	-	0.10	0.22	0.17
AM1	0.40 †	0.02	-0.01	0.05	-0.16	-0.18	0.26 *	-	0.29 *	0.02	0.26 *
AM2	0.09	-0.15	-0.05	-0.04	-0.16	-0.19	-0.05	-	-0.01	-0.15	-0.05
AM3	0.30 †	-0.06	0.15	-0.10	0.05	-0.08	0.17	-	0.24 *	-0.06	0.17
AM4	0.12	-0.07	-0.25 *	-0.09	-0.04	-0.03	-0.05	-	0.04	-0.07	-0.05
B	0.50 †	0.12	0.20	-0.21	-0.03	-0.03	0.41 †	-	0.41 †	0.12	0.41 †
Ca	0.52 †	0.09	0.07	-0.19	-0.06	0.00	0.34 †	-	0.41 †	0.09	0.34 †
Cu	0.01	-0.23 *	0.06	0.01	0.03	-0.04	-0.11	-	-0.01	-0.23 *	-0.11
Fe	-0.40 †	-0.22	-0.06	0.18	0.05	-0.09	-0.35 †	-	-0.34 †	-0.22	-0.35 †
K	0.15	0.01	0.26 *	-0.05	0.27 *	0.00	0.16	-	0.21	0.01	0.16
Mg	-0.02	0.12	0.20	0.10	0.29 *	0.05	0.06	-	0.10	0.12	0.06
Mn	-0.31 †	-0.26 *	-0.08	0.19	0.04	-0.06	-0.31 †	-	-0.25 *	-0.26 *	-0.31 †
Na	-0.39 †	-0.02	-0.02	0.23	0.32 †	0.03	-0.26 *	-	-0.24 *	-0.02	-0.26 *
P	-0.13	-0.16	0.08	0.11	-0.12	-0.09	-0.07	-	-0.12	-0.16	-0.07
S	0.43 †	-0.03	0.17	-0.11	-0.11	-0.14	0.29 *	-	0.37 †	-0.03	0.29 *
Salt	0.45 †	0.06	0.14	-0.09	0.00	-0.03	0.31 †	-	0.40 †	0.06	0.31 †
Zn	0.05	-0.05	0.10	0.10	-0.07	-0.10	0.11	-	0.05	-0.05	0.11
CEC	0.52 †	0.08	0.10	-0.19	-0.04	0.00	0.33 †	-	0.42 †	0.08	0.33 †
%K	-0.46 †	-0.08	0.06	0.17	0.22	-0.01	-0.26 *	-	-0.32 †	-0.08	-0.26 *
%Mg	-0.43 †	0.02	0.06	0.22	0.25 *	0.06	-0.24 *	-	-0.26 *	0.02	-0.24 *
%Ca	0.49 †	0.02	-0.04	-0.21	-0.23	-0.04	0.29 *	-	0.32 †	0.02	0.29 *
%Na	-0.59 †	-0.03	-0.06	0.25 *	0.20	0.02	-0.38 †	-	-0.44 †	-0.03	-0.38 †

* denotes significance at alpha = 0.05.
† denotes significance at alpha = 0.01.

Site 4 had significant correlations in 44 instances, 11 of which were significant at alpha = 0.01, with all coefficients ranging from -0.28 to -0.42 and 0.28 to 0.43. The number of coefficients less-than and greater-than zero were roughly even (197 negative, 210 positive). Correlation coefficients were significant at alpha = 0.05 and 0.01 more often with weed categories than with individual weed species. Total weeds had the highest number of significant correlations at alpha = 0.05 and 0.01; dicots had similarly high numbers of significant correlations as all but one of the species present were dicots. Nitrogen at the third depth layer (N3) had the highest number of significant correlations across all weed species and categories, and all significant coefficients were negative. Kochia, field bindweed, ridgeseed spurge, redroot pigweed, and Russian thistle had no significant correlations with soil variables. Slightly less than half of the soil variables tested did not have significant correlations with weed species or categories.

Site 1 had 77 significant correlations, of which 42 were significant at alpha = 0.01, with all coefficients ranging from -0.23 to -0.59 and 0.23 to 0.68. As with site 4, site 1 had approximately even numbers of negative and positive correlation coefficients (140 negative, 160 positive). The majority of significant correlations were associated with kochia, annuals, dicots, and total weeds, although all weed species and categories (with the exception of perennials, which were not present in the sample set) had at least one significant correlation. All fifteen of the significant correlations associated with kochia were significant at alpha = 0.01. Similarly, annuals, dicots, and total weeds had high numbers of significant correlations at alpha = 0.01, which was likely influenced by the prevalence of kochia at this site. Approximately three quarters of the soil variables had at least one significant correlation coefficient, and over half have four or more.

MRPP analysis of grid sampled data separated by management zone is summarized in Table 2.9. This Table shows only which zones were found to be significantly different by the MRPP test at alpha = 0.05 adjusted for multiple comparisons (0.05 divided by number of comparisons); it does not depict infestation or population density information.

Table 2.9: Multiple-response permutation separation procedure summary, 2001 and 2002.

Year	Site	Weed species or category	Management zone Low	Med	High	Year	Site	Weed species or category	Management zone Low	Med	High
2001	1	SETVE	a	b	b	2002	1	SETVE	a	a	a
2001	1	ABUTH	a	b	ab	2002	1	KCHSC	a	a	a
2001	1	ECHCG	a	a	a	2002	1	ABUTH	a	a	a
2001	1	CCHIN	a	a	a	2002	1	Dicots	a	a	a
2001	1	AMARE	a	a	a	2002	1	Monocots	a	a	a
2001	1	TRBTE	a	a	a	2002	1	Annuals	a	a	a
2001	1	CIRAR	a	a	a	2002	1	Perennials	-	-	-
2001	1	KCHSC	a	b	a	2002	1	All weeds	a	a	a
2001	1	Dicots	a	a	a	2002	4	HELAN	a	a	a
2001	1	Monocots	a	ab	b	2002	4	KCHSC	a	a	a
2001	1	Annuals	a	a	a	2002	4	ECHCG	ab	a	b
2001	1	Perennials	a	a	a	2002	4	CONAR	a	a	a
2001	1	All weeds	a	a	a	2002	4	AMARE	a	a	a
2001	2	ABUTH	a	a	a	2002	4	EPHGL	a	a	a
2001	2	AMARE	a	a	a	2002	4	TRBTE	a	a	a
2001	2	SASKR	a	a	a	2002	4	ABUTH	a	a	a
2001	2	TRBTE	a	a	a	2002	4	SASKR	a	a	a
2001	2	HELAN	a	a	a	2002	4	Dicots	a	a	a
2001	2	KCHSC	a	a	a	2002	4	Monocots	ab	a	b
2001	2	ECHCG	a	a	a	2002	4	Annuals	a	a	a
2001	2	CHEAL	a	a	a	2002	4	Perennials	a	a	a
2001	2	SOLSA	a	a	a	2002	4	All weeds	a	a	a
2001	2	XANST	a	a	a	2002	5	AMARE	a	a	a
2001	2	Dicots	a	a	a	2002	5	SASKR	a	a	a
2001	2	Monocots	a	a	a	2002	5	KCHSC	a	a	a
2001	2	Annuals	a	a	a	2002	5	ECHCG	a	b	ab
2001	2	Perennials	-	-	-	2002	5	TRBTE	a	a	a
2001	2	All weeds	a	a	a	2002	5	SOLRS	a	a	a
2001	3	SOLSA	a	b	ab	2002	5	HELAN	a	a	a
2001	3	AMARE	a	b	b	2002	5	CIRAR	a	a	a
2001	3	CCHIN	a	b	ab	2002	5	ABUTH	a	b	c
2001	3	ECHCG	a	b	b	2002	5	Dicots	a	a	a
2001	3	Dicots	a	b	ab	2002	5	Monocots	a	b	ab
2001	3	Monocots	a	b	ab	2002	5	Annuals	a	a	a
2001	3	Annuals	a	b	ab	2002	5	Perennials	a	a	a
2001	3	Perennials	-	-	-	2002	5	All weeds	a	a	a
2001	3	All weeds	a	b	ab						

Significant differences in weed species or category by zone were found in all sites and years. At least two management zones were similar by this statistical measure in all tests with the exception of velvetleaf at site 5 in 2002. In comparing the two sampling years from site 1, there were no similarities in weed species or category differences by zone in any instance. Likewise, none of the weed species exhibited similar zone-difference patterns between different sites and/or years. The only weed category to show a repetitive pattern with significant differences was monocots for sites 3 (2002), and site 5 (2003, low zone different from medium zone but high zone similar to both low and medium zones).

Contingency table separation summaries based on chi-square tests are presented in Table 2.10. Significant presence/absence differences were generally less prevalent than differences in actual population size (MRPP analysis). Of the 24 weed species or categories that had significant differences in the contingency table analysis, 15 of them were identical to those found with the MRPP analysis. Monocots were the only category that had similar zone difference patterns between sites and years (site 1, 2001 and site 5). There were no consistencies between zone difference patterns with any of the individual weed species.

Table 2.10: Contingency table separation summary from chi-square test, 2001 and 2002.

Year	Site	Weed species or category	Management zone Low	Med	High	Year	Site	Weed species or category	Management zone Low	Med	High
2001	1	SETVE	a	b	b	2002	1	SETVE	a	a	a
2001	1	ABUTH	a	b	a	2002	1	KCHSC	a	b	b
2001	1	ECHCG	a	a	a	2002	1	ABUTH	a	a	a
2001	1	CCHIN	a	a	a	2002	1	Dicots	a	b	b
2001	1	AMARE	a	a	a	2002	1	Monocots	a	a	a
2001	1	TRBTE	a	a	a	2002	1	Annuals	a	b	ab
2001	1	CIRAR	a	a	a	2002	1	Perennials	-	-	-
2001	1	KCHSC	a	a	a	2002	1	All weeds	a	b	ab
2001	1	Dicots	a	b	ab	2002	4	HELAN	a	a	a
2001	1	Monocots	a	b	b	2002	4	KCHSC	a	a	a
2001	1	Annuals	a	a	a	2002	4	ECHCG	a	a	b
2001	1	Perennials	a	a	a	2002	4	CONAR	a	a	a
2001	1	All weeds	a	a	a	2002	4	AMARE	a	a	a
2001	2	ABUTH	a	a	a	2002	4	EPHGL	a	a	a
2001	2	AMARE	ab	a	b	2002	4	TRBTE	ab	a	b
2001	2	SASKR	a	a	a	2002	4	ABUTH	a	a	a
2001	2	TRBTE	a	a	a	2002	4	SASKR	a	a	a
2001	2	HELAN	a	a	a	2002	4	Dicots	a	a	b
2001	2	KCHSC	a	a	a	2002	4	Monocots	a	a	b
2001	2	ECHCG	a	a	a	2002	4	Annuals	a	a	a
2001	2	CHEAL	a	a	a	2002	4	Perennials	a	a	a
2001	2	SOLSA	a	a	a	2002	4	All weeds	a	a	b
2001	2	XANST	a	a	a	2002	5	AMARE	a	a	a
2001	2	Dicots	ab	a	b	2002	5	SASKR	a	a	b
2001	2	Monocots	a	a	a	2002	5	KCHSC	a	a	a
2001	2	Annuals	ab	a	b	2002	5	ECHCG	a	b	b
2001	2	Perennials	-	-	-	2002	5	TRBTE	a	ab	b
2001	2	All weeds	ab	a	b	2002	5	SOLRS	ab	a	b
2001	3	SOLSA	a	a	a	2002	5	HELAN	a	a	a
2001	3	AMARE	a	b	b	2002	5	CIRAR	a	a	a
2001	3	CCHIN	a	a	a	2002	5	ABUTH	a	a	a
2001	3	ECHCG	a	a	a	2002	5	Dicots	a	a	a
2001	3	Dicots	a	a	a	2002	5	Monocots	a	b	b
2001	3	Monocots	a	a	a	2002	5	Annuals	a	a	a
2001	3	Annuals	a	a	a	2002	5	Perennials	a	a	a
2001	3	Perennials	-	-	-	2002	5	All weeds	a	a	a
2001	3	All weeds	a	a	a						

DISCUSSION

The suite of weed species detected at sampling sites was not always consistent between years or sampling strategies. At site 1, two fewer weed species were found during cluster sampling in 2003, and five fewer during grid sampling in 2002 than during the 2001 sampling. Planting dates were similar for all years at site 1. Samples were taken late in the season in 2001, giving weed species more time to emerge. In 2003, samples were taken 60 days earlier in the growing season, and 80 days earlier in the 2003 growing season compared to the 2001 sample. It is probable that the relative time difference between samples enabled more diverse weed species to emerge at later sampling dates. Sampling in 2003 was done only with the cluster method, which may account for not capturing the presence of certain species along the crop perimeter, where weed densities and diversity is often highest.

Sampling strategy may also account for differences in weed species seen at site 4 in 2002. The cluster sampling was performed the day after grid sampling, yet the cluster sample did not include velvetleaf or puncturevine species, which were found in grid sampling; and grid sampling did not include Canada thistle, which was found in the cluster sampling. Cluster samples are spatially intimate within clusters, and clusters are much sparser than individual grid samples. Puncturevine was especially noticeable only within short distances of the field perimeter where cluster samples were rare. Canada thistle was found thinly scattered within the field in tightly bunched patches where individual samples from the grid strategy could easily miss them. Velvetleaf was scarce

in site 4, present in only two quadrats of the 231 samples taken both of which near the Eastern field edge where cluster samples were not present.

Coefficients of dispersion give a rough impression of spatial pattern. Values less than one are often spatially random, values greater than one are spatially aggregated, and values of approximately one are considered to have a regular spatial pattern. Coefficients of dispersion do not give detailed spatial information, but are good indicators, particularly for large sample sets.

The majority of C.D.s for weed species and categories from all sample sets were greater than one, supporting the widely accepted notion that weeds are spatially aggregated in agricultural fields. In 2001, all C.D. values were greater than or equal to 1. The majority of C.D. values at 1 were at site 2 (eight instances), followed by site 1 (four instances); site 3 had no C.D. values equal or less than 1. Half of the C.D. values equal to 1 at sites 1 and 2 were in the high management zone, suggesting this zone may have had a more regular dispersion of several of the weed species/categories at these sites in 2001.

All instances in which C.D.s were less than one occurred in 2002, and only at sites 4 and 5. Site 4 had C.D.s equal to 1 for four of the weed species/categories and less than 1 for five of the weed species/categories in the high zone, suggesting that on a small scale (within the high zone) groupings of weeds appeared to be spatially regular to random. At site 5, the C.D. for kochia in the low management zone was slightly less than 1 (0.94); all other weed species/categories were greater than one indicating weeds were generally aggregated.

None of the weed species or weed categories that had C.D. vaules equal or less than one at site 1 were similar from 2001 to 2002. Likewise, no trends were seen in C.D.

values of the same weed species or category between sites within the same sampling year other than those greater than one. This reinforces the aggregated nature of weeds and suggests the regular or random spatial patterns inferred by C.D.s less than or equal to 1 were local and/or temporal anomalies and not inherently characteristic of the weed species or category.

Coefficients of dispersion were less than one for the majority of soil variables (19 out of 30 at site 4 in 2002; 15 out of 28 at site 1 in 2002), suggesting they are generally randomly distributed spatially. All four of the nitrogen variables at site 4 had values greater than one, indicating that nitrogen may aggregate at both surface and sub-surface levels due to soil and/or nutrient application conditions at this site. However, multi-year data for soil nitrogen was not available for this site, and therefore this cannot be confirmed as a stable trend over time. At site 1, only the sub-surface nitrogen variables exhibited C.D.s greater than one.

Skewness and kurtosis values give information of how the data differs from normally distributed data. Skewness represents the degree of asymmetry of the distribution around the mean. A positive skewness value corresponds to a distribution with an asymmetric tail towards positive values, and vice versa. Kurtosis represents the peakedness of the distribution relative to a normal distribution. Positive kurtosis values imply a more peaked distribution, and negative values a flatter distribution.

For weed count data, the majority of skewness and kurtosis values were positive, indicating peaked distributions with asymmetric tails towards positive values. This is consistent with the negative binomial distribution, which is often associated with weed-count data (Wiles et al., 1992; Cardina et al., 1995; Johnson et al., 1995; Marshall, 1989).

Several kurtosis values were negative for 2002 data. This can be attributed to a high frequency of quadrats with both high and zero weed densities in these situations. This effectively stretches the distribution at the peak, and generates negative kurtosis values.

Weed species and category counts generally did not show high degrees of correlation with soil properties. Significant correlations were found for both negative and positive coefficients in approximately equal proportions, indicating that soil properties relate directly and inversely with weed populations. Between the two site-years, comparable weed species and categories had relatively few common significant correlation coefficients, and even fewer that were both significant and of the same sign.

Several studies have found significant relationships between soil variables related to herbicide adsorbtion (mostly soil texture and organic matter) and weed densities or occurrence (Ervio et al., 1994; Dielman et al., 2000; Gaston et al., 2001). In this study, percent sand was the only soil texture variable that was significantly correlated with a weed variable (perennial weeds, site 4). Organic matter was significantly correlated with only monocots (barnyardgrass) at site 4. The coefficient between percent sand and perennial weeds was negative, which may suggest that perennial weeds prefer finer textured soils for root system stability or lower levels of soil-active herbicides due to increased soil adsorption. Organic matter was positively correlated with monocots, which may indicate that it plays some role in initiating germination or promoting growth for grass species. It is also possible that grasses are highly susceptible to herbicides used at site 4, and they find refuge in areas of high organic matter due to its high adsorption capabilities. The general lack of significant correlations of soil texture variables and organic matter with weeds may suggest that these soil variables were either not a

significant factor in safe-site assertion, or spatial variability was not great enough to account for weed patchiness in this study.

The role of pH in determining the abundance of weed species has been examined in several studies (Buchanan et al., 1975; Weaver and Hamill, 1985; Ervio et al., 1994; Ashad et al., 1997; Dielman et al., 2000; Medlin et al., 2001). Soil pH can affect the means and dispersion of weed seed production, as well as the availability of soil-applied herbicides to weeds. In this study, pH was only significantly correlated with two weed species (kochia and Canada thistle) and annual (total) weeds at site 1. Kochia had a moderate and positive correlation coefficient (0.58) with pH, indicating that it may have a preference for more alkaline soils. Canada thistle, however, had a weaker and negative correlation coefficient (-0.25) with pH. The dominant weed at site 1, in 2003 was kochia, which influenced the annual weeds category to have a similar correlation coefficient to that of kochia.

Soil fertility variables have also been noted to affect weed growth (Banks et al., 1976; Medlin et al., 2001; Ervio 1994), as certain species may be limited or competitively enhanced by nutritional needs and availabilities. Various significant correlations were found between soil fertility variables and weed species or categories in this study, yet again very few similarities between the two sites existed. At site 4, nitrogen and ammonia levels from the top layer of soil did not have any significant correlations with weeds or categories, but had several with levels lower in the soil profile. Site 1 also had no significant correlations between nitrogen at the top soil-layer and weeds, but had four positive correlations with ammonia at the surface. Nitrogen at a depth from 10 to 15 cm beneath the soil surface (N3) seemed to have a strong negative influence on weed

variables at site 4, but a positive influence at site 1. Potassium and phosphorous both had only negative significant correlation coefficients at site 4, yet potassium was only positive when significant phosphorous was never significant at site 1. Similar disparities were abundant for the majority of soil nutrient variables. The only direct similarities in coefficient significance and sign found between sites was with annual weeds and cation exchange capacity (both positive), dicots and percent potassium (both negative), and total weeds and percent potassium (both negative).

Analogous dissimilarities existed with the management zone analysis. The multiple-response permutation procedure results indicate that three management zones delineated by soil color do not correspond well to weed abundance. Of the 35 instances in which significant differences were found between zones, only one found all three zones to be distinct from each other (velvetleaf at site 5 in 2002). The low zone was dissimilar from the other management zones ten times, the high zone eight times, and the medium zone only twice. However, the low and medium zones were significantly different with the high zone and not significantly different from either zone six time; medium and high zones were different with the low zone similar to both zones seven times. If management zones do in fact have some relationship with weed densities, we would expect to see several cases where the low and high zones are significantly different from each other but not from the intermediate medium management zone. However, we see this scenario only twice.

Weed presence or absence differences between zones were also sporadic. Although more than half of the instances that detected differences between at least two zones had the same differences as those found with the MRPP analysis, there were no

cases in which all three zones were significantly different from each other. As with the MRPP, the low and high zones were significantly different from all other zones in the majority and almost equal number of cases (7 and 5, respectively).

Development of sampling strategies for generating weed maps is a fundamental step in the implementation of precision weed control. This study has demonstrated how specific sampling tactics can determine not only the level of infestation, but which weed species are detected as well. The ideal strategy will vary with weed infestation, field size, and resources available. Weeds have an intimate relationship with soil characteristics, but the degree to which soil properties designate if and how many weeds occur at specific sites can vary widely, in both time and space. The results of this study reinforce this, and other factors that may contribute to spatial and temporal placement and/or germination and growth of weed species were not obvious. Environmental conditions such as wind and water movement are possible causes, but it is likely that there is a good deal of randomness involved that would be difficult to model. It is possible to use soil properties to streamline weed sampling strategies. However, the specific method in which they are used must be evaluated on a site by site, and possibly year by year basis.

The use of management zones is still a promising concept for the future of precision agriculture. It is logical to assume that large-scale zones would relate to crop species due to their complete coverage of the area of interest. Weeds rarely come close to completely covering a field, and thus have a weak, if any, relationship with large-scale management zones. The results of this study indicate that weeds may be better classified by two zones as opposed to three. In a spray or no-spray situation, weed densities are unimportant, so delineation of low, medium, and high weed infestation zones are not

necessary. From the results of this study, it is unclear if delineation of weed management zones based solely on soil color is the most appropriate method. Use of actual soil data in the management zone definition process may improve zone correlation with weeds. However, choosing which variables to integrate into the process, and how to use them, may again vary by site and/or year. The degree of patchiness evident in the weed count data would make any large-scale zoning of weed populations seem illogical. Delineation of zones on a smaller scale may be more relevant for categorizing weeds, but it is unknown if this would a feasible practice. Regardless, from the results of this study, it appears unlikely that management zones that are appropriate for variable nutrient application will also be suitable for site-specific herbicide application.

CHAPTER 3

Contributions of Large Scale Soil Properties and Nitrogen Application to the Dissipation of Atrazine and Metolachlor and Implications to Weed Patchiness

INTRODUCTION

It has been well documented that weeds are spatially aggregated in agricultural situations (Marshall, 1988, 1989; Thornton et al., 1990; Wilson and Brain, 1990; Wiles et al., 1992; Mortensen et al., 1993; Chancellor and Goronea, 1994; Brown et al., 1994; Donald, 1994; Cardina et al., 1995; Rew and Cussans, 1995; Johnson et al., 1995, 1996; Gerhards et al., 1997, 2000; Christensen and Heisel, 1998; Mortensen et al., 1998; Dammer et al., 1999; Dielman and Mortensen, 1999; Dielman et al., 2000; Gonzalez-Andujar and Saavedra, 2003; Jurado-Exposito et al., 2003), but the causes of weed patchiness are not well understood. In some cases it has been attributed to mechanisms of seed dispersal and vegetative reproduction, the spatial variation of soil conditions required for initiating germination and promoting growth, and/or the absence of hazards (van Groenendael, 1988; Donald, 1994; Zanin et al., 1998).

The ability to predict the spatial configuration of weed patches is beneficial to both producers and the environment. Chemical application technology can be used to

selectively place agricultural inputs only on areas of fields where it would be beneficial to crop yield. In the case of weed control, herbicides would only be applied to areas where herbicide use, associated producer costs, and environmental risks could be seen with the implementation of precision application technology. However, benefits will only be seen if inputs requirements can be accurately and cost effectively delineated spatially. An understanding of the factors underlying weed patchiness would enhance the efficiencies of field delineation and therefore is a key component in implementing site specific weed control.

In managed areas, pre-emergent herbicides can influence the spatial distribution of weed populations. First, variability in the amount of herbicides at the soil level is inherent in large-scale application processes. Drift, volatilization, and physical inequalities in the application apparatus across the field (speed of sprayer, height of spray boom, etc.) are but a few of the factors that can contribute to variation in herbicide application rates. Secondly, soil conditions such as texture, organic matter, pH, and soil moisture content can affect the availability of soil-applied herbicides to weeds. Both of these factors can create spatial patches where sub-toxic levels of herbicide exist, increasing the likelihood of weed occurrence and thus contributing to overall weed patchiness.

Describing variation in soil conditions across large areas at a useful scale is not a cost efficient method in implementing precision weed control, since it is but one factor in a complex system governing where weed populations exist. In understanding the relationship between herbicide dissipation and soil properties, a more cost effective approach would be to examine large areas of similar soil types within a field.

Khosla et al. (2002) investigated the use of management zones to increase applied nutrient efficiencies. They defined management zones as areas within a field having similar soil traits, and are categorized into low, medium, and high crop producing regions. Decision processes for delineating these zones involves primarily soil information such as reflectance from remotely-sensed imagery, but can utilize farmer's knowledge, topography, and yield data. Khosla et al. (2002) found that these zones have a high potential for increasing nutrient input efficiencies by varying the input across zones in comparison to blanket applications at a fixed rate.

Management zone delineation is largely dictated by soil characteristics. These same soil characteristics also influence soil-applied herbicide degradation and dissipation. There is the potential then that management zones may also correlate with distinct herbicide dissipation properties, and could be used as part of the overall weed mapping process.

It has also been documented that nitrogen applications have some interaction with the degradation of herbicides (Donnelly 1991, Entry et al. 1993, Gebendinger and Radosevich 1999), and may alter the bio-availability of soil applied herbicides. In the presence of nitrogen fertilizer and herbicides, some microorganisms responsible for herbicide degradation will utilize the more readily available nitrogen fertilizer as an energy source before breaking down the herbicide, thereby decreasing the degradation rate of the herbicides.

The objectives of this study were to determine the relationship between two field properties: Management zones and nitrogen application rates, and the dissipation of two commonly used pre-emergent herbicides (atrazine and metolachlor).

MATERIALS AND METHODS

This study was conducted just north of the Agricultural Research, Development, and Education Center (ARDEC) at Colorado State University in Fort Collins, Colorado. The site was a furrow-irrigated corn field that had been divided into three management zones (low, medium, or high productivity) per the method described in Khosla et al. (2002). Within each management zone, four replications of three different nitrogen treatment regimes were set up in a completely randomized block design: 0, 50, and 200 pounds of nitrogen per acre.

Pre-emergent herbicides were applied just after planting and prior to crop emergence. The spray rig was set up with 11004 nozzles with 20 inch spacing; overall boom length was 40 feet and positioned approximately 20 inches from the ground. The pump was operated at 30 psi and the rig speed was approximately 5 mph during application. Calibration and uniformity assessment was performed by measuring individual sprayer-nozzle output at operating pressure for one minute.

Three cellulose filter papers (3 inch diameter) were placed at each sample site prior to herbicide application in order to measure the actual amount of herbicide applied and variability at the soil surface. A tank mixture of atrazine and s-metolachlor was applied at 1.63 and 1.26 lbs. ai./ acre, respectively. Filter papers were collected, placed in sealed plastic bags, and refrigerated immediately after application was completed.

One day after application of herbicides, sample locations were marked with flags and the first set of soil samples were taken from the top 12 inches of soil. Subsequent

samples were taken at 9, 19, 29, 40, 54, 68, and 99 days after application. All but the first set of samples were taken with a zero-contamination sampler. Zero-contamination tubes were stored at 0 °C until extraction and analysis were performed. Each tube was sawed into two 6 inch sections, in order for the 0-6 and 6-12 inch depths to be analyzed separately.

Herbicide residue analysis involved extraction of the herbicides from the soil (or filter paper) into 10 mL of toluene. This was done in a glass centrifuge tube with 10 g of the soil sample (pre-mixed for heterogeneity) or the filter paper, 10 mL of de-ionized water, and 10 mL of toluene. Extraction efficiency was tested prior to sample analyses on spiked field-soil samples with and without 10 mL of de-ionized water. Results found higher recoveries with the water added (99% recovery with versus 80% without). Centrifuge tubes were capped with Teflon-lined screw-caps, shaken vigorously for one hour in a horizontal shaker, and then centrifuged for ten minutes. Two mL of the toluene extraction was then placed in a volumetric tube with 10 micrograms of metribuzin, which was used as the internal standard. Extracts were then transferred to sample vials for gas chromatograph/mass spectrometer analysis. Curve-area ratios were compared against analytical standards run with the samples for quantification of herbicide residues. Quality control samples of untreated soil were spiked with 1.0, 0.1, and 0 ppm of atrazine and metolachlor, run through the same extraction as field samples, and analyzed twice with each sample set to assess accuracy and contamination.

Due to the large amount of variability seen in the data after the samples from the first two time points were analyzed, two samples were randomly selected from each management zone at each of the first two time points and the 0 to 6 inch soil depth was

re-analyzed. This was done in order to determine the portion of variability inherent in the extraction and quantification procedure.

Disassociation coefficients (Kd) were also generated for atrazine and metolachlor with field soils collected from sites throughout the study area with known variability in conductivity values (conductivity is one of the factors used in the delineation of management zones).

For statistical analyses, a log(x + 0.01) transformation were used to normalize data. Initial analysis of the data using repeated measures models did not result in any statistically significant differences. In order to more thoroughly investigate the data, PROC MIXED COVTEST in SAS and Tukey-adjusted least square means was used to determine statistically significant differences per time point. Statistical significance was evaluated with adjusted alpha values by the number of comparisons made to mitigate for Type I errors.

RESULTS

Analysis of the boom-sprayer indicated nozzles ranged in output from 0.33 to 0.35 gal/min. Figure 3.1 illustrates uniformity in spray pattern, with small (~0.02 gal/min) spikes and dips across the boom length, fairly typical of flat fan overlapping spray patterns at the nozzles.

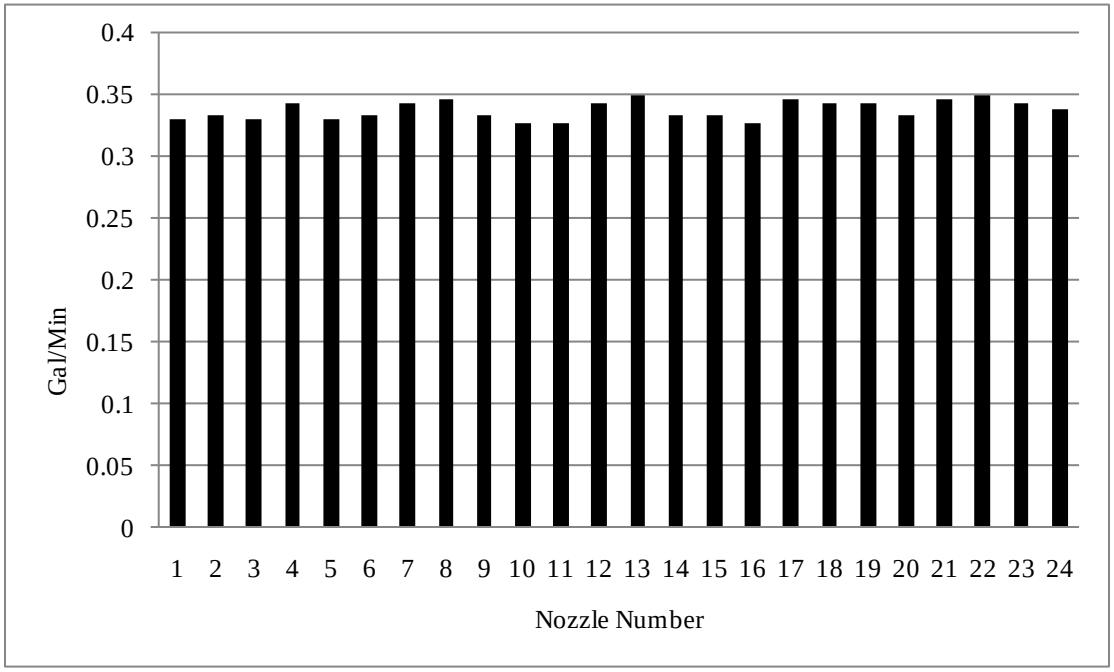

Figure 3.1. Boom sprayer output level by nozzle.

Filter paper herbicide residue statistics are presented in Table 3.1. Values ranged from 405.73 to 1863.01 µg/paper for atrazine and 319.32 to 1296.88 µg/paper for metolachlor. Coefficients of variation were approximately 33% and 32% for atrazine and metolachlor, respectively. Within each cluster of three filter papers placed per sample site, average values ranged from 563.44 µg/paper to 1350.62 µg/paper (standard deviations from 37.42 to 531.21) for atrazine and from 434.52 µg/paper to 1010.08 µg/paper (standard deviations from 12.40 to 341.55) for metolachlor. Converting the average µg residues per filter paper to lbs ai/ac results in 1.60 and 1.27 lb ai/ac for atrazine and metolachlor, respectively.

Table 3.1. Filter paper residues by ug/paper.

Chemical	Mean (μg/paper)	SD
Atrazine	818.98	253.44
Metolachlor	650.22	193.94

Kd values from field soil ranged from 0.34 to 0.79 for atrazine and from 0.72 to 1.35 for metolachlor. Average values and variation are presented in Table 3.2. Coefficients of variation were 16.4% for atrazine and 11.3% for metolachlor. A single factor ANOVA was performed to test for statistical difference between sample replications, p-values were 0.50 ($F_{7, 24} = 0.93$) for atrazine samples and 0.16 ($F_{7, 24} = 1.68$) for metolachlor samples, indicating no statistical differences.

Table 3.2. Kd statistics for atrazine and metolachlor from field soil sample analysis.

Chemical	Mean (Kd)	SD
Atrazine	0.42	0.07
Metolachlor	0.95	0.11

Herbicide residues were found primarily in the top 6 inches of the soil samples. Recoveries from the top 6 inches had initial values ranging from 0.34 ppm to 1.73 ppm for atrazine and 0.26 ppm to 1.85 ppm for metolachlor. Final levels at 99 DAT ranged from 0.01 ppm to 0.96 ppm for atrazine and 0.03 ppm to 0.72 ppm for metholachlor. Average herbicide levels and standard deviations in the 0 to 6 inch depths for all treatments are presented in Tables 3.3-3.4. Dissipation curves are presented in Figures 3.2-3.3.

Table 3.3. Atrazine residues, 0-6 inch depth by management zone and nitrogen treatment over 99 days [mean (standard deviation)]

Management zone	Nitrogen treatment (lbs/ac)	Days after treatment 1	9	19	29	40	54	68	99
	0	1.20 (0.61)	0.78 (0.32)	0.51 (0.25)	0.63 (0.29)	0.60 (0.16)	0.73 (0.33)	0.42 (0.22)	0.05 (0.03)
Low	50	1.26 (0.37)	0.70 (0.42)	0.75 (0.40)	0.58 (0.17)	0.70 (0.25)	1.18 (0.84)	1.07 (0.82)	0.07 (0.08)
	200	1.26 (0.33)	1.06 (1.01)	0.60 (0.34)	0.37 (0.14)	0.53 (0.33)	0.67 (0.29)	0.54 (0.28)	0.33 (0.43)
	0	0.92 (0.50)	0.20 (0.12)	0.53 (0.24)	0.48 (0.24)	0.68 (0.26)	0.62 (0.14)	0.27 (0.33)	0.04 (0.03)
Medium	50	0.78 (0.24)	0.25 (0.14)	0.92 (0.42)	0.43 (0.09)	0.60 (0.19)	0.77 (0.47)	0.46 (0.38)	0.08 (0.08)
	200	0.83 (0.39)	0.55 (0.34)	0.51 (0.05)	0.53 (0.30)	0.53 (0.14)	0.94 (0.48)	0.53 (0.47)	0.04 (0.02)
	0	1.06 (0.19)	0.30 (0.11)	0.30 (0.18)	0.37 (0.12)	0.81 (0.25)	0.59 (0.20)	0.19 (0.11)	0.06 (0.06)
High	50	0.82 (0.25)	0.38 (0.07)	0.44 (0.18)	0.59 (0.13)	0.61 (0.14)	1.00 (0.54)	0.23 (0.16)	0.04 (0.02)
	200	0.92 (0.28)	0.40 (0.07)	0.22 (0.05)	0.34 (0.09)	0.45 (0.21)	1.12 (0.23)	0.16 (0.09)	0.10 (0.08)

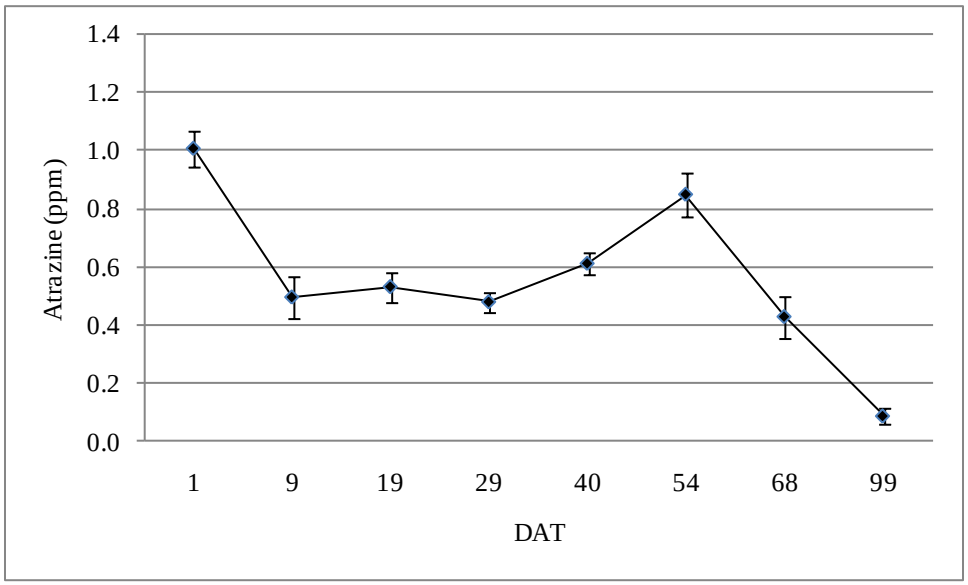

Figure 3.2. Field averages of atrazine levels at 0-6 inch sample depth with standard errors.

Table 3.4. Metolachlor residues, 0-6 inch depth management zone and nitrogen treatment over 99 days [mean (standard deviation)]

Management zone	Nitrogen treatment (lbs/ac)	Days after treatment 1	9	19	29	40	54	68	99
Low	0	0.92 (0.47)	0.57 (0.24)	0.34 (0.22)	0.41 (0.19)	0.36 (0.12)	0.37 (0.18)	0.28 (0.15)	0.17 (0.12)
	50	0.96 (0.28)	0.44 (0.25)	0.53 (0.31)	0.36 (0.11)	0.42 (0.19)	0.70 (0.58)	0.50 (0.30)	0.23 (0.15)
	200	0.97 (0.22)	0.66 (0.65)	0.39 (0.26)	0.24 (0.16)	0.34 (0.26)	0.37 (0.17)	0.38 (0.16)	0.28 (0.30)
Medium	0	0.71 (0.37)	0.12 (0.07)	0.40 (0.17)	0.30 (0.18)	0.46 (0.17)	0.44 (0.10)	0.19 (0.10)	0.13 (0.09)
	50	0.62 (0.18)	0.19 (0.12)	0.74 (0.38)	0.31 (0.11)	0.43 (0.15)	0.46 (0.26)	0.33 (0.21)	0.11 (0.09)
	200	0.67 (0.32)	0.27 (0.16)	0.36 (0.05)	0.35 (0.20)	0.36 (0.09)	0.61 (0.29)	0.56 (0.35)	0.10 (0.06)
High	0	0.78 (0.15)	0.23 (0.08)	0.18 (0.12)	0.22 (0.08)	0.49 (0.18)	0.36 (0.11)	0.23 (0.08)	0.15 (0.08)
	50	0.64 (0.20)	0.28 (0.05)	0.30 (0.13)	0.35 (0.09)	0.37 (0.11)	0.57 (0.32)	0.21 (0.12)	0.09 (0.04)
	200	0.70 (0.22)	0.30 (0.05)	0.14 (0.03)	0.21 (0.06)	0.27 (0.11)	0.66 (0.19)	0.22 (0.06)	0.16 (0.05)

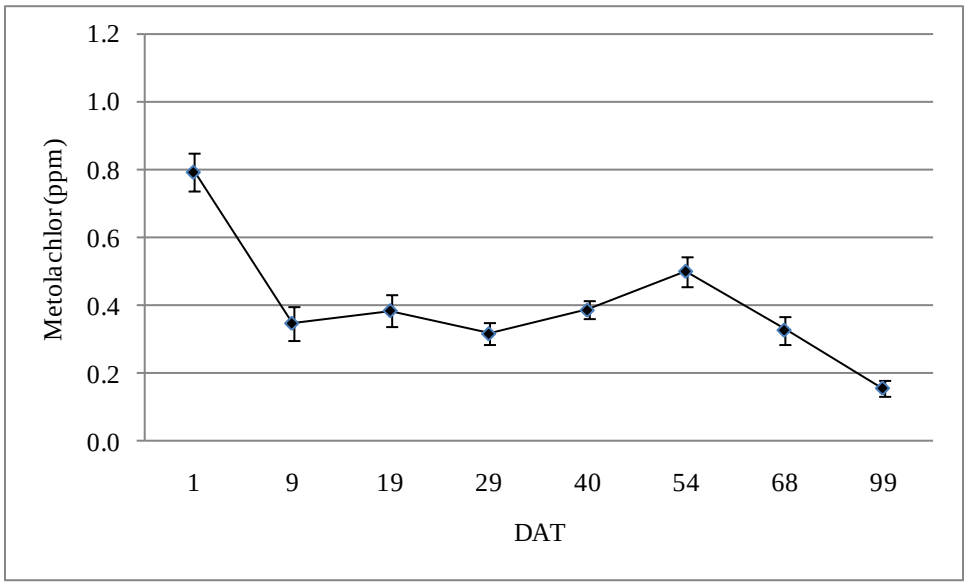

Figure 3.3. Field averages of metolachlor levels at 0-6 inch sample depth with standard errors.

ANOVA tables for all analyses are presented in Appendix I. Statistical analysis for atrazine dissipation in the 0 to 6 inch depths with log(x + 0.01) transformed data determined no significant three-way interaction in the data ($F_{28, 216} = 0.79$, $p = 0.77$). Therefore, data were averaged over management zone to increase sample size for nitrogen treatment comparisons and vice versa. P-values for differences in least squares means by time point are presented in Tables 3.5-3.6. Dissipation curves with standard errors are presented in Figures 3.4-3.5. No statistical differences in atrazine levels in the

0 to 6 inch depths were found between any of the nitrogen treatments at any of the time points ($F_{2, 216} = 3.04$, $p = 0.06$). Management zone comparisons exhibited significant differences ($F_{2, 216} = 12.74$, $p < 0.0001$); comparison of least squares means showed differences between the low and medium management zones at 9 DAT ($p = 0.021$) and between the low and high zone at 68 DAT ($p < 0.001$); all other comparisons were not statistically significant.

Table 3.5. P-values for differences in least squares means for comparison of nitrogen treatments per time point – atrazine at 0-6 inch depth.

Nitrogen treatment comparison	Days after treatment							
(lbs/ac)	1	9	19	29	40	54	68	99
0 vs 50	1.000	1.000	0.954	1.000	1.000	0.999	0.795	1.000
0 vs 200	1.000	0.945	1.000	1.000	0.996	1.000	0.999	0.179
50 vs 200	1.000	0.993	0.966	1.000	1.000	1.000	1.000	0.533

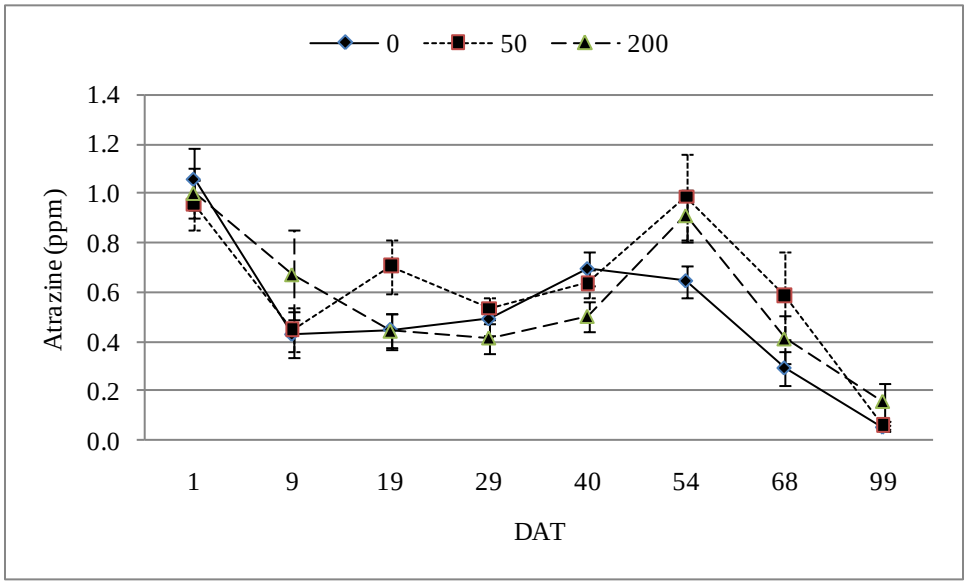

Figure 3.4. Atrazine levels by nitrogen treatment at 0-6 inch sample depth with standard errors.

Table 3.6. P-values for differences in least squares means for comparison of management zones per time point – atrazine at 0-6 inch depth.

Management zone comparison	Days after treatment							
	1	9	19	29	40	54	68	99
Low vs Med	0.987	0.021	1.000	1.000	1.000	1.000	0.371	0.845
Low vs High	1.000	0.516	0.494	1.000	1.000	1.000	<0.001	0.998
Med vs High	1.000	1.000	0.211	1.000	1.000	1.000	0.917	1.000

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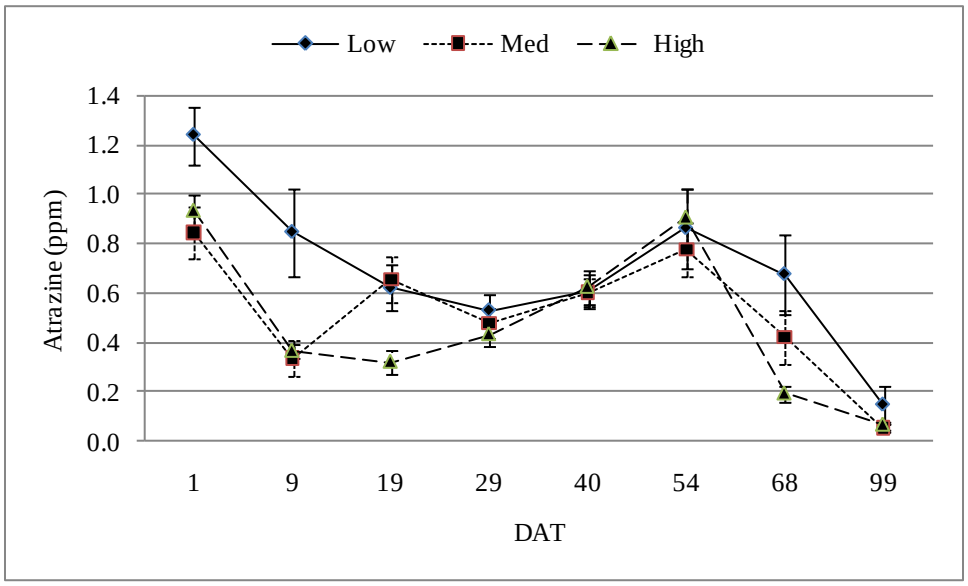

Figure 3.5. Atrazine levels by management zone at 0-6 inch sample depth with standard errors.

Statistical analyses of metolachlor levels were similar to those of atrazine. A significant three-way interaction was not found in the data ($F_{28, 216} = 0.66$, $p = 0.90$), and thus were again pooled over management zone for nitrogen treatment comparisons and vice versa. P-values for differences in least squares means by time point are presented in Tables 3.7-3.8. Dissipation curves with standard errors are presented in Figures 3.6-3.7. No statistical differences were found in metolachlor levels at 0 to 6 inch depths between any of the nitrogen treatments at any of the time points ($F_{2, 216} = 1.79$, $p = 0.17$). Management zones differed significantly ($F_{2, 216} = 7.60$, $p < 0.001$), but Tukey-adjusted

least squares means differences were only significant between the medium and high zones at 19 DAT (p = 0.010).

Table 3.7. P-values for differences in least squares means for comparison of nitrogen treatments per time point – metolachlor at 0-6 inch depth.

Nitrogen treatment comparison	Days after treatment							
(lbs/ac)	1	9	19	29	40	54	68	99
0 vs 50	1.000	1.000	0.683	1.000	1.000	1.000	1.000	1.000
0 vs 200	1.000	0.996	1.000	1.000	0.992	1.000	0.943	1.000
50 vs 200	1.000	1.000	0.743	0.998	1.000	1.000	1.000	1.000

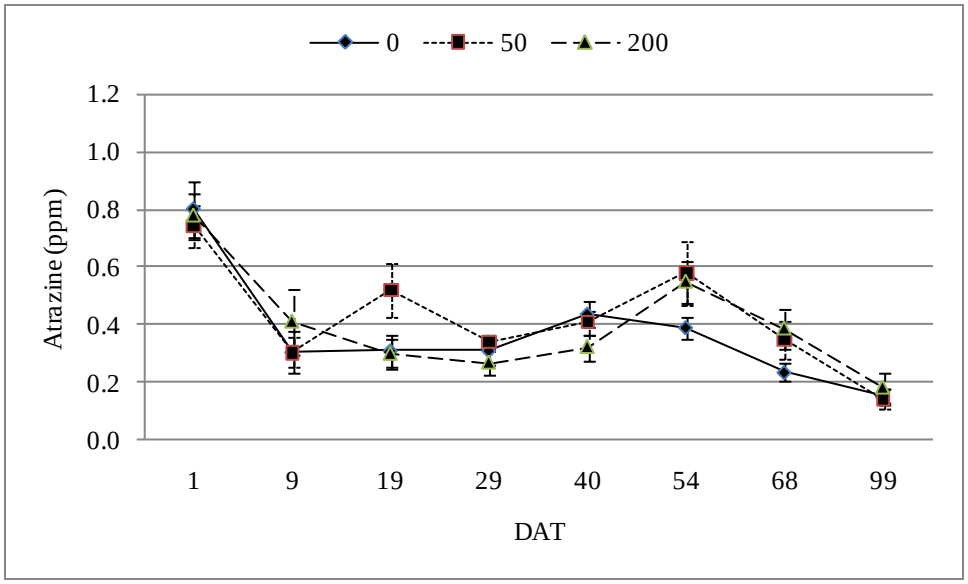

Figure 3.6. Metolachlor levels by nitrogen treatment at 0-6 inch sample depth with standard errors.

Table 3.8. P-values for differences in least squares means for comparison of management zones per time point – metolachlor at 0-6 inch depth.

Management zone comparison	Days after treatment							
	1	9	19	29	40	54	68	99
Low vs Med	0.986	0.001	1.000	1.000	1.000	1.000	1.000	0.434
Low vs High	1.000	0.669	0.319	1.000	1.000	1.000	0.799	0.993
Med vs High	1.000	0.838	0.010	1.000	1.000	1.000	0.994	1.000

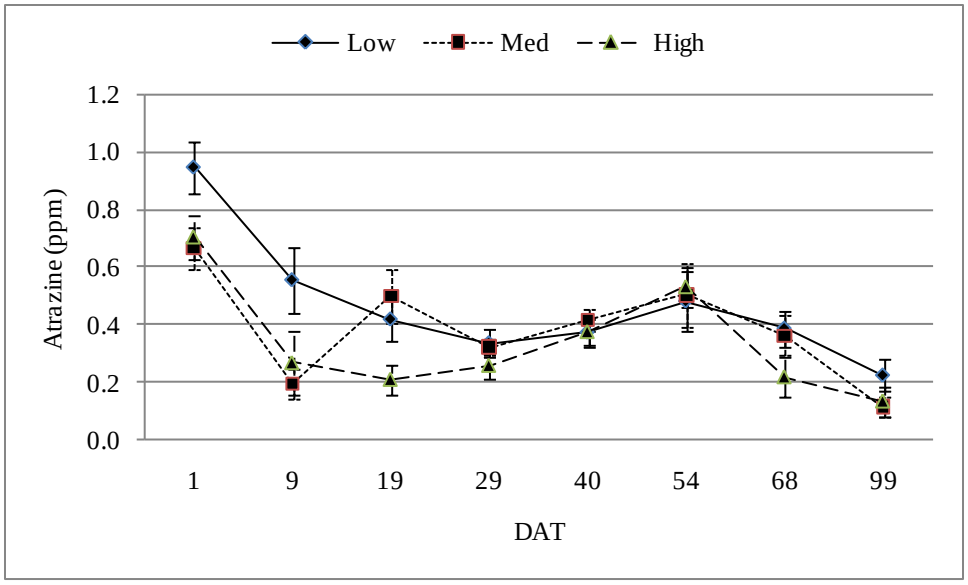

Figure 3.7. Metolachlor levels by management zone at 0-6 inch sample depth with standard errors.

Very little of either herbicide was found in the 6 to 12 inch depths of soil samples. Levels of both atrazine and metolachlor were zero at the first two time points (9 and 19 DAT) and the last time point (99 DAT). At 29 DAT atrazine was recovered from four soil samples at levels between 0.021 and 0.031 ppm; metolachlor was recovered from one sample at 0.025 ppm. Levels of the herbicide peaked in the 6 to 12 inch sample depths between 40 and 54 DAT (0.057 to 0.008 ppm for atrazine and 0.035 to 0.010 ppm for metolachlor) and were last detected between 0.038 to 0.019 ppm for atrazine and 0.020 to 0.025 ppm for metolachlor at 68 DAT. Average herbicide levels and standard deviations in the 6 to 12 inch depths for all treatments are presented in Tables 3.9-3.10. Dissipation curves are presented in Figures 3.8-3.9.

Table 3.9. Atrazine residues, 6-12 inch depth by management zone and nitrogen treatment over 99 days [mean (standard deviation)]

Management zone	Nitrogen treatment (lbs/ac)	Days after treatment 9	19	29	40	54	68	99
	0	0.000 (0.000)	0.000 (0.000)	0.011 (0.013)	0.017 (0.020)	0.005 (0.010)	0.000 (0.000)	0.000 (0.000)
Low	50	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.007 (0.014)	0.000 (0.000)	0.005 (0.010)	0.000 (0.000)
	200	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.012 (0.014)	0.000 (0.000)	0.009 (0.019)	0.000 (0.000)
	0	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.019 (0.013)	0.004 (0.005)	0.000 (0.000)	0.000 (0.000)
Medium	50	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.013 (0.015)	0.014 (0.029)	0.000 (0.000)	0.000 (0.000)
	200	0.000 (0.000)	0.000 (0.000)	0.008 (0.016)	0.013 (0.026)	0.008 (0.016)	0.000 (0.000)	0.000 (0.000)
	0	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.008 (0.016)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
High	50	0.000 (0.000)	0.000 (0.000)	0.005 (0.010)	0.015 (0.017)	0.000 (0.000)	0.007 (0.013)	0.000 (0.000)
	200	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.018 (0.012)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)

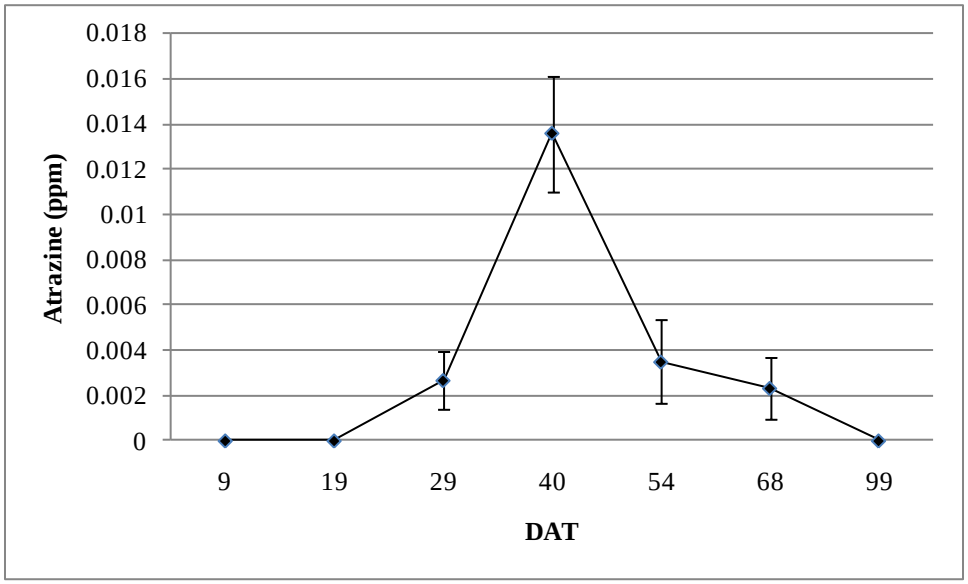

Figure 3.8. Field averages of atrazine levels at 6-12 inch sample depth with standard errors.

Table 3.10. Metorachlor residues, 6-12 inch depth by management zone and nitrogen treatment over 99 days [mean (standard deviation)]

Management zone	Nitrogen treatment (lbs/ac)	Days after treatment 9	19	29	40	54	68	99
	0	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.014 (0.016)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Low	50	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
	200	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
	0	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.013 (0.013)	0.002 (0.005)	0.000 (0.000)	0.000 (0.000)
Medium	50	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.012 (0.012)	0.007 (0.015)	0.000 (0.000)	0.000 (0.000)
	200	0.000 (0.000)	0.000 (0.000)	0.006 (0.013)	0.009 (0.018)	0.006 (0.012)	0.006 (0.013)	0.000 (0.000)
	0	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.006 (0.013)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
High	50	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.012 (0.014)	0.000 (0.000)	0.005 (0.010)	0.000 (0.000)
	200	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.010 (0.012)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)

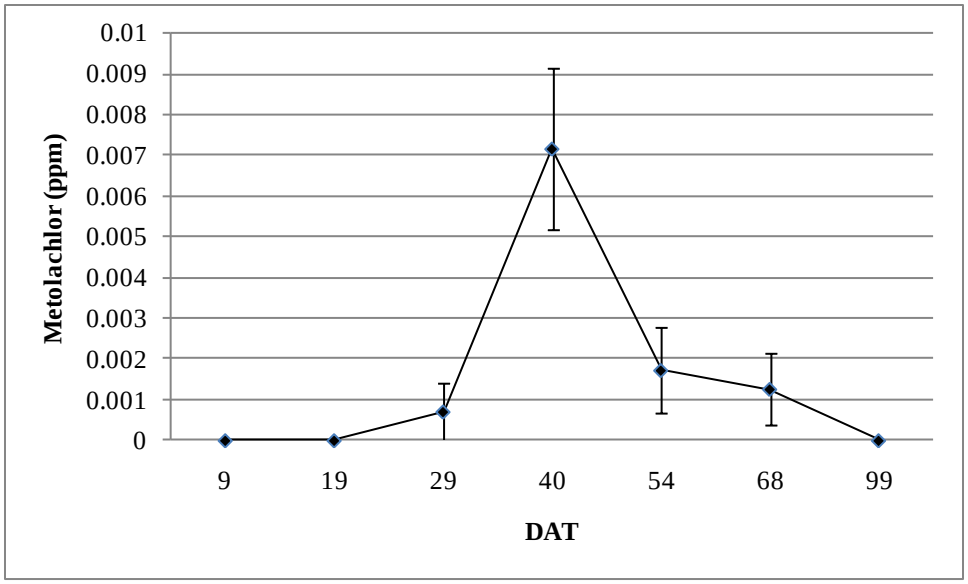

Figure 3.9. Field averages of metolachlor levels at 6-12 inch sample depth with standard errors.

There was no significant three-way interaction in the type 3 test of fixed effects for atrazine at 6 to 12 inch depths ($F_{28, 189} = 0.78$, $p = 0.76$), and results were again averaged over management zones to test nitrogen level effects and vice versa. P-values for differences in least squares means by time point are presented in Tables 3.11-3.12. Dissipation curves with standard errors are presented in Figures 3.10-3.11. No significant differences were found between the levels of atrazine at 6 to 12 inch depths when pooled by nitrogen treatment or management zone.

Table 3.11. P-values for differences in least squares means for comparison of nitrogen treatments per time point – atrazine at 6-12 inch depth.

Nitrogen treatment comparison	Days after treatment						
(lbs/ac)	9	19	29	40	54	68	99
0 vs 50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0 vs 200	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50 vs 200	1.00	1.00	1.00	1.00	1.00	1.00	1.00

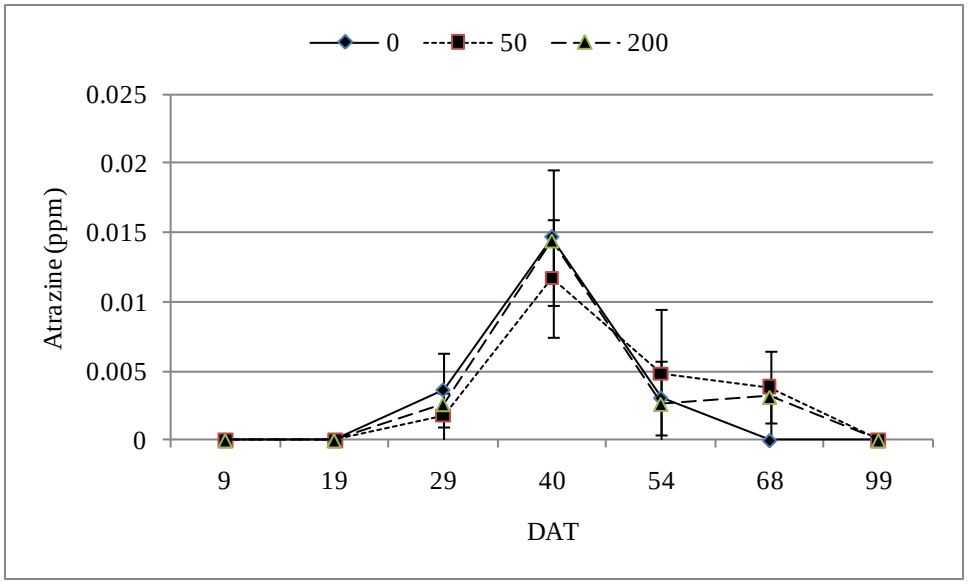

Figure 3.10. Atrazine levels by nitrogen treatment at 6-12 inch sample depth with standard errors.

Table 3.12. P-values for differences in least squares means for comparison of management zones per time point – atrazine at 6-12 inch depth.

Management zone comparison	Days after treatment						
	9	19	29	40	54	68	99
Low vs Med	1.00	1.00	1.00	1.00	0.96	1.00	1.00
Low vs High	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Med vs High	1.00	1.00	1.00	1.00	0.69	1.00	1.00

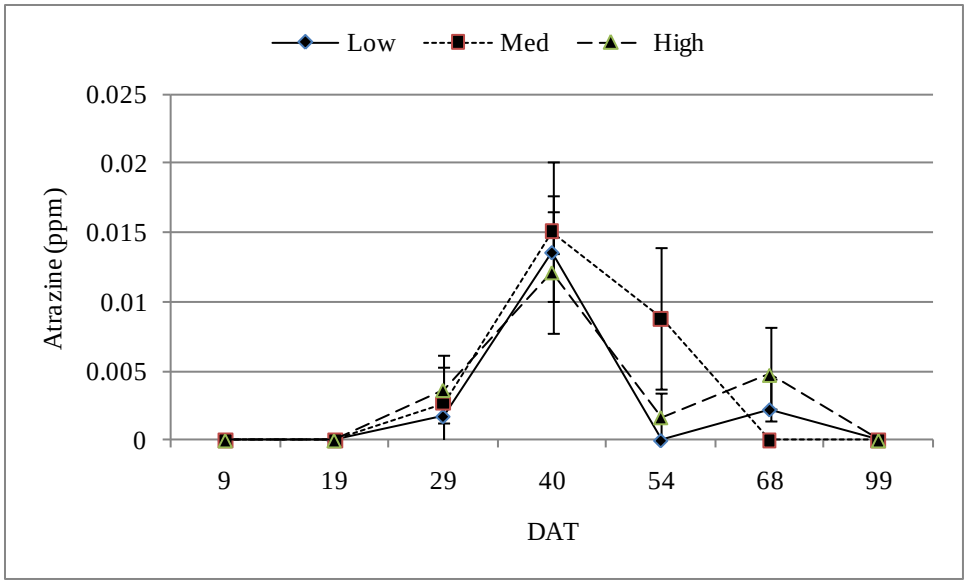

Figure 3.11. Atrazine levels by management zone at 6-12 inch sample depth with standard errors.

Metolachlor levels did not exhibit a significant three-way interaction in the type 3 test of fixed effects ($F_{28, 189} = 0.71$, $p = 0.84$) at 6 to 12 inch depths; results were averaged over management zones to test nitrogen level effects and vice versa. P-values for differences in least squares means by time point are presented in Tables 3.13-3.14. Dissipation curves with standard errors are presented in Figures 3.12-3.13. No significant statistical differences were found in metolachlor levels at 6 to 12 inch sample depths between nitrogen treatments or management zones at any time point.

Table 3.13. P-values for differences in least squares means for comparison of nitrogen treatments and management zones per time point – metolachlor at 6-12 inch depth.

Nitrogen treatment comparison	Days after treatment						
(lbs/ac)	9	19	29	40	54	68	99
0 vs 50	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0 vs 200	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50 vs 200	1.000	1.000	1.000	1.000	1.000	1.000	1.000

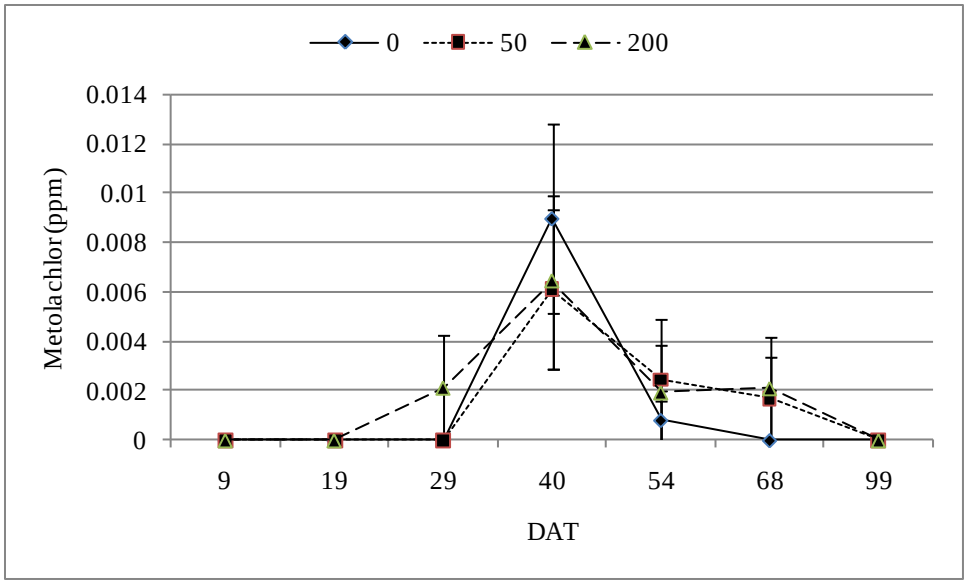

Figure 3.12. Metolachlor levels by nitrogen treatment at 6-12 inch sample depth with standard errors.

Table 3.14. P-values for differences in least squares means for comparison of management zones per time point – metolachlor at 6-12 inch depth.

Management zone comparison	Days after treatment						
	9	19	29	40	54	68	99
Low vs Med	1.000	1.000	1.000	1.000	0.769	1.000	1.000
Low vs High	1.000	1.000	1.000	0.735	1.000	1.000	1.000
Med vs High	1.000	1.000	1.000	0.998	0.769	1.000	1.000

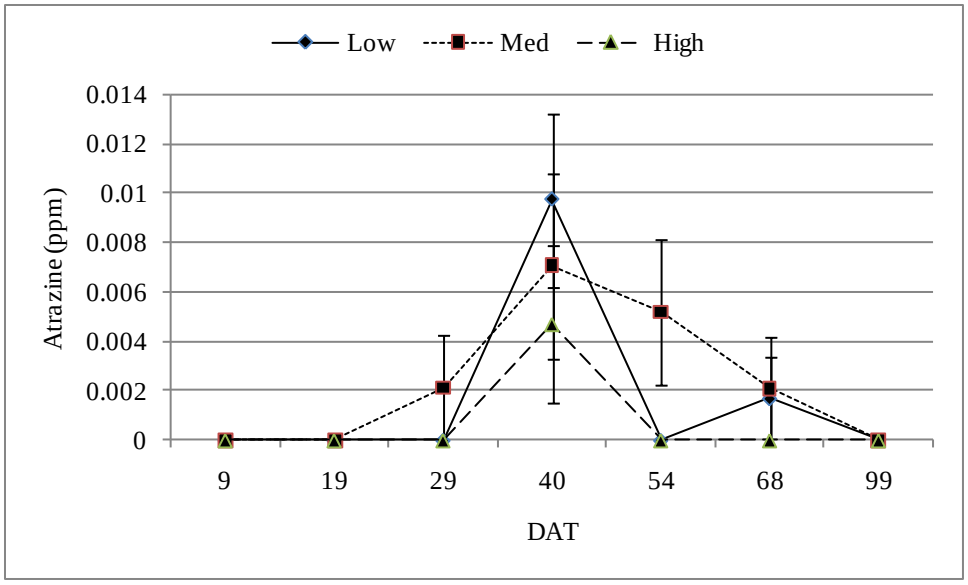

Figure 3.13. Metolachlor levels by management zone at 6-12 inch sample depth with standard errors.

Variability in extraction and quantification assessment results are presented in Tables 3.15-3.16. Re-analysis of samples yielded levels varying from original analysis from less than 0.01 to 0.25 ppm for atrazine and 0.01 to 0.19 ppm for metolachlor. Average absolute differences were 0.14 and 0.19 ppm for atrazine and metolachlor, respectively.

Table 3.15. Atrazine re-analysis measurement comparisons.

DAT	Management zone	Nitrogen Treatment (lbs/ac)	Original measurement (ppm)	Re-analysis measurement (ppm)
1	Low	0	1.72	1.54
1	Low	200	1.01	0.94
1	Medium	0	0.51	0.50
1	Medium	200	0.69	0.67
1	High	0	0.77	0.88
1	High	50	0.73	0.65
9	Low	50	0.96	1.21
9	Low	200	0.27	0.49
9	Medium	50	0.20	0.21
9	Medium	50	0.66	0.87
9	High	0	0.36	0.41
9	High	200	0.40	0.61

Table 3.16. Metolachlor re-analysis measurement comparisons.

DAT	Management zone	Nitrogen Treatment (lbs/ac)	Original measurement (ppm)	Re-analysis measurement (ppm)
1	Low	0	1.33	1.20
1	Low	200	0.71	0.72
1	Medium	0	0.37	0.40
1	Medium	200	0.56	0.53
1	High	0	0.61	0.68
1	High	50	0.59	0.51
9	Low	50	0.64	0.82
9	Low	200	0.20	0.38
9	Medium	50	0.13	0.15
9	Medium	50	0.47	0.63
9	High	0	0.28	0.32
9	High	200	0.30	0.48

A summary of the quality control (standards) samples is presented in Table 3.17. Ranges for the 0.1 standard were 0.09 to 0.13 ppm for atrazine and 0.06 to 0.08 ppm for

metolachlor; for the 1.0 ppm standard ranges were 0.81 to 1.08 ppm for atrazine and 0.94 to 1.11 ppm for metolachlor.

Table 3.17. Summary of quality control sample results from analyses throughout study.

Herbicide	Standard (ppm)	Recovery mean (ppm)	Recovery SD
Atrazine	0.1	0.10	0.008
Atrazine	1.0	0.97	0.053
Metolachlor	0.01	0.11	0.020
Metolachlor	1.0	1.01	0.045

DISCUSSION

The dissipation curves observed in this study are not typical, most notably due to the increase in residue levels starting at 40 DAT, peaking at 54 DAT to levels near or above those seen at 1 DAT, then dropping again at 68 DAT through 99 DAT. Given the available data, it is difficult to determine an exact explanation for this "bump" in residue levels, especially in light of the considerable variability apparent throughout much of the data.

Sources of variability include field application, sample collection, extraction and analysis, and soil characteristics. Analysis of herbicide residue levels on filter papers indicates a high degree of variation in the application of herbicides on both small (within sample point clusters) and large (between sample point clusters) spatial scales. However, when averaged across all samples the levels were very close to the desired application rate. Variation of herbicide levels at application was therefore translated into the overall analysis due to the collection of only one sample per point.

Quality control samples were generally consistent throughout the study and residue was not detected in any of the blanks, indicating that the quantification process was subject to minimal variation and no contamination. Extraction of residues from field samples showed a somewhat greater degree of variability, evident in the re-extraction and analysis of samples. Although again, relatively consistent, the small differences between the original and re-analysis of the sample-subset indicates this was another source or variability which became more significant when the amount of herbicides in the sample is small.

Variability in Kd values from soil samples taken from multiple points across the study area were minimal, and observations did not exhibit statistically significant differences. Differences in percent soil organic matter and possibly texture across the study area may also have influenced the variability. Although sampling and analysis was not conducted for these soil parameters, it is unlikely that variances were large enough and on a spatial scale small enough to influence the observed variability in herbicide residue levels.

One possible explanation for the increase in herbicide residue levels between 40 and 54 DAT could be a second application of the targed herbicide that was unaccounted for. The grower reported an application of glyphosate at 1.25 quarts/acre 30 DAT, which should not have altered the results of the study, but is concerning in that the timing of the application was just prior to the increase in observed levels of atrazine and metolachlor. It is possible that the same application equipment was used for both applications, in which case residual herbicide from the first application could have been applied inadvertently during the second application and altered the results of the study. It would

seem unlikely, however, that small amounts of atrazine and metolachlor from an un-rinsed tank and hoses would have caused the large increased in soil levels apparent in the data.

Little if any effects of nitrogen treatment and management zone on herbicide dissipation were found, likely due to the variability in the data and the unexplained rise in herbicide levels. Differences were inconsistent and few were statistically significant at any given time point. There is some indication in the data that the low management zone without nitrogen application had lower herbicide levels than other zones/treatments, although not consistently. This may indicate some effect of the lower proportions of organic matter within the low management zone and/or higher rates of microbial breakdown in the absence of applied nitrogen. However, the variability and inconsistencies in this study do not strongly support this effect.

The results of this study suggest herbicide applications are inherently variable. Given the variability, it is difficult to extract useful information regarding the correlation between herbicide dissipation with management zones or nitrogen application rates. Subsequently, any relationship between weed occurrence and management zone or nitrogen application cannot be correlated with their influence on herbicide dissipation by means of these data.

Many factors likely contribute to the spatial distribution of weeds in agricultural fields, and it is possible that the majority of them are highly stochastic processes that are difficult to model. A greater understanding of the dynamics influencing the spatial patterns of weeds will facilitate more efficient mapping and management processes.

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APPENDIX I

Table A.1. ANOVA table, analysis of replication effects of Kd analysis for atrazine and metolachlor.

Effect	Num DF	Den DF	F Value	Pr > F
Atrazine Replication	7	24	0.93	0.4992
Metolachlor Replication	7	24	1.68	0.1614

Table A.2. ANOVA table, analysis of atrazine in top 6 inches of soil.

Effect	Num DF	Den DF	F Value	Pr > F
Management Zone	2	216	12.74	<0.0001
Nitrogen Treatment	2	216	3.04	0.0600
Management Zone*Nitrogen Treatment	4	216	0.33	0.8578
Day	7	216	78.13	<0.0001
Management Zone*Day	14	216	2.65	0.0014
Nitrogen Treatment*Day	14	216	2.02	0.0178
Management Zone*Nitrogen Treatment*Day	28	216	0.79	0.7670

Table A.3. ANOVA table, analysis of metolachlor in top 6 inches of soil.

Effect	Num DF	Den DF	F Value	Pr > F
Management Zone	2	216	7.60	0.0006
Nitrogen Treatment	2	216	1.79	0.1686
Management Zone*Nitrogen Treatment	4	216	0.61	0.6581
Day	7	216	31.54	<0.0001
Management Zone*Day	14	216	3.25	0.0001
Nitrogen Treatment*Day	14	216	1.47	0.1232
Management Zone*Nitrogen Treatment*Day	28	216	0.66	0.9017

Table A.4. ANOVA table, analysis of atrazine at 6-12 inch soil depth.

Effect	Num DF	Den DF	F Value	Pr > F
Management Zone	2	189	0.31	0.7361
Nitrogen Treatment	2	189	0.01	0.9892
Management Zone*Nitrogen Treatment	4	189	0.9	0.4638
Day	7	189	12.16	<0.0001
Management Zone*Day	14	189	0.71	0.7359
Nitrogen Treatment*Day	14	189	0.25	0.9952
Management Zone*Nitrogen Treatment*Day	28	189	0.78	0.7601

Table A.5. ANOVA table, analysis of metolachlor at 6-12 inch soil depth.

Effect	Num DF	Den DF	F Value	Pr > F
Management Zone	2	189	1.80	0.1682
Nitrogen Treatment	2	189	0.10	0.9048
Management Zone*Nitrogen Treatment	4	189	1.38	0.2438
Day	7	189	6.78	<0.0001
Management Zone*Day	14	189	0.9	0.5494
Nitrogen Treatment*Day	14	189	0.29	0.9905
Management Zone*Nitrogen Treatment*Day	28	189	0.71	0.8423