Reprinted from *Agronomy Journal*
Vol. 94, No. 5

Yield Mapping to Document Goose Grazing Impacts on Winter Wheat

Michael M. Borman,* Mounir Louhaichi, Douglas E. Johnson, William C. Krueger, Russell S. Karow, and David R. Thomas

ABSTRACT

In southwestern Washington and western Oregon, increasing numbers of wintering Canada geese (*Branta canadensis*) graze several farm crops including wheat (*Triticum aestivum* L.). Our objectives were to develop methods to determine timing, intensity, and locations of grazing, and to measure the impact of grazing on grain yield. Aerial photography with ground-truth photography and repeated sampling worked well to determine timing, intensity, and locations of grazing. Exclosures served as nongrazed controls. A yield-mapping-system-equipped combine measured yields. All data collection points were spatially located via differential global positioning system (DGPS) technology, which allowed us to integrate all data spatially and temporally via geographical information system (GIS) technology. Based on yield-mapping-system data, goose grazing resulted in grain yield differences ranging from a 16% increase on part of one field to a 25% decrease on an area of a field heavily grazed in April, just before geese migrated north. Comparisons of exclosures (nongrazed controls) with paired plots provided variable results. Results from paired-plot comparisons for three fields during 1998 were 25% reduction, no difference, and 13% increase in grain yields in the paired plots available for grazing vs. exclosures. Based on yield-mapping-system data, the same three fields experienced 19, 7, and 5% grain yield reductions due to goose grazing with the extent of reduction depending on a combination of timing, intensity, and extent of grazing. Paired plots did not adequately represent grazing impacts on the fields. The yield-mapping system provided nearly complete coverage of the fields and adequately captured grazing impacts.

CONSERVATION PROGRAMS have resulted in an increase of Canada goose wintering and resident populations in the lower Columbia River and Willamette River Valleys of southwestern Washington and western Oregon. The increase has been from a historical average of approximately 20 000 to 25 000 through the 1970s to more than 225 000 by 1996 (Oregon Dep. of Fish and Wildlife, 1998).

From autumn to spring, geese prefer to eat wheat, pea (*Pisum* sp.), clover (*Trifolium* sp.), corn (*Zea mays* L.), grass seed, and other farm crops. Substantial crop damage has been reported by farmers and by the Oregon Department of Agriculture (Oregon Dep. of Agric., 1998).

Results of several studies differ on the extent and impact of geese foraging on wheat and other crops. Clark and Jarvis (1978) suggested that goose grazing did not adversely impact production of annual ryegrass (*Lolium multiflorum* Lam.) seed in the Willamette Valley, Oregon. In other studies, however, geese have reduced the yield of winter wheat in relation to intensity of grazing (Allen et al., 1985; Flegler et al., 1987) and to timing of grazing (Kahl and Samson, 1984).

Substantial yield losses in grass and cereal crops have been reported at a wide range of grazing levels by geese (Patterson, 1991). Estimating loss of yield at specific levels of grazing, however, was difficult. Patterson (1991) suggested exclosures should be used to measure actual yield loss.

Recent technologies such as geographical information systems (GIS) and global positioning systems (GPS) provide new opportunities to more accurately measure crop yield and damage caused by wildlife or other factors. Geographical information systems have the ability to spatially interrelate multiple files or data layers once the layers are in geographic registration (Lillesand and Kiefer, 1994). Global positioning systems can accurately determine the position of every sample point. Combining these technologies provides visual representations of changes through time (Anderson, 1996) and provides the tools necessary to create yield maps.

We designed our study to develop and evaluate methods to achieve the following objectives: (i) identify locations grazed by geese, (ii) determine when and how intensely geese were grazing the fields, and (iii) measure grazing impact on grain yield. In this paper we describe methods found effective for mapping and measuring the spatial extent and severity of yield loss. The methods include aerial photography; ground observations, which include platform photography at known locations via GPS; and precision-farming technology. Data from the various methods are integrated via GIS technology.

METHODS[1]

Study Area

Test fields were located on Sauvie Island, Multnomah County, Oregon, approximately 15 km northwest of Portland (45°40′ N, 122°47′ 30 W). The north half of the island is a wildlife refuge managed primarily for waterfowl and the south half is agricultural and residential.

Fields studied during 1996–1997 were VK1 (60.4 ha), VK2 (36.6 ha), and VK3 (40.7 ha). Fields studied during 1997–1998 were No Haze (15.3 ha), Spencer North (19.6 ha), and Spencer

M.M. Borman, M. Louhaichi, D.E. Johnson, and W.C. Krueger, Dep. of Rangeland Resources, Oregon State Univ., Corvallis, OR 97331; R.S. Karow, Dep. of Crop and Soil Sciences, Oregon State Univ., Corvallis, OR 97331; and D.R. Thomas, Dep. of Statistics, Oregon State Univ., Corvallis, OR 97331. Submitted as Technical Paper no. 11577, Oregon Agric. Exp. Stn. Funding provided by the Oregon Agric. Legal Foundation and the Oregon State Legislature. Received 13 Feb. 2001. *Corresponding author (michael.borman@oregonstate.edu).

Published in Agron. J. 94:1087–1093 (2002).

[1] Mention of product names or corporations is for the convenience of the reader and does not constitute an official endorsement or approval by Oregon State University or the Oregon Agricultural Experiment Station of any product or service to the exclusion of others that may be suitable.

Abbreviations: DGPS, differential global positioning system; GIS, geographical information system; GPS, global positioning systems; PVC, polyvinyl chloride; RMS, root mean square.

South (36.0 ha). Farmers hazed geese as part of their normal farming operations on all fields except No Haze throughout the winter and spring to reduce grazing impacts on wheat grain production. Propane cannons, scarecrows, and employees on all terrain vehicles were used to scare geese. The No Haze field was intentionally not hazed to improve the likelihood of having a grazing-induced impact on at least one field to facilitate testing of methods to identify impacted areas within the field, to determine grazing intensity, and to measure grain yield reductions.

Soils in the test fields are composed of very deep, poorly drained, silt loams and silty-clay loams. These soils were formed in recent silty alluvium on broad undulating flood plains where slopes are 0 to 2%. These soils are in the Sauvie series and classified as fine-silty, mixed, mesic Fluvaquentic Haplaquolls.

Climate is influenced by winds from the Pacific Ocean; summers are warm and winters and springs are usually cool and moist. Mean annual temperature (1961–1998) is 17°C and varies from 4.5°C in January to 20.5°C in August. Most precipitation occurs during late fall and winter. Mean (1951–1998) annual rainfall is 945 mm, with a range from 570 to 1290 mm.

Goose Exclosures

We constructed exclosures shortly after fields were planted in mid-September. Poultry wire, 50 cm high, supported by fiberglass posts and flagged at each corner, prevented geese from entering exclosures from the sides. Exclosure tops were not covered, but the area enclosed was small enough that geese did not land in them. Tops were left open to prevent interference with aerial photography and to allow normal plant growth. Nine to 12 exclosures were established in each field depending on field size, shape, and the locations within the field in which we expected grazing. During the first year of study, exclosures (5 by 5 m) were randomly assigned within strata that were expected to be heavily, moderately, and lightly grazed. We placed 10, 9, and 12 exclosures in fields VK1, VK2, and VK3, respectively. Of those, only three, two, and four exclosures were located in areas of VK1, VK2, and VK3, respectively, that geese grazed moderately to heavily. During the second year, we concentrated the majority of exclosures in areas where we expected geese would concentrate their grazing and increased their size to 6 by 13 m. We placed nine exclosures in each of the three fields. We attempted to space the exclosures in such a way that they would not interfere with grazing patterns around adjacent exclosures. With that constraint, nine exclosures per field was the maximum we considered possible within areas in which we anticipated most grazing would occur. The larger size was needed to accommodate the width of a commercial mechanical harvester (6 m) and to increase the number of data points that could be obtained within each exclosure. Data from ungrazed areas of the fields collected during the first year by a combine equipped with a yield-mapping system were analyzed to calculate the sample size necessary to determine grain yield within ±5% with a confidence of 95% (Zar, 1996). For most areas tested, this sample size was 13 or fewer observations. Data were collected at approximately 1-m intervals as the harvester moved through the field. Our exclosures were larger than those used in previous studies of wild geese (Allen et al., 1985; Bédard et al., 1986; Clark and Jarvis, 1978).

We paired each exclosure with a plot of the same size in areas where geese could graze. A paired plot was 20 m from one end of each exclosure. This distance was large enough to minimize the effect of the exclosure on goose foraging patterns. Each paired plot was positioned along the same drill rows of grain, was the same distance from cover for predators, and contained the same soil and catena position as its companion exclosure. We marked the four corners of each exclosure with DGPS and plotted them on aerial photographs and on maps, which themselves had been corrected (rectified) based on DGPS geopositioned ground-control points.

Color Aerial Photography

Color aerial photographs (1:14 000) were taken in January, March, mid-April when geese departed, and in July before grain harvest. We used a 35-mm Nikon 6006 camera, operated with a cable release, mounted on the undercarriage of a fixed-wing aircraft. Sauvie Island is located in Portland International Airport airspace, which restricted the altitude of aerial photos to below 420 m. This required use of a 28-mm wide-angle lens. Kodak Royal Gold 400 Film was used for color photography. During the second year of study, we placed white targets (0.3 by 0.3 m) within the interior and around the perimeter of each field. Target locations were positioned with a Trimble Pathfinder Pro XR DGPS, by collecting 180 positional fixes, and post differentially corrected to a Portland, OR base station with Trimble Pathfinder Office Software (Trimble Navigation, 1998). Root mean square (RMS) errors for each target were <1 m.

Because of the low altitude flight restriction, several photographs were required to cover an entire field. We mosaiced those photographs to create a composite image of a complete field and scanned it into digital format with a Hewlett-Packard Scanjet 6100C. The image was then geocorrected and rectified using ground control points (white targets) within the Idrisi software (Eastman, 1997).

Ground Reference Photography

We constructed a lightweight platform of polyvinyl chloride (PVC) tubing, which consisted of a 1-m^2 base and a vertical frame to mount a 35-mm camera 1.7 m aboveground (Louhaichi et al., 2001). This configuration allowed us to take high resolution (1-mm^2 pixel size) color photographs of the area within the 1-m^2 quadrat. Concurrently with aerial photographs, we took ground-reference photographs at approximately 50-m intervals along transects and in exclosures and their paired plots. These photographs showed grazed leaves on wheat, bird footprints, goose droppings, and weeds. We used digital image analysis to precisely measure wheat cover (Bennett et al., 2000; Louhaichi et al., 2001). We recorded average leaf length, grazing intensity, and number of goose droppings. If clipped leaves and goose droppings or footprints indicated goose-grazing activity, grazing intensity was determined by a combination of remaining plant height and percent foliar cover relative to a control (Table 1). Since plant height and foliar cover changed through the growing season and from year to year, grazing intensity levels described as heavy, moderate, or light also changed through the growing season and were slightly different between years (Table 1). Grazing intensity levels used in this paper are specific to this study.

We recorded the location of each sampling point with DGPS. Transect lines were placed to get representative whole-field coverage. Approximately 40 to 50 platform photographs were taken per field during each observation period.

Field Maps

Base maps of each field were constructed during fall when crops were planted using DGPS to locate points around the perimeter. Data were imported to Idrisi GIS format for display and spatial analysis. Color aerial photographs taken during a major flood in February 1996 were converted to GIS format to delineate areas of the fields subject to periodic flooding.

These maps facilitated the placement of goose exclosures, their paired plots, and ground-reference photographs.

An unsupervised classification (clustering) procedure in Idrisi (Eastman, 1997) was used to identify areas in the image with similar spectral characteristics. The unsupervised classification corresponded well with areas in the field that contained dense wheat cover, moderate wheat cover, thin wheat cover, ponded water, trees, and roads. Because we had ground observations that documented areas where geese had grazed, we were able to separate areas that had moderate or thin wheat cover due to grazing vs. other factors. We then superimposed platform-photograph locations and other DGPS ground observations on the unsupervised classification map and assigned categories based upon goose-grazing intensity, wheat damaged by standing water, or wheat cover differences due to soil factors or previous farming practices. Areas of the field with trees or roads were eliminated. We then delineated, via on-screen digitizing, portions of the field contained in goose-grazing intensity and water categories. These maps were created for April 1997 and for January, March, and April 1998.

Wheat Yield

We equipped one commercial harvester with a John Deere GreenStar Yield-Mapping System. The yield-mapping system provided DGPS locations recorded at 1-s intervals concurrently with measurements of grain yield. This resulted in a data point collected at approximately 1-m intervals, which varied slightly depending on harvester ground speed. The pressure-plate unit for measuring yield was calibrated in each field by harvesting a test area with the system in calibration mode, weighing harvested grain, and adjusting to actual grain weight. During 1998, in addition to calibration, wheat was also weighed out of each field at a certified scale and compared to the yield recorded by the GreenStar system to estimate potential error. The difference between grain weight and yield-mapping-system estimate for the fields varied between 2 and 5%.

During the 1997 harvest, we evaluated the potential of the yield-mapping system for measuring differences in wheat grain yield between areas of a field receiving little or no grazing vs. areas receiving moderate to heavy grazing. The 5 by 5 m exclosures were too small for the commercial-size harvesters. To facilitate statistical comparisons of grazed vs. ungrazed wheat yields during the first year, we utilized a small-plot combine to harvest through four exclosures and their paired plots in field VK3. We also used the small-plot combine to harvest along transects in field areas that were stratified as lightly grazed (field VK1) or not grazed (fields VK2 and VK3) and areas that were moderately to heavily grazed in all three fields. There were no areas in field VK1 in the nongrazed class. Samples collected with the small-plot combine were bagged. Field area for each sample was measured and its location was logged via DGPS. Limited access to the small-plot combine precluded more extensive sampling.

During 1997, three commercial harvesters ran simultaneously on ungrazed and lightly grazed areas of each field. One of the three harvesters was equipped with the yield-mapping system. We used only the yield-mapping-equipped machine to harvest moderately and heavily grazed portions of fields. During 1998, only the yield-mapping-equipped harvester was used on test fields.

During 1998 we used the GreenStar flags option to record data for preselected conditions (header-not-full, thistle, other weeds) and for exclosures. We deleted data points obtained when the harvester header was not full, e.g., during turns or when harvesting narrow strips of grain. Data from exclosures within a field served as ungrazed controls for comparison with grain yields from grazed areas in the field.

Table 1. Grazing intensity as a function of plant height and foliar cover.

Grazing intensity†	Sampling period	Plant height	Foliar cover
		cm	%
Heavy grazing	March 1997	<10	<20
	April 1997	<10	<20
	March 1998	<10	<25
	April 1998	<10	<30
Moderate grazing	March 1997	10–15	20–50
	April 1997	10–30	20–70
	March 1998	10–15	25–50
	April 1998	10–25	30–50
Light grazing	March 1997	>15	>50
	April 1997	>30	>50
	March 1998	>15	>30
	April 1998	>25	>50

† Presence of clipped leaves, goose footprints, and/or goose droppings was required for a grazing intensity category to be assigned. If no evidence of grazing was observed, the area was considered to be not grazed. Grazing intensity was determined by a combination of remaining plant height and percent foliar cover relative to ungrazed exclosures. Since plant height and foliar cover changed through the growing season and from one year to the next, grazing intensity levels described as heavy, moderate, or light also changed through the growing season and were slightly different between years. Grazing intensity levels are specific to this study.

Data Analysis

Statistical analysis for 1996–1997 crop-year data was limited to plots harvested by the small-plot combine. Wheat yields along transects from areas lightly (field VK1 only) and not grazed (fields VK2 and VK3) served as the basis for t-test comparisons to yields from areas moderately to heavily grazed. Analyses were within fields. Yields from four exclosures in a heavily grazed area of field VK3 were compared via paired t-test to yields from their paired plots.

During 1998, wheat-grain yield of exclosures within each field, measured with the yield-mapping system, were compared with their paired plots using a paired t-test. For this analysis, all nine sets of exclosures and their paired plots within each field were used.

On a field-scale basis, no statistical inferential methods are needed for comparison between grazed classes when using the yield-mapping system because it measured yields over entire areas within each grazing class. Grain yields for 1997 from areas lightly grazed (field VK1 only) or not grazed (fields VK2 and VK3) are presented along with grain yields from areas moderately to heavily grazed. For 1998, fields were classified into areas defined by grazing intensity in January, March, and mid-April. Average grain yields in areas representing each class are presented: exclosures, areas by grazed class for April, areas by grazed class in March but not grazed in April, and areas by grazed class in January but not grazed later. Total recorded observations were 14 310 in No Haze field, 22 269 in Spencer South field, and 18 784 in Spencer North field.

RESULTS AND DISCUSSION

Grazing Effects on Wheat Cover

Geese grazed wheat to a height between 2 and 10 cm of remaining leaf/stem in heavily grazed areas of fields. As the season progressed we observed that heavily grazed areas of fields were more likely to be grazed repeatedly. The reasons could be predator avoidance behavior, a function of grazing preference, or both. In ungrazed and previously lightly grazed areas, the geese may have viewed

Fig. 1. April 1998 aerial photograph of a portion of No Haze field illustrating the contrast in cover between ungrazed wheat within exclosures (dark rectangles, 6 by 13 m) vs. grazed wheat outside exclosures.

areas of taller wheat as potential cover for predators and restricted their grazing to more open areas (Belling, 1985). In areas previously grazed, regrowth of wheat plants could have been preferred because digestibility and protein were likely higher, as was found in a study by Bédard et al. (1986). Wheat cover was reduced in areas heavily grazed by geese compared with exclosures and areas of fields not as heavily grazed by geese (Fig. 1). We found a strong negative correlation ($r = -0.85$) between percent wheat cover and intensity of grazing at ground-photograph locations.

Zones of Impact and Yield Comparisons

By mid-April 1997, areas with heavy or moderate grazing by Canada geese ranged from 23 to 29% in the three fields (Table 2). Based on yield-mapping-system data, grain yield was 25, 16, and 23% lower in heavily grazed areas of fields VK1, VK2, and VK3, respectively, than areas not grazed (fields VK2 and VK3) or only lightly grazed (field VK1) during 1997 (Table 3). Yield was 4 and 3% lower in moderately grazed areas of fields VK1 and VK3, respectively. However, yield was 3% higher in moderately grazed areas of field VK2. For portions of the fields sampled by the small-plot combine, recorded yields were higher but trends were similar to results obtained from the yield-mapping system (Tables 3 and 4). Grain yield in the four exclosures was greater than in the heavily grazed paired plots in field VK3 (Table 4). Along transects, yields were higher in the ungrazed (fields VK2 and VK3) or lightly grazed (field

Table 2. Area† and percent‡ of wheat fields occupied by grazing intensity classes within sampling period.

Field	Sampling period	Grazing intensity level							
		None		Light		Moderate		Heavy	
		ha	%	ha	%	ha	%	ha	%
VK1	April 1997	0	0	46.0	77	10.6	18	3.0	5
VK2	April 1997	25.9	75	0	0	5.4	16	3.3	10
VK3	April 1997	27.5	71	0	0	5.0	13	6.1	16
No Haze	January 1998	0.1	<1	1.4	9	11.8	78	1.8	12
	March 1998	0.1	<1	2.3	15	4.7	31	8.0	53
	April 1998	5.4	36	7.0	47	0	0	2.4	16
Spencer North	January 1998	0.9	5	16.9	95	0	0	0	0
	March 1998	8.8	50	0	0	4.6	26	4.3	24
	April 1998	16.4	92	1.5	8	0	0	0	0
Spencer South	January 1998	0.1	<1	13.9	74	0	0	4.8	26
	March 1998	14.0	78	4.0	22	0	0	0	0
	April 1998	18.0	100	0	0	0	0	0	0

† Areas not available for grazing (e.g., ponded water, trees, roads) were not included in this table. Summations of field areas reported in this table are less than field areas reported under Study Area in the Methods section, and may be different from one sampling period to another, primarily due to differences in area covered by ponded water.
‡ Summation of percent in each category may not total 100% due to rounding. Percent is relative to the field area available for grazing during the sampling period.

Table 3. Grain yields for portions of test fields identified as ungrazed, lightly, moderately, or heavily grazed in April 1997. A combine equipped with DGPS yield-mapping system harvested all areas for which data are reported.

Field	Goose grazing intensity during April 1997			
	None	Light	Moderate	Heavy
	$g\ m^{-2}$			
VK1	NA†	640	612	482
VK2	552	NA†	566	462
VK3	571	NA†	555	439

† Field VK1 had no areas not grazed (except exclosures, which are not included here) and fields VK2 and VK3 had no areas lightly grazed during April 1997.

VK1) areas compared with areas of the fields moderately to heavily grazed (Table 4). Because of the much larger field area sampled, data generated by the yield-mapping system better represents actual yield within areas of impact and at a field scale than do data from the small-plot combine, which sampled very small areas.

During 1998, geese grazed No Haze field more heavily and extensively than the two Spencer fields (Table 2). Extensive areas of No Haze field were moderately or heavily grazed in January. Nearly half the field was moderately or heavily grazed in March. Only 12% of the field was heavily grazed in April, with the remainder of the field either lightly grazed or not grazed.

No Haze field was the only one of the three fields tested in 1998 that received heavy grazing during April. Areas heavily grazed in April had a 24% lower grain yield than exclosures (Table 5), which was consistent with results from 1997 on areas of fields heavily grazed in April (Table 3). Areas lightly grazed in April 1998 had an 18% lower grain yield than exclosures (Table 5). This was a greater impact on grain yield than occurred on field areas moderately grazed in April 1997. Areas of No Haze field moderately or heavily grazed earlier in 1998, but not in April, had approximately an 18% lower yield compared with the exclosures (Table 5). Overall field-average yield was 19% lower than yield within the exclosures.

Table 4. Yield comparisons for 1997 based on small-plot combine harvested samples.

Field	Grazed	*n*	Ungrazed	*n*	*p*
	$g\ m^{-2}$		$g\ m^{-2}$		
			Paired plots from heavily grazed area†		
VK3	433	4	688	4	0.01
			Transects‡		
VK1	595	9	754	10	0.02
VK2	550	3	606	6	0.1
VK3	570	6	643	26	0.03

† Analysis by paired *t*-test. All four exclosures and paired plots were in a heavily grazed area.
‡ Analysis by *t*-test. Grazed areas were moderately to heavily grazed. In field VK1, the *ungrazed* area for this analysis was actually lightly grazed. Except for exclosures, which were not included in this analysis, there was no area in field VK1 determined to be completely ungrazed.

Table 5. Wheat grain yield for areas of test fields grazed by geese in January through April 1998 based on yield-mapping-system data.

Field	Grazing intensity and period	Area	Yield†	SD	*n*‡
No Haze		ha	$g\ m^{-2}$		
	Exclosures	0.1	527	110	96
	Light March, no April	2.0	430	96	1 679
	Mod. March, no April	2.9	419	75	2 701
	Heavy March, no April	0.7	431	81	737
	Light April	7.0	433	85	6 642
	Heavy April	2.4	400	84	2 017
Spencer South					
	Exclosures	0.1	388	74	82
	Light January, no April	13.5	342	89	11 295
	Heavy January, no April	0.4	360	67	293
	Light March, no April	4.1	449	94	3 516
Spencer North					
	Exclosures	0.1	573	64	99
	Light January, no March or April	7.9	499	102	7 631
	Light March, no April	4.2	566	75	4 102
	Heavy March, no April	3.4	548	112	3 326
	Light April	1.5	560	60	1 384
	Soil/previous use difference	1.9	147	114	1 722

† No statistical inferential methods are needed for comparing the grain yield among the "Grazing intensity and period" categories because the yields were measured over the entire field by the combine yield-mapping system. Means are of entire populations rather than subsamples.
‡ *n* represents the number of data points recorded by the yield-mapping system within each "Grazing intensity and period" category.

In Spencer North, most of the field was lightly grazed in January 1998 with no moderate or heavy grazing recorded (Table 2). Grazing intensity increased by mid-March with nearly half the field either moderately or heavily grazed. Most of the field was not grazed during April. In Spencer South, nearly 75% of the field was lightly grazed in January and about 25% was heavily grazed (Table 2). In March, <25% of the field was lightly grazed and the balance was not grazed. By April, grazing was not a factor. Hazing by farmers during March and April was likely responsible for much of the difference in use by geese of the two Spencer fields compared with No Haze field.

Differences in grain yield between exclosures and grazed areas existed for both Spencer fields (Table 5). The differences, ranging from 2 to 16%, were somewhat less and more variable than those in No Haze field. Reduced goose grazing due to hazing during March and April appears to have been largely responsible for the smaller yield differences. In the area of Spencer South lightly grazed in March, a grain yield increase of 16% was recorded. We suspect the increase was due to goose grazing interfering with a fungal infection that apparently reduced wheat grain yield in that field. Tillering was not enhanced in areas grazed in March vs. exclosures (57 vs. 92 tillers m^{-1}, respectively, $P = 0.1$), but grain weight was heavier in the grazed areas (13.9 vs. 11.7 g per 300 seeds, respectively, $P = 0.001$). Overall field-average yields were lower than yields within exclosures by 5% in Spencer South and 7% in Spencer North. Although goose grazing was neither as heavy nor as extensive in the Spencer fields compared with No Haze field, our results suggest that grain yield reductions resulted from grazing.

Comparison of grain yield between exclosures and their paired plots using yield-mapping-system data was possible only during 1998 when the exclosures were large enough to harvest with a commercial-size combine. Paired-plot comparisons presented variable results. Grazed plots in No Haze field had 25% lower yield than the exclosures ($P < 0.01$, $n = 9$). In Spencer North field, there was no difference ($P = 0.15$, $n = 9$). In Spencer South field, the paired plots had 13% higher yield ($P = 0.02$, $n = 9$).

Results from paired-plot comparisons in the two Spencer fields were not consistent with results from yield-mapping-system data for a specific area of impact or for an entire field. In Spencer South, grazing impacts on grain yield were a 12% decrease in areas lightly grazed in January, but not later; a 7% decrease in areas heavily grazed in January, but not later; and a 16% increase in areas lightly grazed in March, but not in April (Table 5). In Spencer North, grazing impacts on grain yield were a 13% decrease in areas lightly grazed in January, but not later; a 1% decrease in areas lightly grazed in March, but not later; a 4% decrease in areas heavily grazed in March, but not later; and a 2% decrease in areas lightly grazed in April (Table 5). This suggests that paired plots did not effectively capture impacts from grazing activity within the fields.

Methods Development

Aerial photography combined with spatially located, ground-level data collection and photographs proved effective for identifying location and timing of goose grazing on winter wheat fields. We were able to document that as time progressed, goose grazing on wheat changed from variable intensity over larger areas within fields to more concentrated heavily used areas. Once the wheat jointed (stage when growth points begin to elevate above ground level; ungrazed plants jointed first), previously ungrazed and lightly grazed areas were avoided and the geese then concentrated on wheat regrowth in areas previously heavily grazed.

The yield-mapping system provided relatively complete spatial (two-dimensional) coverage of a field, which allowed us to compare areas with different intensities and timing of grazing. Data points encompassed an area of approximately 6 m^2. The area comprising a data point was variable depending on the ground speed of the combine. Small portions of fields were not covered because the header was not full due to turns or cleaning up strips that are a normal part of harvest. Because yields were measured over nearly the entire field, differences were real and no statistical inferential methods were needed for comparing grain yield of the various grazed classes to the ungrazed exclosures.

The paired-plot technique did not adequately measure grain yield differences known to exist based on results obtained from the more extensive yield-mapping-system sampling. We had to place exclosures with their paired plots in a field before geese arrived in the fall. We were concerned about influencing goose-grazing patterns, which constrained our ability to place enough of them at appropriate locations to capture the variability in timing and patterns of grazing. Allen et al. (1985) noted that exclosures influenced goose-grazing patterns.

We have developed a protocol that can be used to measure goose-grazing impacts on wheat grain yields. Additional research would be helpful to address questions related to permutations of the methods tested in this study. We need to develop methods to analyze data when only some percentage of the combines are equipped with yield-mapping systems and a field is subsampled in strips interspersed with strips harvested by combines not equipped with yield-mapping systems. We need to consider appropriate exclosure placement to facilitate statistical analysis when an entire field is not harvested with combines equipped with a yield-mapping system.

CONCLUSIONS

Grazing by geese generally reduced grain yield of winter wheat. Yields and yield reductions were variable within a field. The amount of yield reduction was related to extent, intensity, and timing of goose grazing. Under specific circumstances, goose grazing apparently increased grain yield. For those who wish to document the degree of impact that goose grazing has on grain yield, the protocols we have developed can be used to measure the impact throughout a field and to verify that it was goose grazing, rather than other factors, that caused the yield difference.

ACKNOWLEDGMENTS

The authors acknowledge the Oregon Agricultural Experiment Station, Oregon State University, and the Oregon Agricultural Legal Foundation for support and funding. Contributions were provided by numerous individuals, farms, agribusinesses, commodity commissions, and the Oregon State Legislature through the Oregon Department of Agriculture.

We thank Dale and Mark VanderZanden and Dave Kunkel of Columbia Farms and Connie Wheeler, and their crews, for exceptional cooperation throughout the project. Ernie Marx, Darcie Smith, Mohamadou Sissokho, Mary Borman, and Adele Johnson provided valuable technical and field assistance.

REFERENCES

Allen, H.A., Jr., D. Samsons, R. Brinsfield, and R. Limpert. 1985. The effects of Canada goose grazing on winter wheat: An experimental approach. p. 135–141. *In* P.T. Bromley (ed.) Proc. of the Eastern

Wildlife Damage Control Conf., 2nd, North Carolina State Univ., Raleigh, NC. 22–25 Sept. 1985. Dep. of Biostatistics, Johns Hopkins School Public Health, Baltimore, MD.

Anderson, G. 1996. The application of spatial technologies for rangeland research and management: State of the art. Geocarto Int. 11:5–11.

Bédard, J., A. Nadeau, and G. Gauthier. 1986. Effects of spring grazing by greater snow geese on hay production. J. Appl. Ecol. 23:65–75.

Belling, K.M. 1985. Winter wheat depredation by Canada geese in central New York State. M.S. thesis. State Univ. of New York, Syracuse.

Bennett, L.T., T.S. Judd, and M.A. Adams. 2000. Close-range vertical photography for measuring cover changes in perennial grasslands. J. Range Manage. 53:634–641.

Clark, S.L., and R.L. Jarvis. 1978. Effects of winter grazing by geese on yield of ryegrass seed. Wildlife Soc. Bull. 6:84–87.

Eastman, J.R. 1997. Idrisi for windows, user's guide, version 2.0. Clark Labs for Cartographic Technology and Geographic Analysis, Worchester, MA.

Flegler, J.E., Jr., H.H. Prince, and W.C. Johnson.1987. Effects of grazing by Canada geese on winter wheat yield. Wildlife Soc. Bull. 15:402–405.

Kahl, B.R., and F.B. Samson. 1984. Factors affecting yield of winter wheat grazed by geese. Wildlife Soc. Bull. 12:256–262.

Lillesand, M.T., and W.R. Kiefer. 1994. Remote sensing and image interpretation. John Wiley & Sons, New York.

Louhaichi, M., M.M. Borman, and D.E. Johnson. 2001. Spatially located platform and aerial photography for documentation of grazing impacts on wheat. Geocarto Int. 16:63–68.

Oregon Department of Agriculture. 1998. Wildlife damage to Oregon agriculture, 1997 survey summary. Oregon Dep. of Agric., Animal Health Div., Salem, OR.

Oregon Department of Fish and Wildlife. 1998. Oregon's Access & Habitat Board News, Fall 1998. Vol. 3(4).

Patterson, I.J. 1991. Conflict between geese and agriculture: Does goose grazing cause damage to crops? Ardea 79:179–186.

Trimble Navigation. 1998. Trimble pathfinder office software reference guide. Trimble Navigation, Ltd., Sunnyvale, CA.

Zar, J.H. 1996. Biostatistical analysis. 3rd ed. Prentice Hall, Upper Saddle River, NJ.