AN ABSTRACT OF THE DISSERTATION OF

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Michael M. Borman

A greater than 10-fold increase in Canada goose (*Branta canadensis*) populations over the past several years has resulted in concerns over grazing impacts on grass seed production in the mid-Willamette Valley, Oregon. This study was designed to develop methods to quantify and statistically analyze goose-grazing impacts on seed yields of tall fescue (*Festuca arundinacea* Schreb.) and perennial ryegrass (*Lolium perenne* L.). Yield-mapping-system equipped combines, incorporating global positioning system (GPS) technology, were used to measure and map yields. Image processing of ground-level photography to estimate crop cover and other relevant observations were spatially located via GPS to establish spatial-temporal goose grazing patterns. We sampled each field semi-monthly from mid-winter through spring. Spatially located yield data, soils information, exclosure locations, and grazing patterns were integrated via geographical information system (GIS) technology. To avoid concerns about autocorrelation, a bootstrapping procedure for subsampling spatially contiguous

seed yield data was used to organize the data for appropriate use of analysis of variance. The procedure was used to evaluate grazing impacts on seed yield for areas of fields with different soils and with differential timing and intensity of goose grazing activity. We also used a standard paired-plot procedure, involving exclosures and associated plots available for grazing. The combination of spatially explicit photography and yield mapping, integrated with GIS, proved effective in establishing cause-and-effect relationships between goose grazing and seed yield differences. Exclosures were essential for providing nongrazed controls. Both statistical approaches were effective in documenting goose-grazing impacts. Paired-plots were restricted by small size and few numbers and did not capture grazing impacts as effectively as comparison of larger areas to exclosures. Bootstrapping to subsample larger areas of yield for comparison was an effective method of avoiding autocorrelation of data while better representing impacts within a field. Occasional yield increases, ranging from 1 to 5 percent, were recorded following goose grazing. Goose grazing generally resulted in seed yield reductions, ranging up to 20 percent. Later and more intensive grazing tended to increase yield reductions. Newly seeded tall fescue tended to be the most sensitive to grazing. Established perennial ryegrass tended to be more resilient.

Methods to Assess Factors that Influence Grass Seed Yield

by
Mounir Louhaichi

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Mounir Louhaichi, Author

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Mounir Louhaichi was involved with experimental design, data collection, data analysis, GIS analysis, and writing of each manuscript. Dr. Michael M. Borman was involved with experimental design, data collection, data analysis, and writing of each manuscript. Dr. Douglas E. Johnson was involved with experimental design, data collection, data analysis, GIS analysis, and writing of each manuscript. Ms. Adele L. Johnson helped with data collection, data analysis, and writing and editing manuscripts.

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METHODS TO ASSESS FACTORS THAT INFLUENCE GRASS SEED YIELD

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

GOOSE POPULATION INCREASES

Prior to 1980, wild Canada geese (*Branta canadensis*) use of grain crops and grass seed fields in Northwest Oregon was not considered by area farmers to be a significant problem. By the mid-1980s, geese number was estimated at approximately 50,000, an increase over the historical numbers of 20,000 to 25,000 for the Lower Columbia and Willamette Valleys (United States Department of Fish and Wildlife, 1998). In the mid-1980s, hunting restrictions were imposed to protect the Cackler and Dusky subspecies. Cackler populations were being impacted by wildlife predation (Oregon Department of Fish and Wildlife, 1997) and egg gathering by natives in Alaska. Cackler populations have since recovered and dramatically increased. However, a treaty with the Yupik people in Alaska requires even higher numbers. The Dusky population has declined since the 1964 Alaskan earthquake, which raised the nesting grounds thus providing access to predators (Ken Durbin, ODFW, personal communication). Low Dusky numbers continue to be a concern to the United States Department of Fish and Wildlife Service, which is responsible for waterfowl under the Endangered Species Act.

A mid-1970s study in the Willamette Valley, Oregon, suggested that goose grazing did not adversely impact annual ryegrass (*Lolium multiflorum* Lam.) seed production (Clark and Jarvis, 1978). Results from that study were used to support an increase in the target level of geese from 25,000 to 50,000. Today, the winter population of all subspecies of Canada geese are estimated at over 225,000 in the Lower Columbia and Willamette Valleys, more than at any time in recorded history (Oregon Department of Fish and Wildlife, 1998). Goose numbers build in the fall as migrants arrive, and remain high through mid-April, when most geese return north.

As a result of this growth in goose numbers, their use of crop fields has become progressively more intense in the winter and spring months, and according to area farmers, has resulted in economic loss. Area farmers have also stated that additional crops have been impacted. According to the Oregon Department of Agriculture (Oregon Department of Agriculture, 1997) the total loss in crops due to goose depredation in 1997 was estimated at nearly $15 million.

IMPORTANCE OF GRASS SEED PRODUCTION IN THE PACIFIC NORTHWEST

As noted by Young *et al.* (1997) Oregon is the world's major producer of cool season forage and turf grass seed. Three things contribute to Oregon growers' ability to produce seed of the highest quality: climate, expertise, and infrastructure (Young, 1997). The cool season grasses are well adapted to the mild winters and dry harvest conditions found in the Pacific Northwest. Although the total annual rainfall in the Willamette Valley is more than 1000 mm, it rarely rains in the summer months. This presents an advantage for seed production. The majority of the grass seed acreage is grown without the help of irrigation, then dried in the field with little risk of being damaged by rain (Chastain, 2000).

GRAZING IMPACTS

Several studies have been conducted on the relationship between defoliation (grazing or cutting) of grass and seed production. In a 1969 preliminary investigation report, Chilcote *et al.* (1973) concluded that heavy goose grazing in an area can severely damage annual ryegrass seed production by elimination of the stand. They also observed that moderate goose grazing did not damage yield and may lead to an increase in seed yield as compared to no grazing. On the basis of these preliminary results, the authors stated that it would be desirable to initiate a more intensive study of the effects of goose grazing on annual ryegrass fields. Among other suggestions, they recommended that attempts should be made to determine the total areas impacted by varying goose grazing intensities.

Clark and Jarvis (1978) reported results of goose grazing on both annual and perennial ryegrasses during the 1974-1975 crop year. The authors concluded that grazing by geese in winter may have an immediate effect on ryegrass but does not reduce yield of seed, and in some cases may increase yield. The study involved erecting five exclosures per field (1.0-m high by 1.2-m diameter) at 50-m intervals along a transect. After the geese migrated north, comparisons with grazed plots were established in each field, on the portion of the field that had received the highest use by geese during winter. The grazed plots were parallel to and generally within, 25 m of the transect of ungrazed plots. At the time of the study, population levels of geese in the Willamette Valley were estimated to be 20,000 to 30,000.

Significant yield losses in grass and cereal crops were reported at a wide range of grazing intensities by geese (Patterson, 1991). In the same paper Patterson stated that due to variability, even within single studies, predicting yield losses due to grazing would be nearly impossible without a detailed study carried out over several years in the specific area where the prediction is to be used. He also suggested that clipping and grazing impacts by penned geese may not predict losses to be expected from grazing by wild geese. This means that compensation schemes should ideally be based on measurement of the actual yield losses themselves, using exclosure techniques. Traditional methods for obtaining sufficient data to accurately and precisely document differences involve extensive sampling in each grazed field, which is time consuming and expensive.

Young *et al.* (1996) studied the effect of sheep grazing on annual ryegrass using four grazing treatments (durations) over a two-year period. Results of this experiment suggest that annual ryegrass may be grazed until primary tillers have had their apical meristems grazed without any harmful effect on seed yield. Longer grazing duration progressively reduced leaf area. On the other hand, the number of fertile tillers increased as grazing duration increased during the first year. The impact was not significant in the second year. Findings also suggest that a short grazing period (until about one-third of primary tillers lose their apical meristem) may in fact increase seed yield. Jewiss (1972) reported that the increase in number of tillers per plant most likely resulted from the release of axillary tiller buds accompanying the removal of apical meristems on the main stem.

In a study conducted on 11 Connecticut fields often grazed by geese, leaf biomass of rye (*Secale cereale*) by mid-winter was 535 percent greater inside exclosures than in grazed portions of the same fields. By spring, rye leaf biomass was only 177 percent greater inside than outside of the exclosures (Conover, 1988).

Bedard *et al.* (1986) studied the effect of spring grazing by greater snow geese (*Chen caerulescens atlantica*, Linnaeus) on hay production in Montmagny, Quebec. Fifty-one sampling stations were randomly located. Each station had a paired plot (1.5 by 5.5 m) and a permanent strip transect. Goose grazing was monitored by counting the number of goose droppings every four days. Results indicated that the reduction in yield as a consequence of April and May grazing mounted to 14.3 percent.

Roberts (1965) tested five leafy grass varieties under different sheep grazing treatments. He concluded that defoliation in the fall/winter period until approximately two weeks before the formation of inflorescences did not reduce the yield of seed. He recommended that grazing in spring beyond the stage of inflorescence formation (a few weeks after ear formation when the inflorescences reach a vulnerable height within the sheath) should be avoided.

In a study at the Welsh Plant Breeding Station in Aberystwyth, Wales, Roberts (1958) reported that when sheep grazing occurred no later than mid-April, perennial ryegrass S101 showed no seed yield reduction. However, when grazing was postponed until May and drought occurred, there was a significant reduction in seed yield. The same study also suggested that March grazing of perennial ryegrass may be considered advantageous for seed production.

Brown (1980) reported that in all five comparisons between grazed and ungrazed perennial ryegrass plots, seed heads were smaller in grazed crops and in some cases seeds were also lighter. These results support the concept that grazing may have a negative impact on head size and seed weight.

Watson and Watson (1982) conducted a study in Mississippi involving a sward of tall fescue grown under three levels of nitrogen and five defoliation regimes. They found that both dry matter and seed yields were reduced significantly in plots defoliated after March 30. The explanation for the lowered seed yield was decreased tiller density and the number of spikelets per panicle. In addition, for all plots defoliated later than March 30, the seed quality was inferior. Thus, the results of this study indicate that tall fescue seed fields should not be defoliated in the spring, especially after tillers start to elongate and become erect, if maximum seed yield is to be obtained.

Fox *et al.* (1998) studied the effect of simulated spring goose grazing on the growth rate of timothy grass (*Phleum pratense*) leaves. Results showed that clipping three to four times resulted in 25 to 41 percent increases in cumulative elongation of youngest laminae compared to unclipped plants. However, the total cumulative laminae growth of entire plants showed no significant difference between clipped and unclipped plants, therefore no overcompensation took place.

Similar studies have been conducted on the effect of defoliation of winter wheat on yield production. Louhaichi (1999) reported that goose grazing impact on winter wheat varied considerably as field size, shape, and proximity to road varied. Yield maps revealed that goose grazing had reduced grain yield by 25 percent or more in heavily grazed areas. At harvest time, wheat grain in the heavily grazed areas had higher moisture content due to delayed maturity. Because of this, those areas were harvested two weeks later. Heavily grazed areas also had more weeds than ungrazed portions of the field. Late-season (April) grazing was more damaging to wheat yield than was earlier grazing, but early-season grazing generally had a negative impact on yield.

Kahl and Samson (1984) reported that in six trials, heavy grazing of winter wheat by Canada geese during fall or early-to-late spring resulted in less dense and shorter wheat stands through May 1. They also reported that grazed areas produced 30 to 78 percent less wheat than controls, and that heavy grazing reduced grain yields by 33 to 98 percent in eight of 11 trials.

Hubert *et al.* (1985) found that grazed plots had consistently lower yields than ungrazed plots with mean differences ranging from 0 to 13 percent. Differences were related to intensity of grazing. The effect of grazing extended beyond a simple loss of yield to include a delay in maturity and a reduction in plant height at harvest. Timing of grazing plays an important role. Belling (1985) found that field size and crop type were important variables in selection of feeding site.

Geese impact the fields in several ways, the most obvious being removal of green leaves throughout the winter and early spring seasons. Intense grazing may leave plants with only 1 cm protruding above the ground (Allen Jr. *et al.*, 1985). Geese can also pull an emerging plant from soggy soil or damage plants by trampling (Kahl and Samson, 1984).

Farmers have observed substantial yield reduction in areas of fields where geese concentrate. In extreme cases, portions of fields have been replanted to an alternative crop. In addition to yield reduction, there may be accompanying crop quality reductions due to increased weed contamination and variable maturity of the grain (Allen Jr. *et al.*, 1985). A study conducted in Michigan concluded that a single, intense grazing reduced yield by 18, 30, and 16 percent, respectively for young, dormant, and spring wheat (Flegler *et al.*, 1987). Sharrow (1990) reported that wheat grain yield was relatively insensitive to the intensity of sheep grazing applied, but that grazing within 110 days of harvest consistently reduced wheat grain yields.

QUANTIFYING GRAZING IMPACTS

Remote Sensing

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with it (Lillesand and Kiefer, 1994). Remote sensing enables us to measure the reflected, emitted, or backscattered electromagnetic radiation from Earth's surface using instruments stationed at a distance from the site of interest (Roughgarden *et al.*, 1991). These instruments can be a camera or a bank of sensors operated from a platform, an airplane, or a satellite. It provides the ability to monitor conditions expediently and efficiently in a non-destructive manner (Tucker, 1980; Friedl *et al.*, 1994; Hall *et al.*, 1995). Remotely sensed data have been used to estimate biophysical parameters such as amount of photosynthetically active tissue (Wiegand *et al.*, 1986; Wiegand and Richardson, 1990). Spectral signatures of plants are mainly determined by chlorophyll content. Commonly used vegetation indices include the greenness vegetation index (GVI) (Kauth and Thomas, 1976) calculated from observations in three or more bands; the simple ratio vegetation index (SRVI), defined by NIR/R in which NIR and R designate the energy reflected in the near-infrared and red portions of the electromagnetic spectrum (Sellers *et al.,* 1994), and the normalized difference vegetation index (NDVI), defined by (NIR-R)/(NIR+R) (Tucker, 1979).

Conventional aerial photographs remain the main source of remote sensing data in natural resource assessment despite the many developments in digital remote sensing (Avery, 1977; Howard, 1991; Driscoll, 1992). Many remote sensing applications currently involve the use of color film. The main advantage of color is that the human eye can discriminate many more shades of color than it can tones of gray. This capability is important in many applications of air-photo interpretation (Lillesand and Kiefer, 1994).

Accurate analysis of remotely sensed plant community data is dependent on an understanding of the reflectance/absorbance of energy from vegetation. Energy in the blue and red ranges is absorbed by plant chlorophyll and is used to power the photosynthetic apparatus (Salisbury and Ross, 1992). Therefore, dense, high chlorophyll-content vegetation will absorb more and reflect less red and blue energy than sparse or low chlorophyll-content vegetation. Where the vegetative cover is of a homogenous composition, reductions in reflectance form a gradient indicating greater biomass. Certain plant species reflect noticeably more blue light. Thus, the blue band potentially contains more information for some types of vegetation and even for the same species but at different phenological stage than does the red band (Harris, 1998). For instance, Tucker (1977) noted that wet or dry weight biomass had its strongest correlation with the blue band (0.35 to 0.44 μm). This is a valid statement as long as the distance between sensor and object is relatively short (less than 150 m) such as the case of low-level or platform photography. The longer the atmospheric pathway, the more severely the blue channel is distorted by scatter "noise" (Harris, 1998).

Platform Photography

Traditional sampling techniques for monitoring changes in herbaceous cover are subjective, time consuming, costly, and destructive. Attempts in using photography for measuring cover through automated digital image analysis are numerous. Louhaichi *et al.* (2001) and Johnson *et al.* (1998) developed an algorithm based on the red, green, and blue bands of color photography. The digital numbers of each pixel are ratioed resulting is a Boolean image where green leaf is classified as cover and soil as nonliving. Similarly Richardson *et al.* (2001) adopted a digital image analysis to estimate cover in turfgrass. Digital images are obtained with a digital camera and analyzed individually using SigmaScan Pro® software (SPSS Inc., Chicago, Illinois). The color threshold feature (hue and saturation) is adjusted until an acceptable color tone is reached. The measurement of percent green cover is estimated by ratioing the number of green pixels by the total pixel count of the image. Close-range of repeated vertical photographs of permanent plots (1 m^2) were classified using supervised image analysis. Images were edited and analyzed using Adobe Photoshop® (Adobe Systems Inc., San Jose, California). Soil colored pixels were selected and deleted. The remaining pixels (representing plant cover) were recolored black and the percentage of black pixels was recorded (Bennett *et al.*, 2000).

Various types of ground-based platforms can be used for the purpose of collecting highly detailed data by remote sensing. Field-level sensors may be located on the ground or on platforms very near ground level. Portable masts can also be used to support cameras and sensors to measure reflection and emission spectra in different atmospheric conditions (Barrett and Curtis, 1992). Louhaichi *et al.* (2001) mounted a 35-mm camera on a lightweight platform of polyvinyl chloride (PVC) tubing to monitor goose grazing on wheat. The camera was pointed vertically downward 1.7 m above the ground. A 1-m^2 frame was central in the photograph, which provided an estimate of scale. Bennet *et al.*, (2000) constructed a portable self-supporting aluminum stand equipped with a collapsible camera arm and two telescopic legs. The height of the camera above the ground was 2 m. Using a 35-mm focal length, the image area covered about 1.4 by 2.1 m. Ridchardson *et al.* (2001) used a monopod made of 10-cm-diameter PVC tubing. It consisted of a vertical stand that was 1.5 m in height and a horizontal arm that was mounted at a 90° from vertical and extended 1 m away from the vertical axis.

Geographical Information Systems

Geographical information systems (GIS) is "a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth" (Dueker and Kjerne, 1989). GIS is needed to perform spatial analyses such as overlay analysis and image classification. GIS has the ability to spatially interrelate multiple files or data layers. Once all layers are in geographic registration, the analyst can manipulate and overlay the information contained in, or derived from, the various data files (Lillesand and Kiefer, 1994). Image classification refers to the computer-assisted interpretation of digital remotely-sensed images. It can be supervised or unsupervised. Supervised classification routines are based on training sites and areas of known ground cover assigned by the operator. They classify the image by assigning each pixel in the image to one of the land cover categories described by the training sites. Unsupervised classification uses cluster analysis to detect differences in reflectance values across a set of bands and creates a classification from typical reflectance patterns (Eastman, 1997).

Global Positioning Systems

It is critical to accurately determine the position of every sample point, both to allow the ground samples to be located and to permit the integration of inventory data using a Geographical Information System software. This can be achieved using Global Positioning System (GPS) navigation during photography (Spencer *et al.*, 1997). In the 1970s the U.S. Department of Defense began launching global positioning satellites. GPS is based on a system of 24 satellites covering the earth in precise orbits at about 17,600-km altitude. Each satellite carries several atomic clocks. There are as many as 12 satellites available for signal transmission and receiver reception at any one time. A receiver measures the distance from the satellite for a two-dimensional position fix. Signals from at least four satellites add altitude, providing a three-dimensional fix (Deckard and Bolstad, 1996; Langley, 2000). At various times of the day, and at various locations on the surface of the earth, the number of satellites and the length of time they are above an observer's horizon will vary. Although at certain times of the day there may be up to 12 satellites visible simultaneously, there are occasional periods of degraded satellite coverage. Degraded satellite coverage is generally defined in terms of the magnitude of the Dilution of Precision (DOP) factor, a measure of the quality of satellite geometry. The higher the DOP value, the poorer the satellite geometry. Errors in the satellite clock, satellite positions, receiver clock, and atmospheric delays of the signals degrade accuracy (Misra and Enge, 2001). With a process called differential correction, GPS coordinates can be corrected to provide accuracy within a few millimeters (Herring, 1996). A stand-alone GPS receiver without differential correction obtains position estimates that are accurate to within 100 m (Anderson, 1996; Trimble Navigation, 1996).

The satellites transmit on two L-band frequencies: L1 = 1575.42 MHz and L2 = 1227.6 MHz. These are radio frequency waves capable of transmission through the atmosphere over great distances, but they are unable to penetrate solid objects. The L-band carrier waves themselves carry no information and must be modified (or modulated) in some way.

In the Global Positioning System, the L-band carrier waves are modulated by three ranging codes and the navigation message. The three GPS ranging codes are:

- The C/A code (sometimes referred to as the "clear/access" or "coarse/acquisition" code), also referred to as the "S code". It has a 1.023-MHz chip rate, a period of 1 millisecond, and is used primarily to acquire the P-code.
- The P code (the "private" or "precise" code) was designed for use only by the military and other authorized users. It has a 10.23-MHz rate, is changed every seven days, and is the principal navigation ranging code.
- The Y-code is used in place of the P-code whenever the anti-spoofing (A-S) mode of operation is activated. Both carrier signals contain the navigation message.

The C/A and P (or Y) codes provide the means by which a GPS receiver can measure one-way ranges to the satellites. Each satellite transmits a navigation message containing its orbital elements, clock behavior, system time, and status messages. In addition, an almanac is also provided which gives the approximate data for each active satellite. This allows the user to find all satellites once the first has been acquired. These codes have the characteristics of random noise, but are in fact binary codes generated by mathematical algorithms and are therefore referred to as "pseudo-random-noise" or PRN codes. One C/A code is assigned to each GPS satellite. The P code is a far more complex binary sequence of 0s and 1s. The resolution of this code is 10 times the resolution of the C/A code (Trimble Navigation, 2001; Wells *et al.*, 1987).

Yield Mapping Systems

Today, Global Positioning System (GPS) technology has revolutionized the way we navigate. When utilized in farming, a combine equipped with GPS and a yield monitor can record its exact location in the field and yield at that location. That information is transferred to a computer and provides the data for a detailed yield map of the field (Lotz, 1977).

The yield monitor measures the rate at which harvested grain enters the grain tank. A sensor in the stream of grain measures the mass flow. The most common method is to measure the force of the grain striking a plate located at the top of the "clean-grain" elevator. Yield and moisture data are collected simultaneously to obtain corrected yield. Most sensors measure the capacitance of the grain and can provide continuous moisture data. The accuracy depends on the elevator speed, the type of crop, and the moisture of the grain. A yield monitor must be calibrated to provide accurate yield data. Calibration must be performed for each type of grain harvested at the beginning of the harvest season. Accuracy usually improves when several loads are used to perform the calibration. Re-calibration should be performed as necessary, especially later in the season as average moisture content drops or when there is a significant change in crop conditions. Calibration is usually as simple as weighing and recording the moisture of the first several loads collected under a variety of conditions, such as various operating speeds or grain flow rates (Casady *et al.*, 1998).

Yield-mapping software is evolving rapidly. Many of the new packages make it easy to download data from a card to a computer, which can then produce color yield maps. These software packages typically allow the user many options in defining how a map is constructed. One of the most common methods is a vector map, in which each point defines a single yield estimate on the map. The color of each dot reflects a category of yield estimate. Other common options include displaying data cells or grids of differing sizes to help categorize yields over larger areas. Contour maps can also help users visualize differences among yield categories by smoothing or interpolating between yield estimates (John Deere Corp., 1997). According to Anderson (1996), when used in combination, GIS, GPS, and local assessment tools can integrate information sources, create new information, validate results, and provide visual representations of the spatial dynamics for an area.

Digital Elevation Model

In recent years, the use of Digital Elevation Models (DEMs) has become popular and common for topographic analyses and mapping of topographic attributes. DEMs can be used to derive a wealth of information about the morphology of land surface (United States Geological Survey, 1987). They often serve as a base theme on which other data layers, such as plant community distribution, are overlain. A DEM is digital cartographic/geographic data in raster form. The terrain elevations for ground positions are sampled at regularly spaced horizontal intervals. The most widely available high-resolution DEMs in the U.S. are the 7.5-minute Level 1 DEMs available from the United States Geological Survey. These 7.5-minute DEMs are made from contour lines and are classified into two major resolution groups: 30-m and 10-m grid posting. The 30-m DEM is the standard product produced by the USGS. The area covered in the 30-m DEM is split into squares with 30-m sides; hence, hills or valleys smaller than the 30-m cells will not show up. In an attempt to enhance the data, the United States Geological Survey recently experimented in producing 10-m DEMs. These 10-m DEMs come from the same data source: the digital line graph (DLG) with 20 and 40-foot contours. The elevation information is interpolated down to a finer resolution to produce a closer grid spacing DEM, thus portraying the Earth's surface in a finer detail (United States Geological Survey, 2002).

In agronomic systems, Bakhsh *et al.* (2000) found that yield was influenced by topographic position within a field. The vertical resolution of DEMs needs to be precise enough to identify subtle differences that influence or control the pattern of vegetation and soils. For 7.5-minute DEMs derived from a photogrammetric source, 90 percent of control points on the ground have a vertical accuracy of 7-m root mean square error or better and 10 percent are in the 8 to 15-m range. For 7.5 and 15-minute digital elevation models derived from vector or digital line graph hypsographic and hydrographic source data, a root mean square error of one-half contour interval or better is required (National Mapping Division, U.S. Geological

Survey, 1998). This level of resolution is not sufficient for many ecological studies or for precision agriculture.

McCormac (1991) reported that traditional engineering surveying techniques including transits, theodolites, and total stations can generate high resolution maps but they are usually time consuming and expensive. Similarly commercial remote sensing data providers using airborne LIDAR (light detection and ranging) systems for topographic mapping can provide a 1.5-m XY resolution and 0.4-m vertical accuracy (Terrapoint, 2000). However, the current cost of commercial LIDAR data is too great for most agricultural uses (Davis and Wang, 2001).

New technologies have recently become available including laser level combined with GPS, which may offer viable alternatives for topographic mapping (Clark and Lee, 1998). Coarse-acquisition code differential corrected global positioning system (C/A code DGPS) technology has revolutionized field mapping and is widely used in natural resources because X (longitude) and Y (latitude) position can be ascertained with a root mean square error of 50 to 100 cm (Trimble Navigation, 2001). However, vertical errors of 100 to 200 cm are common with coarse-acquisition code differential global positioning systems (Clark and Lee, 1998; Trimble Navigation, 1996). Real-time stop-and-go and real-time kinematic carrier-phase differential global positioning systems mounted on vehicles have been used to map boundaries (Sumpter and Asher, 1994) and elevation with vertical root mean square errors are reported to vary from 2 to 9 cm (Clark and Lee, 1998; Johansen *et al.*, 2001; Trimble Navigation Ltd., 2001; Leica Geosystems AG, 1999). Carrier-phase differential global positioning system units cost from $20,000 to $100,000 (Johansen *et al.*, 2001). Because of the cost, carrier-phase differential global positioning systems are not as widely available as coarse-acquisition code differential global positioning systems.

Data Structure and Statistical Analysis

Spatial variability in soil productivity, crop growth, and yield have always been realities of farming. Farm fields are characterized by areas with varying potential to produce crop output. Across a given field, one could find variability with respect to soil type, nutrient status, landscape position, organic matter content, water holding capacity, and so on. Variation in these factors leads to variation in the potential of different areas to utilize applied inputs and produce crop output (Carr *et al.*, 1991; Wibawa *et al.*, 1993; Sawyer, 1994).

With recent technologies, such as yield monitors and differential global positioning systems mapping, delineating field variability has become possible. Site-specific crop management systems, which attempt to manage different areas within a field to their optimum, may improve economic returns and reduce environmental contamination due to a more judicial application of nutrients and better utilization of the soil's resources (Fridgen *et al.*, 2000).

The use of traditional parametric procedures assumes that the data are normally distributed, uncorrelated or independent, and exhibiting constant variance

(Ramsey and Schafer, 1997). Yield mapping systems record continuous data that are collected serially in space and time. Performing statistical analysis on data sets that exhibit positive autocorrelation as if they were uncorrelated has serious implications. The precision of the estimators is often overstated, resulting in test statistics that are too large and p-values that are too small (Schabenberger and Pierce, 2002).

Geostatistics, based on the theory of regionalized variables, is the primary tool of spatial variability analysis. The results obtained from a geostatistical analysis are dependent on a number of variables, such as sampling frequency and number, sampling spacing and accuracy, and analysis parameter selection (Webster and Oliver, 1990). Blocking was advocated by R.A. Fisher as a way to overcome the effects of spatial heterogeneity. Randomization neutralizes those effects unaccounted by the blocking scheme (Schabenberger and Pierce, 2002). Stratified sampling is obtained by separating the population into groups or strata, and then independently selecting a random sample from each stratum (Scheaffer *et al.*, 1996).

"Bootstrapping" is a resampling procedure that can be used to subsample continuous data and produce statistical inferences that are not compromised by autocorrection. Bootstrap methods are computer-intensive methods of statistical analysis that use simulation to calculate standard errors, confidence intervals, and significance tests. Each subsample is a random sample with replacement from the full sample. In short, a bootstrap refers to using the original data set to generate new data sets (Knox and Peet, 1989).

A distinction between bootstrapping and randomization needs to be clarified. Bootstrap procedures take the combined samples as a representation of the population from which the data came, and create several bootstrapped samples by drawing, with replacement, from that pseudo-population. Randomization procedures also start with the original data, but, instead of drawing samples with replacement, these procedures systematically or randomly reorder (shuffle) the data several times and calculate the appropriate test statistic on each reordering. Since shuffling data amounts to sampling without replacement, the issue of replacement is one distinction between the two approaches. Aside from the replacement issue, the two approaches differ in a very fundamental way. Bootstrapping is primarily focused on estimating population parameters, and it attempts to draw inferences about the population(s) from which the data came. Randomization approaches, on the other hand, are not particularly concerned about populations or their parameters. Instead, randomization procedures focus on the underlying mechanism that led to the data being distributed between groups in the way that they are (Efron and Tibshirani, 1993; Pillar, 1999).

STUDY OBJECTIVES

This study was designed to develop methods that could be used by farmers to document the impact of grazing geese on grass seed production. Study objectives included:

- develop methods that provide reliable estimates of goose impact on grass seed yield;
- develop methods to separate goose damage from other factors that lower yield, such as poor soil or waterlogging;
- identify the timing of goose use of selected grass seed fields;
- provide an estimate of goose impact on grass seed yield on specific fields during the research period;
- test the assumption that early grazing by geese is not detrimental to plant growth and production;
- determine the optimum exclosure size to collect enough samples to accurately measure yield;
- identify optimum timing for taking aerial photography (single flight);
- develop and test a new technique for generating high resolution digital elevation models for research plots and agronomic fields;
- develop a sound and efficient data sampling and analysis strategy for the yield-mapping-system data.

To achieve these objectives, we employed Global Positioning Systems (GPS), Geographical Information Systems (GIS), remote sensing, and precision farming technologies. An emphasis on the higher technology methods was considered necessary because we are transitioning to a digital world. Computers have replaced slide rules, GIS files are replacing map cabinets, and soon GPS will replace the compass (Warner *et al.*, 1996).

LITERATURE CITED

Allen, H.A. Jr., D. Samsons, R. Brinsfield, and R. Limpert. 1985. The effects of Canada goose grazing: an experimental approach. Proceedings of the Eastern Wildlife Damage Control Conference 2:135-141. Wildlife Review 206.

Anderson, G. 1996. The application of spatial technologies for rangeland research and management: state of the art. Geocarto International 11(3):5-11.

Avery, T. A. 1977. Interpretation of Aerial Photographs, Third Edition. Burgess Publishing Company, Minneapolis, Minnesota. 392p.

Bakhsh, A., T.S. Colvin, D.B. Jaynes, R.S. Kanwar, and U.S. Tim. 2000. Using soil attributes and GIS for interpretation of spatial variability in yield. Transactions of the American Society of Agricultural Engineers 43:819-828.

Barrett, E.C. and L.F. Curtis. 1992. Introduction to environmental remote sensing. Chapman and Hall, New York. 426p.

Bédard, J., A. Nadeau, and G. Gauthier. 1986. Effects of spring grazing by greater snow geese on hay production. Journal of Applied Ecology 23:65-75.

Belling, K. M. 1985. Winter wheat depredation by Canada geese in central New York State. M.S. Thesis, State University of New York, Syracuse. 108p.

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

Brown, K.R. 1980. Seed production in New Zealand ryegrasses: I. Effect of grazing. New Zealand Journal of Experimental Agriculture 8:27-32.

Carr, P.M., G.R. Carlson, J.S. Jacobson, G.A. Nielsen, and E.O. Skogley. 1991. Farming soils, not fields: A strategy for increasing fertilizer profitability. Journal of Production Agriculture 4(1): 57-61.

Casady, W., D. Pfsot, C. Ellis, and K. Shannon page. 1998. Online. Precision Agriculture: Yield Monitors. University of Missouri, Columbia. http://www.fse.missouri.edu/mpac/pubs/wq0451.htm (Accessed May 22, 2002).

Chastain, T. G. 2000. Precipitation and Grass Seed Yield in the Willamette Valley. Seed Production Research at Oregon State University USDA-ARS cooperating. Oregon Seed Publications.

Chilcote, D., E.P. Peloquin, and R.S. Rodgers. 1973. Goose grazing in relation to seed yield of annual ryegrass. Proceedings 33rd Annual Meeting of the Oregon Seed Growers League, Eugene, Oregon.

Clark, R.L. and R. Lee. 1998. Development of topographic maps for precision farming with kinematic GPS. Transactions of the American Society of Agricultural Engineers 41:909-916.

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

Conover, M.R. 1988. The effect of grazing by Canada geese on the winter growth of rye. Journal of Wildlife Management 52(1):76-80.

Davis C.H. and X. Wang. 2001. High-resolution DEMs for urban applications from NAPP photography. Photogrammetric Engineering and Remote Sensing 67(5):585-592.

Deckard, C. and P. Bolstad. 1996. Forest canopy, terrain, and distance effects on global positioning point accuracy. Photogrammetric Engineering and Remote Sensing 62(3):317-321.

Driscoll, R.S. 1992. Remote sensing – An invaluable ally for assessing and managing renewable natural resources. GIS World 5(4):66-69.

Dueker, K.J. and D. Kjerne. 1989. Multipurpose Cadastre Terms and Definitions. American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, Virginia.

Eastman, J.R. 1997. Idrisi for windows, user's guide, version 2.0. Clark Labs for Cartographic Technology and Geographic Analysis, Worchester, Massachusetts. 386p.

Efron, B. and R.J. Tibshirani. 1993. An introduction to the bootstrap. Chapman and Hall, New York. 436p.

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

Fox, A.D., N.J. Kristiansen, D.A. Stroud, and H. Boyd. 1998. The effects of simulated spring goose grazing on the growth rate and protein content of *Phleum pratense* leaves. Oecologia 116:154-159.

Fridgen, J.J., C.W. Fraisse, N.R. Kitchen, and K.A. Sudduth. 2000. Delineation and analysis of site-specific management zones. Second International Conference on Geospatial Information in Agriculture and Forestry. Lake Buena Vista, Florida.

Friedl, M.A., J. Michaelsen, F.W. Davis, H. Walker, and D.S. Schimel. 1994. Estimating grassland and leaf area index using ground and satellite data. International Journal of Remote Sensing 15:1401-1420.

Hall, F.G., J.R. Townshend, and E.T. Engman. 1995. Status of remote sensing algorithms for estimation of land surface state parameters. Remote Sensing of Environment 51:138-156.

Harris, N.R. 1998. Spatial patterns of tree effects on pasture production in open canopied agroforest. M. S. thesis, Oregon State University, Corvallis. 109p.

Herring, T.A. 1996. The global positioning system. Scientific American 274(2):44-50.

Howard, J.A. 1991. Remote Sensing of Forest Resources. Chapman and Hall, London, England. 417p.

Hubert, A. Jr., D. Dammons, R. Brinsfield, and R. Limpert. 1985. The effects of Canada goose grazing on winter wheat: an experimental approach. Proceedings: Eastern Wildlife Damage Control Conference 2:135-141.

Jewiss, O.R. 1972. Tillering in grasses: Its significance and control. Journal of British Grassland Society 27:65-82.

Johansen, D.P., D.E. Clay, C.G. Carlson, K.W. Stange, S.A. Clay, D.D. Malo, and J.A. Schumacher. 2001. Vertical accuracy of two differentially corrected global positioning satellite systems. Journal of Soil and Water Conservation 56:198-201.

John Deere Corp. 1997. John Deere Yield Mapping System. JDmap GreenStar™. Version 2.1. User's Guide.

Johnson, D.E., M.M. Borman, M. Louhaichi, D.J. Smith, and N.R. Harris. 1998. What's good for the grower. GPS World 9(3):30-36.

Kahl, B.R. and F.B. Samson. 1984. Factors affecting yield of winter wheat grazed by geese. Wildlife Society Bulletin 12: 256-262.

Kauth, R.J. and G.S. Thomas. 1976. The Tasseled Cap - a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. Proceedings of Symposium on Machine Processing of Remotely Sensed Data. IEEE, New York. pp 41-49.

Knox, R.G. and R.K. Peet. 1989. Bootstrapped ordination: a method for estimating sampling effects in indirect gradient analysis. Vegetation 80:153-165.

Langley, R.B. 2000. Navigation 101: Basic navigation with a GPS receiver. GPS World 11(10):50-54.

Leica Geosystems AG. 1999. GPS Surveying – system 500. Leica Geosystems AG. Heerbrugg, Switzerland.

Lillesand, M.T. and W.R. Kiefer. 1994. Remote Sensing and Image Interpretation. John Wiley and Sons, Inc. 750p.

Lotz, L. 1997. Yield Monitors and Maps: Making Decisions. Ohio State University Extension Fact Sheet AEX-550-97. The Ohio State University. 4p.

Louhaichi, M., M.M. Borman, and D.E. Johnson. 2001. Spatially located platform and aerial photography for documentation of grazing impacts on wheat. GEOCARTO International (16)1:63-68.

Louhaichi, Mounir. 1999. Assessment of impacts of Canada geese on wheat production. M. S. thesis, Oregon State University, Corvallis. 104p.

McCormac, J.C. 1991. Surveying Fundamentals. Prentice Hall, Englewoods Cliffs, New Jersey. 608p.

Misra, P. and P. Enge. 2001. Global Positioning Systems: Signals, Measurements, and Performance. Ganga-Jamuna Press. Lincoln, Massachusetts. 408p.

National Mapping Division, United States Geological Survey. 1998. National Mapping Program Technical Instructions: Standards for Digital Elevation Models. Version 01/1998. Silver Spring, Maryland.

Oregon Department of Agriculture page. 1997. Online. Oregon wildlife damage survey. Oregon Agricultural Statistics Service. http://www.oda.state.or.us/oass/wildlife.htm (Accessed July 3, 2002).

Oregon Department of Fish and Wildlife and Washington Department of Fish and Wildlife. 1997. Pacific Northwest Goose Management. Portland, Oregon.

Oregon Department of Fish and Wildlife. 1998. Oregon's Access & habitat Board News, Fall 1998, Vol. 3, No. 4.

Patterson, I.J. 1991. Conflict between geese and agriculture: does goose grazing cause damage to crops? ARDEA 79(2):179-186.

Pillar, V.D. 1999. The bootstrapped ordination re-examined. Journal of Vegetation Science 10:895-902.

Ramsey, F.L. and D.W. Schafer. 1997. The Statistical Sleuth: A Course of Methods of Data Analysis. Duxbury Press, California. 742p.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Science 41:1884-1888.

Roberts, M.H. 1958. The effect of defoliation on the seed-producing capacity of bred strains of grasses. I. Timothy and perennial ryegrass. Journal of the British Grassland Society 13:255- 261.

Roberts, M.H. 1965. The effect of defoliation on the seed-producing capacity of bred strains of grasses. III. Varieties of perennial ryegrass, cocksfoot, meadow fescue and timothy. Journal of British Grassland Society 20:283-289.

Roughgarden, J., Running, S.W., Matson, P.A. 1991. What does remote sensing do for ecology? Ecology 72(6):1918-1922.

Salisbury, F. and C. Ross. 1992. Plant Physiology, Fourth edition. Wadsworth Publishing Company, Belmont, California. 600p.

Sawyer, J.E. 1994. Concepts of variable rate technology with considerations for fertilizer application. Journal of Production Agriculture 7(2):195-201.

Schabenberger, O. and F.J. Pierce. 2002. Contemporary Statistical Models for the Plant and Soil Sciences. CRC Press, New York. 738p.

Scheaffer, R.L., W. Mendenhall III., and R.L. Ott. 1996. Elementary Survey Sampling. Duxbury Press, New York. 501p.

Sellers, P.J., S.O. Los, C.O. Justice, D.A. Dazlich, G.J. Collatz, and D.A. Randall. 1994. A Global 1 x 1 NDVI data set for climate studies. Part 2: The generation of global fields of terrestrial biophysical parameters from NDVI. International Journal of Remote Sensing 15:3519-3545.

Sharrow, S.H. 1990. Defoliation effects on biomass yield components of winter wheat. Canadian Journal of Plant Science 70: 1191-1194.

Spencer, D.R., M.A. Green, and P.H. Biggs. 1997. Integrating eucalupt forest inventory and GIS in Western Australia. Photogrammetric Engineering and Remote Sensing Vol. LXIII, Number 2:114-216.

Summers, R.W. and G. Hillman. 1990. Scaring brent geese (*Branta bernicla*) from fields of winter wheat with tape. Crop Production 9:459-462.

Sumpter, C.W. and G.W. Asher. 1994. Real-time kinematic GPS for cadastral surveys. Proceedings of the American Congress on Survey and Mapping. American Society for Photogrammetry and Remote Sensing International Meeting 1994. Reno, Nevada.

Terrapoint page. 2000. Online. Lidar Advantages and Approach. TerraPoint, LLC, The woodlands, Texas. http://www.terrapoint.com/tfc/Real_Estate/TerraPoint/Technology/default.asp (Accessed May 18, 2002).

Trimble Navigation. 1996. Trimble Pathfinder Office™, Software Reference Guide. Trimble Navigation, Ltd., Sunnyvale, California. 432p.

Trimble Navigation page. 2002. Online. GPS Satellites. http://www.trimble.com/gps/satellites.html (Accessed June 10, 2002).

Trimble Navigation. 2001. Trimble 5700 Receiver. Trimble Navigation Engineering and Construction. Dayton, Ohio.

Tucker, C.J. 1977. Spectral estimation of grass canopy variables. Remote Sensing of the Environment 6:11-26.

Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment 8:127-150.

Tucker, C.J. 1980. A critical review of remote sensing and other methods for non-destructive estimation of standing crop biomass. Range and Forage Science 35:177-182.

United States Fish and Wildlife Service. 1998. Waterfowl Population Status, 1998. U.S. Fish and Wildlife Service, Department of Interior. I 49.100/3: 998.

United States Geological Survey. 1987. Digital Elevation Models. U.S. Geological Survey Data User's Guide 5. 38p.

United States Geological Survey page. 2002. Online. USGS Digital Elevation Model. http://edcwww.cr.usgs.gov/glis/hyper/guide/usgs_dem (Accessed June 3, 2002).

Warner, W.S., R.W. Graham, and R.E. Read. 1996. Small Format Aerial Photography. American Society for Photogrammetry and Remote Sensing. Whittles Publishing, Scotland, United Kingdom. 348p.

Watson, C.E., Jr. and V.H. Watson. 1982. Nitrogen and date of defoliation effects on seed yield and seed quality of tall fescue. Agronomy Journal 74:891-893

Webster, R. and M.A. Oliver. 1990. Statistical Methods in Soil and Land Resource Survey. Oxford University Press, New York. 316p.

Wells, D.E., N. Beck, D. Delikaraoglou, A. Kleusberg, E.J. Krakiwsky, G. Lachapelkle, R.B. Langley, M. Nakiboglu, K.P. Schwarz, J.M. Tranquilla, and P. Vanicek. 1987. Guide to GPS Positioning. 2nd edition. Canadian GPS Associates, Fredericton. New Brunswick, Canada. 600p.

Wibawa, W.D., D.L. Dludlu, L.J. Swenson, D.G. Hopkins, and W.C. Dhanke. 1993. Variable fertilizer application based on yield goal, soil fertility and soil map unit. Journal of Production Agriculture 6 (2):255-261.

Wiegand, C.L., A.J. Richardson, and P.R. Nixon. 1986. Spectral components analysis: a bridge between spectral observations and agro-meterological crop models. IEEE Transactions on Geoscience and Remote Sensing GE-24(1):83-89.

Wiegand, C.L. and A.J. Richardson. 1990. Use of spectral vegetation indices to infer leaf area, evapotranspiration and yield: I. Results. Agronomy Journal 82:623-629.

Young III, W.C., D.O. Chilcote, and H.W. Youngberg. 1996. Annual ryegrass seed yield response to grazing during early stem elongation. Agronomy Journal 88:211-215.

Young III, W.C. 1997. *Festuca arundinacea* Schreb. (Tall Fescue) in the USA. In: Forage Seed Production. Volume 1: Temperate Species. Edited by Fairey, D.T and J.G. Hampton. CAB International, New York. pp 287-296.

Young III, W.C., M.E. Mellbye, and G.A. Gingrich page. 1997. Online. The Oregon Grass Seed Industry. http://www.css.orst.edu/seed-ext/pub/industry.htm (Accessed May 15, 2002).

CHAPTER 2: CREATING LOW-COST HIGH-RESOLUTION DIGITAL ELEVATION MODELS

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Key Words: digital elevation model, DEM, digital terrain model, DTM, geographic information systems, GIS, global position system, GPS, topography.

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ABSTRACT

Ecologists and agronomists are interested in topography because it affects soil, plants, and hydrologic processes. Digital elevation models (DEMs) accurate to several centimeters of vertical elevation are needed, but construction is time consuming and expensive when traditional surveying methods are used. Carrier-phase differential global positioning systems can map vertical changes in topography with root mean square errors (RMSE) of 2 to 9 cm, but equipment is expensive (\$20,000 to \$100,000). Coarse-acquisition code differential global positioning systems (C/A code-DGPS) are much cheaper (< \$8,000) and widely available, but vertical errors are large with root mean square errors of 100 to 200 cm, which severely limits their usefulness in ecological studies. We combined a coarse-acquisition code differential global positioning system and a laser level (<\$1,000) to map topographic change in fields, wetlands, and research plots. Our technique uses the coarse-acquisition code differential global positioning system for longitudinal and latitudinal (X or easting, Y or northing) position, while the laser level provides vertical position (elevation) as measured from a ground control point or monument. Measuring elevation across a field scale area is a 2-step procedure. At each sample location the distance from the laser level to the ground is determined and entered as a comment in the differential global positioning systems data logger. In the office, sample locations are differentially corrected and elevation is calculated by subtracting the laser level-to-ground distance from the elevation of the laser. Data is then imported to geographic information system

(GIS) software that interpolates between points. The differential global positioning system yields X, Y locations with a root mean square error of between 0.5 and 1.0 m. Elevations measured with our laser level had an accuracy of better than 2 cm across its 230-m working radius. Our technique works best for areas up to approximately 40 ha on open, rolling terrain.

RESUMEN

Los ecólogos y los agrónomos están interesados en la topografía porque afecta los procesos hidrológicos, el suelo y la planta. Se necesita la precisión de los modelos de elevación digital (DEMs) a varios centímetros de elevación vertical, pero la elaboración consume tiempo y es costoso cuando se utilizan métodos tradicionales de estudio. Los sistemas de posicionador global diferencial puede mapear cambios verticales en la topografía, con valores de la raíz del cuadrado medio de los errores (RMSE) de 2 a 8 cm, pero el equipo es costoso ($20,000 a $100,000 dólares americanos). La adquisición gruesa (C/A) de código DGPS es mucho más barata (<$8,000 dólares americanos) y esta disponible ampliamente, pero los errores verticales son mayores, con un RMSE de 100 a 200 cm; el cual, limita severamente su uso en estudios ecológicos. Nosotros combinamos la C/A de código DGPS y un nivel láser (<$1,000 dólares americanos) para mapear los cambios topográficos en los terrenos de cultivo, tierras húmedas y las parcelas de investigación. Nuestra técnica usa la C/A de código DGPS para la posición longitudinal y latitudinal (X,Y), mientras que el nivel láser provee la posición

vertical (elevación) como medida de punto o mojón de control en el terreno. La elevación medida a través de una área en el terreno de cultivo consiste en dos procedimientos. En cada ubicación de la muestra, se determina la distancia del nivel láser al suelo, y se captura como una observación en el registrador de datos DGPS. En la oficina, las ubicaciones de las muestras se corrigen diferencialmente y se calcula la elevación por diferencia del nivel láser a la distancia al suelo, desde la elevación del láser. Luego los datos se importan a un programa de información geográfica (GIS) que hace la interpolación entre puntos. Las muestras DGPS permiten una ubicación de X, Y con un RMSE entre 0.5 y 1.0 m. Las elevaciones medidas con nuestro nivel láser tuvo una certeza mayor de 2 cm a lo largo de los 230-m de radio de trabajo. Nuestra técnica funciona mejor en áreas hasta, aproximadamente, de 40 ha en terreno ondulado y abierto.

INTRODUCTION

Patterns of plants, soils, and water on landscapes can be influenced by subtle changes in topography (Brady and Weil, 2001; Young and Hammer, 2000; Stoeckel and Miller-Goodman, 2001; Brooks *et al.*, 1997). In agronomic systems, Bakhsh *et al.* (2000) found that yield was influenced by topographic position within a field. Because topography and associated response patterns are spatial, geographic information systems (GIS) have been used to map and link them. Elevation or terrain models often serve as a base theme on which other data layers, such as plant community distribution, are overlain. The vertical resolution of digital elevation models (DEMs) needs to be precise enough to identify subtle differences that influence or control the pattern of vegetation and soils. Unfortunately, the most widely available digital elevation model used for natural resource/agronomic management is the United States Geological Survey (USGS) 7.5-minute digital elevation model, which is relatively imprecise in the vertical direction. The root mean square error (RMSE) is used to describe the digital elevation model accuracy and is defined as:

$$RMSE = \sqrt{\frac{\sum (Z_i - Z_t)^2}{n}}$$

where Z_i = interpolated DEM elevation of a test point

Z_t = true elevation of a test point

n = number of test points

For 7.5-minute digital elevation models derived from a photogrammetric source, 90 percent of control points on the ground have a vertical accuracy of 7-m root mean square error or better and 10 percent are in the 8 to 15 m range. For 7.5 and 15-minute digital elevation models derived from vector or digital line graph hypsographic and hydrographic source data, a root mean square error of one-half contour interval or better is required (National Mapping Division, United States Geological Survey, 1998). This level of resolution is inadequate for many ecological studies and for precision agriculture.

Coarse-acquisition code differential corrected global positioning system (C/A code DGPS) technology has revolutionized field mapping and is widely used in natural resources because X (longitude) and Y (latitude) position can be ascertained with a root mean square error of 50 to 100 cm (Trimble Navigation., 2001a). However, vertical errors of 100 to 200 cm are common with coarse-acquisition code differential global positioning systems (Clark and Lee, 1998; Trimble Navigation, 1996). Real-time stop-and-go and real-time kinematic carrier-phase differential global positioning systems mounted on vehicles have been used to map boundaries (Sumpter and Asher, 1994) and elevation with vertical root mean square errors reported to be from 2 to 9 cm (Clark and Lee, 1998; Johansen *et al.*, 2001; Trimble Navigation, 2001b; Leica Geosystems AG, 1999). Carrier-phase differential global positioning system units cost from $20,000 to $100,000 (Johansen *et al.*, 2001). Because of the cost, carrier-phase differential global positioning systems are not as widely available as coarse-acquisition code differential global positioning systems.

Our research required a digital elevation model with vertical accuracy (root mean square error) of approximately 10 cm. Neither a real-time stop-and-go nor real-time kinematic carrier-phase differential global positioning system was available. Therefore, we developed a method to efficiently generate highly accurate elevation models for open, relatively level land using a coarse-acquisition code differential global positioning system (<$8000) and a low-cost laser level (<$1000).

MATERIALS AND METHODS

The procedure we have developed includes both data collection in the field and computer processing in the office (Figure 2.1).

Field Setup

We collected topographic information via 2 technologies: coarse-acquisition (C/A) code differential global positioning system for the latitude (Y) and longitude (X) position and laser level with metric leveling rod for elevation (Z) (Figure 2.2). We used a Trimble Navigation Pathfinder Pro XR®, 12-channel, L1/CA-code differential global positioning system. With this system we were able to obtain an X, Y coordinate with a root mean square error of 50 to 100 cm in approximately 25 seconds. The laser level system was a Laser Reference Inc. Proshot L4® with a R4® laser receiver and a Crain Enterprises, Inc. CR-5.0M® metric leveling rod. This laser level has a working radius of 230 m, with a leveling accuracy of better than 2 cm. Laser levels of this type are readily available from equipment rental stores for approximately $40 per day. Necessary components are described in Table 2.1.

If it is important to determine the true elevation of the laser for reasons other than creating a relative digital elevation model, it is necessary to either find an existing National Geodetic Survey (NGS) ground control point or establish a temporary bench mark. The National Geodetic Survey maintains ground control points represented by survey monuments.

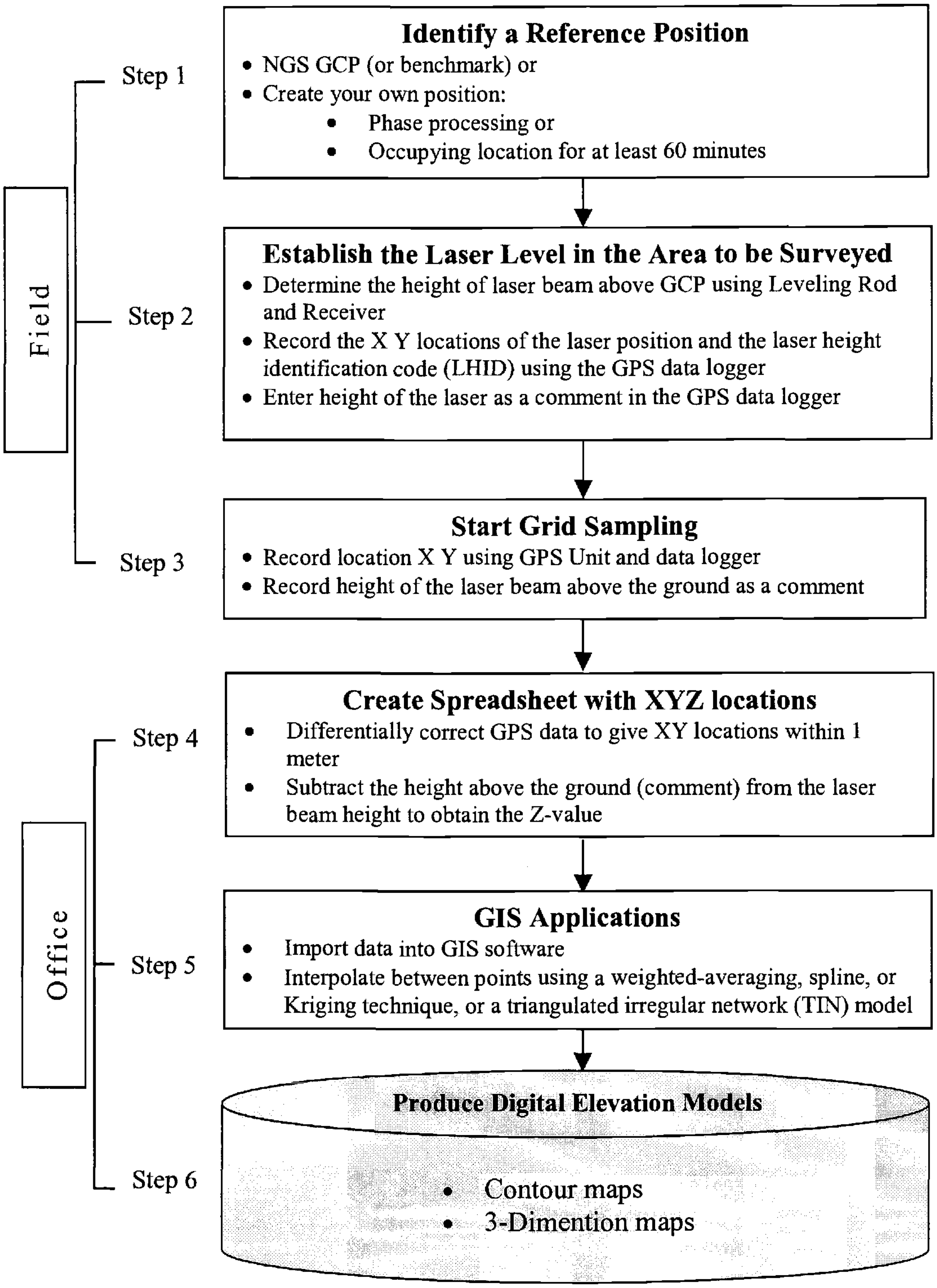


Figure 2.1. Flow chart showing procedures for generating a high-resolution digital elevation model.

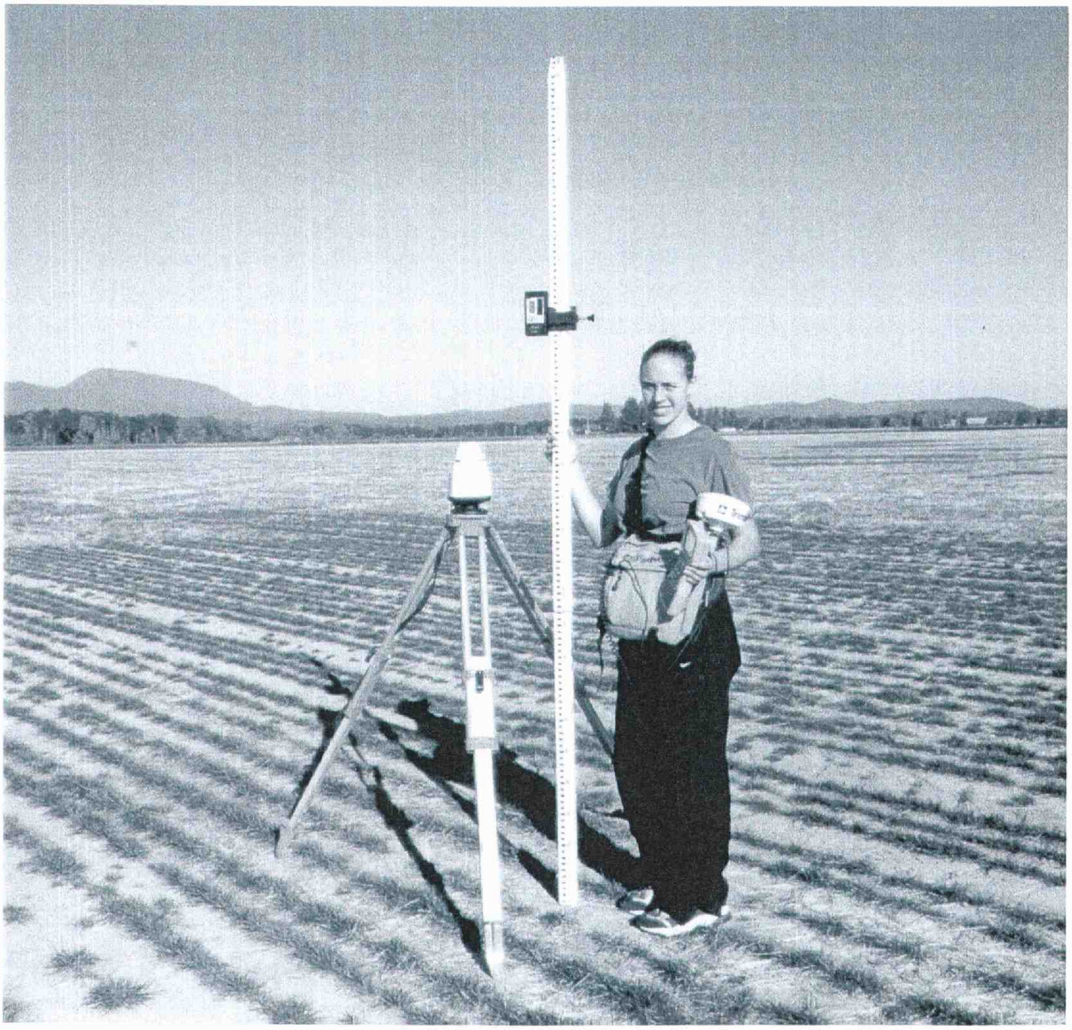


Figure 2.2. Equipment used to generate highly accurate digital elevation models. This includes a laser level and a sliding laser receiver attached to a leveling rod. In the horizontal mode, the laser level self levels via a wire-hung, air-damped compensator. The Pro Shot® L4 (Laser Reference, Inc.) laser level we used has a working radius of 230 m, with a leveling accuracy of 1.6 mm per 30 m.

Table 2.1. Equipment used to collect topographic data in the field.

Equipment	Specification	Accuracy
Differential Global Positioning System (DGPS) with Data Logger	12-channel, L1/CA[1] code Differential Global Positioning System	Normally 50 to 100 cm with open sky conditions
Laser Level System		
Laser Level	Self-leveling compensated laser level	2 cm across 230-m working radius
Laser Receiver	Laser receiver with rod clamp	
Tripod	Aluminum tripod with 1.6-m maximum height	
Leveling Rod	5.0-m fiberglass leveling rod	0.5 cm
Stakes		

[1] Global Positioning System satellites transmit ranging signals on 2 D-band frequencies: Link 1 (L1) and Link 2 (L2). Two different ranging codes are transmitted, a coarse-acquisition (C/A) code on L1 frequency and a precision (P) code on both L1 and L2 frequencies.

Locations of these can be obtained from National Geodetic Survey (1996) on CD-ROM or found on the web at: http://www.ngs.noaa.gov/datasheet.html (accessed April 2002). In most cases a National Geodetic Survey ground control point marker will not exist in the vicinity, so a temporary bench mark must be established by marking the point with a surveyor's stake and using differential global positioning system or traditional survey techniques to determine its location.

Since all elevations collected using the laser level are referenced to this initial point, it is advantageous to establish the temporary bench mark at a location where vehicles or vandals will not damage it, and it can be used in the future. It should be placed close to and visible from the area to be surveyed. For most of our work, we are interested in vertical position relative to the elevation of the temporary bench mark. In this case, we position the temporary bench mark by collecting numerous coarse-acquisition code differential global positioning system fixes with the global positioning system antenna in a static position on a tripod at a set height above the point. Our coarse-acquisition code differential global positioning system records a position every second and we normally record data for an hour or more to achieve accuracy within 60 cm. If we want to define absolute elevations of the area being surveyed, we will position the temporary bench mark using either traditional survey techniques or carrier-phase differential global positioning system. Carrier-phase differential global positioning system requires two global positioning system units, a rover, and a local base station. Accuracies within 10 cm (Trimble Navigation, 1996) are attainable with carrier-phase differential global positioning system processing by occupying a location for 30 minutes.

Once the temporary bench mark has been positioned, the laser level (source) is set in the area to be surveyed and the height of the laser above the reference point is measured with a leveling rod and laser receiver (Figure 2.2). Our laser level has a working radius of 230 m. We record the X, Y location of the laser level with the differential global positioning system and 2 additional pieces of information as comments in the data file: (1) the laser height identification code, which includes the date and sequence number of each particular setup of the laser level and (2) the elevation of the laser beam. The elevation of the rotating laser is determined by measuring its height above the temporary bench mark with a laser receiver attached to a leveling rod, then adding the elevation of the temporary bench mark. This information will be used to determine the elevation of each point and helps us organize data during office processing.

Grid Sampling

Once the laser level has been set up on a ground-control position, it rotates 360° automatically and the 2-person crew moves across the area to be surveyed, stopping to record differential global positioning system points across the terrain. At each sample location the person carrying the differential global positioning system records a northing (latitude or Y) and easting (longitude or X) coordinate. The second person adjusts the height of the electronic laser receiver on the calibrated leveling rod to capture the rotating laser beam and measures the height of the laser beam above the ground. This height is entered into the differential global positioning system data logger as a comment. A 2-person crew can record a location in approximately 25 seconds, plus walking time. The crew would typically pace across the landscape in a grid pattern to systematically sample the field. It is important that they also sample other features of interest, such as hilltops and low spots, as well as 'break lines' along drainage ways and ridges. To ensure that areas are adequately sampled, each point is marked with foam that persists long enough to finish the job. The quality of the digital elevation model will be a function of: (1) how many points are obtained and (2) how the points are positioned (Clark and Lee, 1998). As Clark and Lee (1998) point out "the procedure requires good judgment on the part of the surveyor, and is essential to obtaining a good topographic map."

On level, open terrain without brush or other obstructions, 16 ha can be measured from a single, central, laser location. For larger areas, we back-shoot from a new instrument location to the original temporary bench mark reference point. Since the elevation data is referenced to the temporary bench mark or ground control points, data can be collected over an extended time, as long as the temporary bench mark remains in place. Because the rotating laser beam sweeps 360°, more than 1 team can collect data at the same time. We have sampled agronomic fields, wetlands, and research plots using this technique. We collected the data necessary to map a 35-ha grass seed field on a 20-m grid pattern (1204 sample points) with 1 team in 24 hours.

Office Processing

In the office we differentially correct the global positioning system data with data from a local base station. We then export data to a spreadsheet program with each worksheet containing all data collected while the laser was at 1 location and height. Ground elevation is calculated for each sample point by subtracting the laser beam-to-ground distance (comment value in the global positioning system data logger) from the elevation of the laser beam that was determined from the temporary bench mark. Interpolation of a digital elevation model from point data is accomplished with any of the numerous commercial geographic information system software packages (ERDAS®, IDRISI®, Rockworks®, ArcView® ArcGIS®, etc.). The sampling pattern and resulting contour map of a 76-ha field, sampled with 2181 points, is shown in Figure 2.3. Figure 2.4 illustrates a color aerial image draped over the digital elevation model.

Limitations

This technique was developed for measuring land with gently rolling topography, such as found in agronomic fields, wetlands, and research plots. Since X, Y coordinates may have a root mean square error of 50 to 100 cm, it is not appropriate for short, deep cut-banks or short, steep escarpments where the cut face must be precisely positioned. Because the leveling rod and receiver unit has a working height from near ground level to 5 m, rugged land can require frequent repositioning of the laser level, which reduces efficiency and increases costs. Shrubs and trees that block either the laser beam or reception of NAVSTAR satellite signals limit application of our technique, as do weather conditions such as fog, rain, or excessive dust that absorb the laser beam and reduce the working radius of the laser level. For large fields or extensive areas, the labor cost of our technique can be high, thus making the use of carrier-phase differential global positioning system technology more attractive.

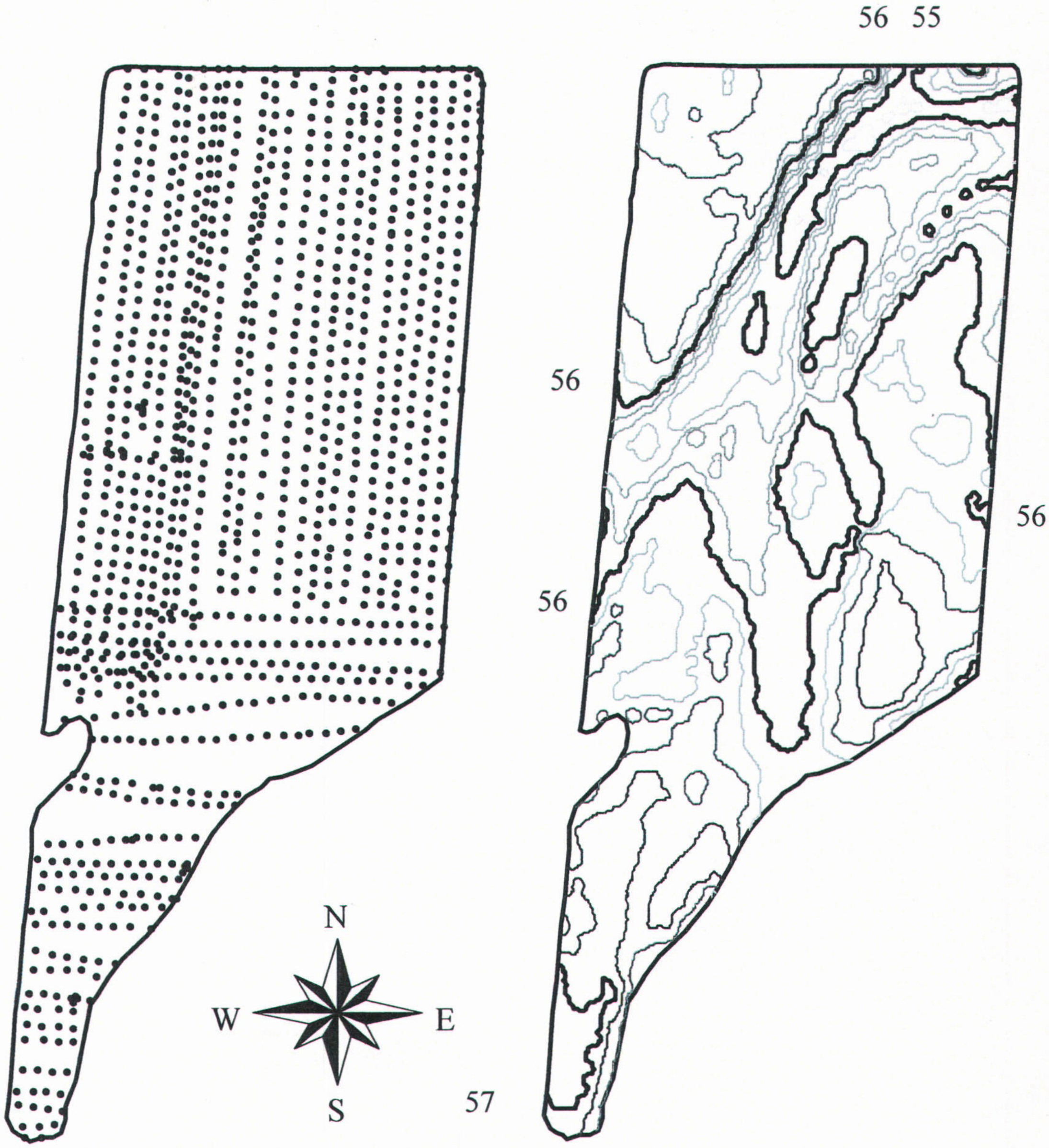


Figure 2.3. Grid sampling and contour map. Sample locations are depicted by the dots on the image of the field on the left. A contour map of the field, which was created by interpolation between sample locations, is shown on the right. Numbers are meters above ellipsoid (approximately above sea level). Note both within field variability and a general increase in elevation from north to south.

Figure 2.4. Color aerial image draped over the digital elevation model. Generated in Erdas® Imagine® using virtual GIS menu.

This procedure is intended to generate topographic models for agricultural and ecological interpretation. It is not appropriate for legal definition of floodplains, property boundaries, etc., which would require professional surveyors.

Cost

Assuming possession of a differential global positioning system and geographical information system/Image processing software, the cost of acquiring the field data and producing a topographic map are salary for 2 technicians and rental of the laser level. Spring 2002 cost of traditional surveying methods for the 35-ha field described above was $2000 to $2500 (professional surveyors bids). Our cost, assuming $15 per hour labor cost, was $720 for field time plus $120 laser rental, plus 6 hours computer processing time for a total of $930.

CONCLUSION

The technique described above allows researchers and others to create high-resolution digital elevation models in a cost-effective fashion. This method is suitable for research fields, wetlands, and experimental plots. The digital elevation model can be used to help explain patterns of vegetation, yield, and soils, and to help elucidate the role of topography on ecological processes.

LITERATURE CITED

Brady, N.C. and R.R. Weil. 2001. The Nature and Properties of Soils. 13th edition. Prentice Hall, Upper Saddle River, New Jersey.

Bakhsh, A., T.S. Colvin, D.B. Jaynes, R.S. Kanwar, and U.S. Tim. 2000. Using soil attributes and GIS for interpretation of spatial variability in yield. Transactions of the American Society of Agricultural Engineers 43:819-828.

Brooks, K.N., P.F. Ffolliott, H.M. Gregersen, and L.F. DeBano. 1997. Hydrology and the management of watersheds. Second edition. Iowa State Univ. Press, Ames, Iowa.

Clark, R.L. and R. Lee. 1998. Development of topographic maps for precision farming with kinematic GPS. Trans. Amer. Soc. of Agr. Eng. 41:909-916.

Johansen, D.P., D.E. Clay, C.G. Carlson, K.W. Stange, S.A. Clay, D.D. Malo, and J.A. Schumacher. 2001. Vertical accuracy of two differentially corrected global positioning satellite systems. Journal of Soil and Water Conservation 56:198-201.

Leica Geosystems AG. 1999. GPS Surveying – system 500. Leica Geosystems AG. Heerbrugg, Switzerland.

National Geodetic Survey. 1996. Data sheets on CD-ROM for the Western United States and Pacific Territories: AK, CA, HI, ID, OR, WA, and Pacific Territories. Silver Spring, Maryland.

National Mapping Division, U.S. Geological Survey. 1998. National Mapping Program Technical Instructions: Standards for Digital Elevation Models. Version 01/1998. Silver Spring, Maryland.

Stoeckel D.M. and M.S. Miller-Goodman. 2001. Seasonal nutrient dynamics of forested floodplain soil influenced by microtopography and depth. Soil Science Society of America Journal 65:922-931.

Sumpter, C.W. and G.W. Asher. 1994. Real-time kinematic GPS for cadastral surveys. Proceedings of the American Congress on Survey and Mapping. American Society for Photogrammetry and Remote Sensing International Meeting 1994. Reno, Nevada.

Trimble Navigation. 1996. Trimble Pathfinder Office™, Software Reference Guide. Trimble Navigation Ltd., Sunnyvale, California.

Trimble Navigation. 2001a. GPS Pathfinder Systems. Trimble Navigation Limited. Sunnyvale California.

Trimble Navigation. 2001b. Trimble 5700 Receiver. Trimble Navigation Engineering and Construction. Dayton, Ohio.

Young, F.J. and R.D. Hammer. 2000. Soil-landform relationships on a loess-mantled upland landscape in Missouri. Soil Science Society of America Journal 64:1443-1454.

CHAPTER 3: A SPATIAL-TEMPORAL ANALYSIS OF GOOSE GRAZING ON GRASS SEED CROPS

ABSTRACT

More than 10-fold increase in Canada goose (*Branta Canadensis*) populations over the past two-decades has resulted in concerns over grazing impacts on grass seed production in the Willamette Valley, Oregon. This study was conducted to develop methods to quantify and statistically analyze goose-grazing impacts on seed yields of tall fescue (*Festuca arundinacea* Schreb.) and perennial ryegrass (*Lolium perenne* L.). Yield-mapping-system equipped combines, incorporating global positioning system (GPS) technology, were used to measure and map yields. Ground-level photography, plant height and cover, and other relevant observations were spatially located via GPS to establish grazing patterns and timing when geese were in residence. From mid-winter through spring, frequent field visits were scheduled to monitor goose grazing activity and other factors affecting yield. Exclosures provided nongrazed controls. Spatially located yield data, soils information, exclosure locations, and grazing patterns were integrated via geographical information system (GIS) technology. To avoid concerns about autocorrelation, we introduced a general technique called bootstrapping for making statistical inference from yield-mapping data. This procedure for subsampling spatially contiguous seed-yield data was used to organize the data for appropriate use of analysis of variance. Thus we were able to evaluate grazing impacts on yield for areas of fields with different soils and with

differential timing and intensity of goose grazing activity. We also evaluated the use of a traditional approach; one that uses paired plots comparisons, involving exclosures and associated plots available for grazing. The combination of spatially-explicit photography and yield mapping, integrated with GIS, proved effective in establishing cause-and-effect relationships between goose grazing and seed-yield differences. Exclosures were essential for providing nongrazed controls. Both paired-plot comparisons and comparisons of larger areas of homogeneous soils and grazing patterns, to exclosures were effective in documenting goose-grazing impacts. Paired-plots were restricted by small size and few numbers and did not capture grazing impacts as effectively as comparison of larger areas to exclosures. Bootstrapping to subsample larger areas of yield for comparison was an effective method of avoiding autocorrelation of data while better representing impacts within a field. Occasional yield increases, ranging from 1 to 5 percent, were recorded following goose grazing. Goose grazing generally resulted in seed yield reductions, ranging up to 20 percent. Later and more intensive grazing tended to increase yield reductions. Newly seeded tall fescue tended to be the most sensitive to grazing. Established perennial ryegrass tended to be more resilient.

INTRODUCTION

Goose Grazing and Grass Seed Production

Oregon is the world's major producer of cool-season forage and turf grass seed. The majority of the acreage is located in the Willamette Valley, the "grass seed capital of the world." Mild and moist winters with dry summers favoring seed development and harvest make the Valley an ideal place to produce high quality seed. Oregon's Willamette Valley produces almost two-thirds of the total U.S. production of cool-season grasses (Young *et al.*, 1997). Area farmers are concerned about goose grazing impacts on grass seed production. Prior to the early 1980s, goose use of fields in the Lower Columbia and Willamette Valleys was not considered by area farmers to be a significant problem. In fact, light or non-repeated grazing of grass-type crops had been shown to be beneficial in both past studies and practice. Since the early 1980s, goose use of grass-seed fields has become progressively more intense in the winter and spring. For the Lower Columbia and Willamette Valleys, historical overwintering goose populations were estimated at 20,000 to 25,000. By the mid-1980s, goose numbers were estimated at approximately 50,000, and today the population in this region is estimated in excess of 250,000. Population increases have been at least partly due to hunting restrictions that were imposed to protect the Cackler and Dusky subspecies. A shift of wintering grounds by the Cackler subspecies from California to this region has been a major factor in the increased populations for this region.

Several studies have been conducted on the relationship between grass seed crops and defoliation (grazing or cutting) and yield production. Results of these studies differ on the extent and impact of geese foraging on grass seed fields.

Clark and Jarvis (1978) suggested that goose grazing did not adversely impact production of ryegrass (*Lolium* spp.) seed in the Willamette Valley, Oregon.

The study involved erecting five exclosures per field (1.0-m high by 1.2-m diameter) at 50-m intervals along a transect. At the time of the study, population levels of geese in the Willamette Valley were estimated to be 20,000 to 30,000.

Roberts (1965) tested five leafy grass varieties under different defoliation treatments. He concluded that defoliation in the fall/winter period until approximately two weeks before the formation of inflorescences did not reduce the yield of seed. He recommended that grazing in spring beyond the stage of inflorescence formation should be avoided.

In a report of a 1969 preliminary investigation, Chilcote *et al.* (1973) concluded that heavy goose grazing in an area can severely damage annual ryegrass seed production by elimination of the stand. They observed that moderate goose grazing did not damage yield and may lead to an increase in seed yield as compared to no grazing or defoliation.

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.

Spatial Variability

Determination of sub-field areas is difficult due to the complex combination of factors that may affect crop yield. In some cases the factors affecting yield may interact with each other (Fridgen, 2000). Soil productivity and spatial variability in crop growth and yield have always been realities of farming. Farm fields are characterized by areas with varying potential to produce crop output. Across a given field, one could find variability with respect to soil type, nutrient status, landscape position, organic matter content, water holding capacity, and so on. Variation in these factors leads to variation in the potential of different areas to utilize applied inputs and produce crop output (Carr *et al.*, 1991; Sawyer, 1994; Wibawa *et al.*, 1993). Techniques are now available to account for the multiple factors that influence production.

Base maps are geographic data that form the foundation upon which all other map data are overlain. They consist of a multi-layered compilation of geographic data including such features as roads, lakes, topographic contours, cultivated crop, and soil types. Digital orthophotographic quarter quadrangles (DOQQ) have become increasingly available in the United States and are often utilized as base-maps and/or interpreted to derive information for applications such as soil surveys, surface hydrology, land use, and land cover (Terry and Bury, 1997).

Geographical Information Systems (GIS) and Global Positioning Systems (GPS) provide new opportunities to more accurately document and measure goose grazing impact on grass seed production. GIS has the ability to spatially interrelate multiple files or data layers once the layers are in geographic registration (Lillesand and Kiefer, 1994). GPS can accurately determine the position of every sample point. Combining these technologies provides visual representation of changes through time (Anderson, 1996) and provides the tools necessary to create yield maps.

Ground-Level Photography

Traditional sampling techniques for monitoring changes in herbaceous cover are subjective, time consuming, costly, and destructive. Attempts at using photography for measuring cover through automated digital image analysis are numerous. Louhaichi *et al.* (2001) and Johnson *et al.* (1998) developed an algorithm based on the red, green, and blue bands of color photography. The digital numbers of each pixel were ratioed resulting in a Boolean image where green leaf is classified as plant cover and soil as non-living. Similarly, Richardson *et al.* (2001) adopted a digital image analysis to estimate cover in turfgrass. Digital images were obtained with a digital camera and analyzed individually using SigmaScan Pro® software (SPSS Inc., Chicago, Illinois). The color threshold feature (hue and saturation) was adjusted until an acceptable color tone was reached. The measurement of percent green cover was estimated by ratioing the number of green pixels by the total pixel count of the image. Repeated vertical photographs of permanent plots (1 m^2) were classified using supervised image analysis. Images were edited and analyzed using Adobe Photoshop® (Adobe Systems Inc., San Jose, California). Soil-colored pixels were selected and deleted. The remaining pixels (representing plant cover) were recolored black and the percentage of black pixels was recorded (Bennett *et al.*, 2000).

Various types of ground-based platforms can be used for the purpose of collecting highly detailed data by remote sensing. A 35-mm camera mounted on a lightweight platform of polyvinyl chloride (PVC) tubing was used to monitor goose grazing on wheat. The camera was pointed vertically downward 1.7 m above the ground. A 1-m^2 frame was central in the photograph, which provided an estimate of scale (Louhaichi *et al.*, 2001). Bennet *et al.* (2000) constructed a portable self-supporting aluminum stand equipped with a collapsible camera arm and two telescopic legs. The height of the camera above the ground was 2 m. Using a 35-mm focal length the image area covered about 1.4 by 2.1 m.

Ridchardson *et al.* (2001) used a monopod made of 10-cm-diameter polyvinylchloride tubing. It consisted of a vertical stand that was 1.5 m in height and a horizontal arm that was mounted at a 90° from vertical and extended 1.0 m away from the vertical axis.

Yield Mapping

Today, Global Positioning System (GPS) technology has revolutionized the way we navigate. When utilized in farming, a combine, equipped with GPS and a yield monitor, can record its exact location in the field and yield at that location. That information is transferred to a computer and provides the data for a detailed yield map of the field.

Most GIS systems offer fundamental operations such as database capabilities, data import/export options, graphical interfaces, and cartographic-quality output. However, many systems fall short when it comes to basic statistical analyses. Users are forced to exercise the import/export capabilities and do computations using other software. The use of traditional parametric procedures assumes that the data are normally distributed, uncorrelated or independent, and exhibiting constant variance (Ramsey and Schafer, 1997). Yield-mapping systems record continuous data that are collected serially in space and time. Most standard statistical tests assume that the observations are independent, i.e. the data are not autocorrelated. Performing statistical analysis on data that exhibit positive autocorrelation as if they were uncorrelated has serious implications. Precision of the estimators is often overstated, resulting in test statistics that are too large and p-values that are too small (Schabenberger and Pierce, 2002).

Bootstrapping

Bootstrapping is a resampling procedure that pulls random observations from an entire data set. This procedure is generally applied to large datasets with many observations. Electronic, automatic sampling often generates this type of data. Bootstrap methods are computer-intensive methods of obtaining a subset of the data that meets statistical assumptions and can be used to calculate standard errors, confidence intervals, and significance tests. Each subsample is a random sample with replacement from the full sample. Bootstrapping refers to randomly sub-sampling the original data set to generate new data sets (Knox and Peet, 1989).

Bootstrapping and randomization are not the same. Bootstrap procedures take the combined samples as a representation of the population from which the data came and create several bootstrapped samples by drawing, with replacement, from that pseudo-population. Randomization procedures also start with the original data; but, instead of drawing samples with replacement, these procedures systematically or randomly reorder (shuffle) the data several times, and calculate the appropriate test statistic on each reordering. Since shuffling data amounts to sampling without replacement, the issue of replacement is one distinction between the two approaches. Aside from the replacement issue, the two approaches different in a very fundamental way. Bootstrapping is primarily focused on estimating population parameters and it attempts to draw inferences about the population(s) from which the data came. Randomization approaches, on the other hand, are not particularly concerned about populations and/or their parameters. Instead, randomization procedures focus on the underlying mechanism that led to the data being distributed between groups in the way that they are (Efron and Tibshirani, 1993; Pillar, 1999).

Study Objectives

This study was designed to develop and evaluate methods to achieve the following objectives: identify locations grazed by geese, determine when and how intensely geese were grazing the fields, and 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.

MATERIALS AND METHODS

Study Location and Description

Within the mid-Willamette Valley in Oregon, seven grass seed fields were selected for intensive study. The study was conducted for two crop years (October 1999 through July 2000 and October 2000 through July 2001). Two cool-season perennial tufted bunchgrass species were used in this study: tall fescue (*Festuca arundinacea* Schreb.) and perennial ryegrass (*Lolium perenne* L.). Selection criteria for fields included in the study fields were: 1) fields had to be in grass seed production, 2) fields have been grazed by geese, and 3) fields were farmed by farmers willing to cooperate with the study. Fields varied in shape, size, and distance from roads and dwellings. Farming practices were similar. The study fields covered a total of 369 ha. Field size ranged from 18 to 97 ha. During the first year of the study one field was newly seeded perennial ryegrass (field Npr-00), one was established perennial ryegrass (field Epr-00), one field was newly seeded tall fescue (field Ntf-00), and two were established tall fescue (fields Etf-1-00 and Etf-2-00). During the second year two fields were established perennial ryegrass (fields Epr-1-01 and Epr-2-01), two were established tall fescue (Etf-1-01 and Etf-2-01), and one was newly seeded tall fescue (Ntf-01). Three of the fields were included in both years: Npr-00/Epr-1-01; Epr-00/Epr-2-01; and Etf-1-00/Etf-1-01. Overall we had five fields for each crop year (Appendix 1).

Soils consisted of deep, well-drained to poorly-drained soils of the Willamette Valley terraces (Appendices 2 and 3) (United States Department of Agriculture Soil Conservation Service and Oregon Agricultural Experiment Station, 1975). They occupy areas between alluvial soils of the bottomlands and the foothills of the Coast range. Slopes are mainly 0 to 3 percent. Three soil associations were found in study fields:

- Woodburn-Willamette association: moderately well-drained and well-drained silt loams.
- Dayton-Amity Association: poorly-drained and somewhat poorly-drained silt loams.
- Malabon-Coburg association: well-drained and moderately well-drained silty clay loams.

The climate of the valley is relatively mild throughout the year, characterized by cool, wet winters and warm, dry summers. The climatic conditions closely resemble the Mediterranean climates that occur in California, although Oregon's winters are somewhat wetter and cooler. Growing seasons in the Willamette Valley are long and moisture is generally abundant during the growing season.

Like the remainder of western Oregon, the Willamette Valley has a predominantly winter rainfall climate. Typical precipitation distribution includes about 50 percent of the annual total from December through February, lesser amounts in the spring and fall, and very little during summer. Rainfall tends to vary inversely with temperatures. The cooler months are the wettest, the warm summer months are the driest. Long-term average precipitation (90 years) is 1020 mm; with most occurring as rain (Appendix 4). Monthly precipitation during the second year of the study was significantly lower than the average monthly precipitation. The 2000-2001 water year, which ran from October 1, 2000-September 30, 2001 was among the driest in Oregon in history (received about 52 percent of long-term average precipitation) (Appendices 5 and 6).

Extreme temperatures in the Valley are rare. Days with maximum temperature above 32°C occur only 5 to 15 times per year on average, and temperatures below -17.8°C occur only about once every 25 years. Mean high temperatures range from 26°C in the summer to about 4.5°C in the coldest months, while average lows are generally in the low 10s in summer and around -1°C in winter (Appendix 7). The mean growing season is 150 to 180 days in the lower portions of the Valley, and 110 to 130 days in the foothills (Oregon Climate Service, 2001). Elevation of the study area averages about 75 m.

Sampling Procedure and Monitoring Protocol

Our primary objective was to develop methods that estimate the impact of goose grazing on grass seed production. The challenge was to separate the impact of goose grazing from other sources of impacts, such as water damage. To address this question we needed to identify major factors that influenced grass seed yield. The impact of wild geese on grass seed yield is confused by other factors such as poor drainage, soil differences, and uneven topography. In addition, researches have indicated that soil pH is an important factor in grass seed production. Fortunately, pH was not of concern for our test fields, since adequate lime was applied. Other factors such as insects or disease may also have to be addressed. Because soil, topography, and associated response patterns are spatial, geographic information systems (GIS) can be used to map and link them. The following sections explain the steps needed to create a spatial and temporal analysis of goose grazing on test fields.

Base Maps

Base maps were a necessary component of our methodology. They represented the starting point and the foundation upon which all other map data were overlain. Base maps were constructed for each field. To measure each test field's surface area and to quantify each field's spatial characteristics and position, we used a 12-channel, L1, C/A-code differential GPS (DGPS) receiver with data logger.

Digital Orthophotographic Quarter Quads were obtained from the United States Geological Service and color aerial photographs (WAC Corporation, Eugene, Oregon) taken during 2001 were rectified. These maps facilitated the placement of goose exclosures, their paired-grazed plots, and ground-reference photographs. We overlaid other vector information such as roads, streams, and field boundaries onto United States Geological Survey (USGS) digital orthophotographic raster maps. This allowed us to map the relative position of other features visible on the orthophotos, such as trees, thickets, and dwellings, and to determine linear distances from visible objects to all points in the field. A digital soil map for each field was acquired either by digitizing a paper soil map from the County Soil Survey or from the United States Department of Agriculture Natural Resource Conservation Service.

Goose Exclosures

Prior to goose grazing, which often begins in October, we constructed exclosures to keep the geese out of designated control areas. In most of the fields, exclosures were placed so that all areas of a field had at least one exclosure. We attempted to place more exclosures in portions of fields where we expected more goose grazing activity. We waited until goose grazing had begun to place exclosures in field Ntf-01, and concentrated exclosures in the area being grazed, so the entire field was not represented by exclosures.

Exclosures were positioned to accommodate farming operations. Where feasible, we kept them along the same drill rows. This was intended to minimize interference with spraying, swathing, and harvesting activities. We attempted to keep enough distance between exclosures so that they would not interfere with geese landing in a field and would not create artificial barriers to normal movement (except within the exclosures themselves). Exclosures that were impacted by ponded water, or in which yield-mapping-system equipment was not functioning properly, were excluded from yield analysis. A total of 86 exclosures were used during the two years of study (Appendix 1). Each exclosure was 6 by 20 m (Figure 3.1). The dimension of the exclosure was necessary to accommodate the width of the combine and to collect several data points by the combine-mounted yield-mapping system. Data was 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 (Clark and Jarvis, 1978; Allen *et al.*, 1985; Bedard *et al.*, 1986; Louhaichi, 1999).

Exclosures consisted of 50-cm high poultry netting held up by fiberglass posts. Fluorescent flagging tape tied to the top of the poultry netting provided an additional visual barrier to the geese. Tops were left open to prevent interference with platform photography and to allow normal plant growth (Figure 3.1). This particular configuration proved sufficient to dissuade geese from entering or landing inside the exclosure. We paired each exclosure with plots of the same size open to grazing. For each exclosure, two paired plots were positioned at least 20 m from each end to cover the same drill rows, be the same distance from cover (for potential predators), and contain the same soil and catena position. Each exclosure was geo-positioned so it could be overlaid on the base map, located on rectified aerial photographs, and used as a reference to extract yield data inside exclosures.

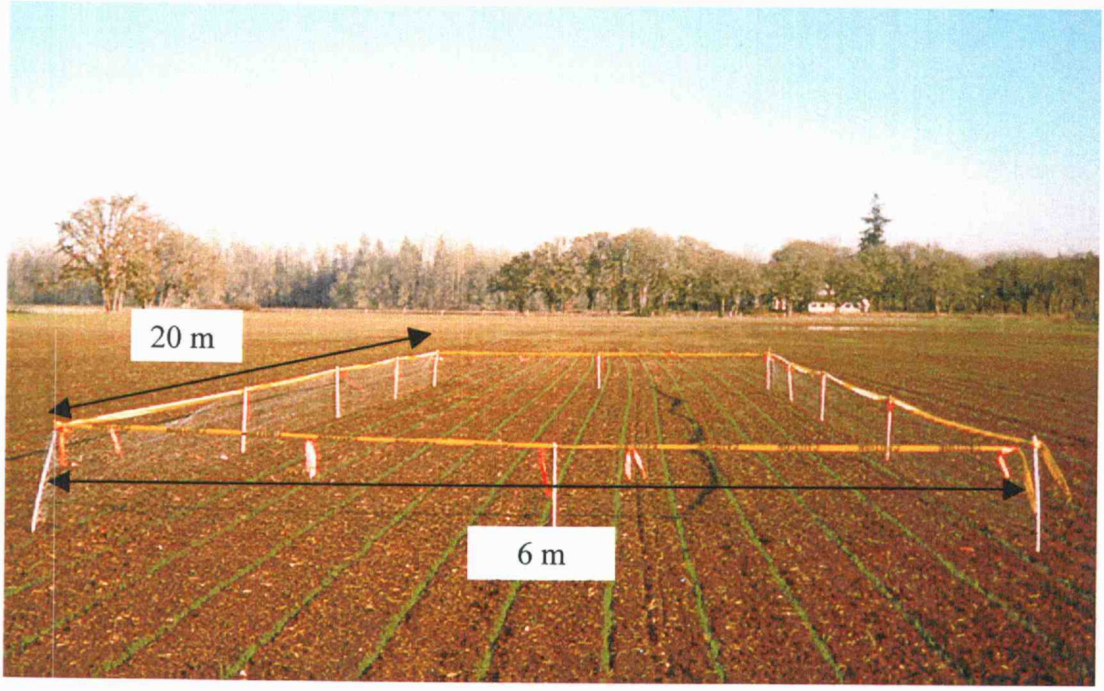


Figure 3.1. Exclosure using poultry netting and fiberglass posts.

Ground-Level Photography

Ground-level photographs along transects across the fields were taken to identify where grazing had been occurring, where flooding was a factor, and to detect any other potential impact. Other ground level photographs were taken within exclosures and their paired plots. These corroborated grazing and flooding events throughout the growing season. The ground photos were taken using a lightweight platform of polyvinyl chloride (PVC) tubing on which we mounted a camera. The camera was mounted on a bracket, attached to the 1-m^2 quadrat, to provide consistency. A 35-mm color photograph was taken vertically downward from a height of 1.7 m at each point location. Central in the photograph was a 1-m^2 plot frame that provided an estimate of scale, allowing us to measure objects in the photo (Figure 3.2). Photographs taken with this camera had a pixel size of 1 mm^2 and showed grazed leaf-tips on grass, bird footprints, goose droppings, weeds, and grass cover and vigor.

For the 1999-2000 field season, we conducted ground-level photography and data collection along transects within each field during January 29-February 4, March 20-23, and April 24-29. For the 2000-2001 field season, we conducted ground-level photography and data collection along transects within each field during the periods of February 2-14, March 19-30, and April 17-May 1.

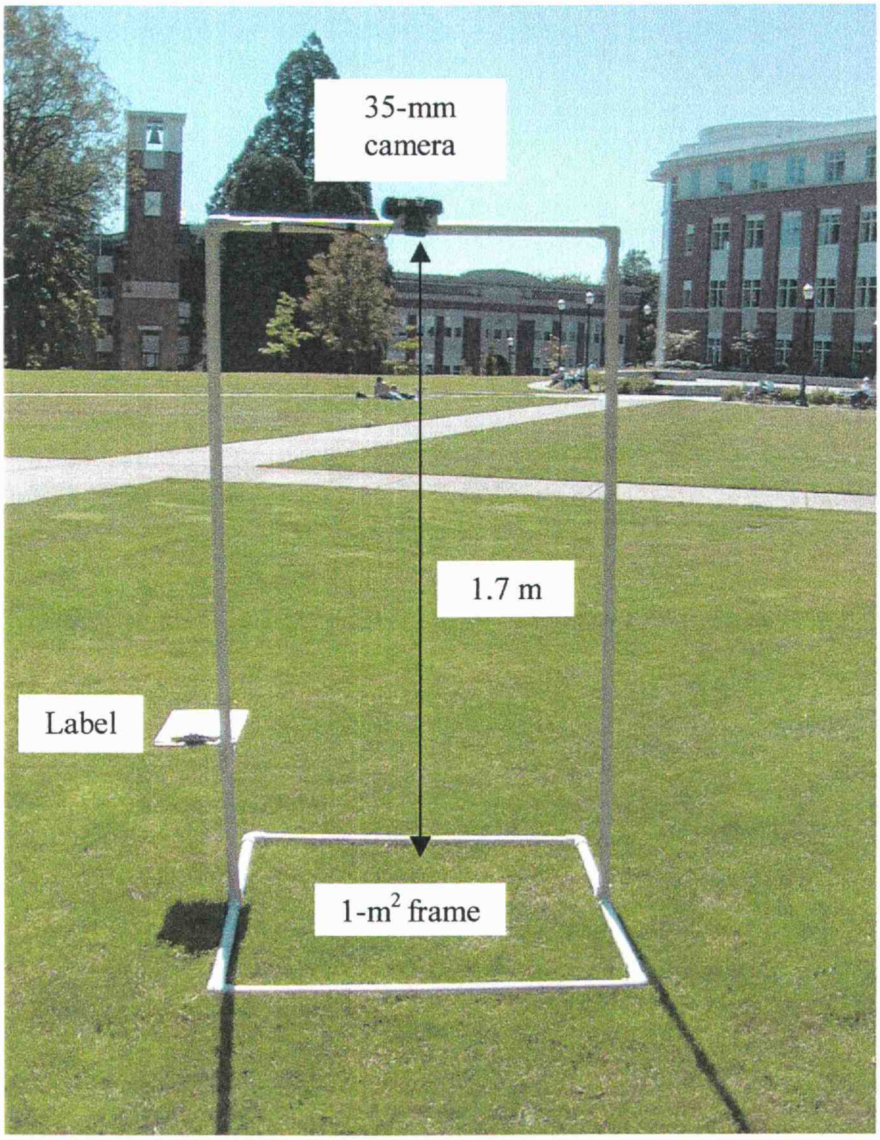


Figure 3.2. Platform photography. A 35-mm camera mounted on a lightweight platform of polyvinyl chloride tubing used to monitor goose grazing.

While photographing the area, we recorded other information such as typical leaf length, presence or absence of goose grazing, number of goose droppings, water damage, and any other source of impacts. We used our DGPS data collector to log the location of each photograph. Geo-positioned ground photographs were taken from the platform. During the first year of the study we adopted a systematic line-transect monitoring protocol. Three to seven transect lines were laid per field. Although transect lines were placed to get representative whole-field coverage, some portions of the fields were not documented. During the second year we shifted our layout to a more subjective monitoring. Without restricting ourselves to specific transect lines, we were able to map and document the cause of any unusual growth pattern (Figure 3.3). This monitoring technique allowed us to map the extent of goose grazing and any other impacts.

Between 20 and 50 photographs were taken per field during each observation period. In addition, photographs were also taken within each exclosure and its paired plots. This type of monitoring was performed three times during the grazing season (January, March, and late April). In addition to point locations, we used the GPS to delineate the extent of impacted area either by goose grazing, water damage, or weed infestation. This feature allowed us to create polygon vector files that could be overlaid on base maps. Weekly field visits were undertaken to monitor goose activity. During these visits the technician used the base map and a hand-held camera to record and document any significant events (grazing, water damage, etc).

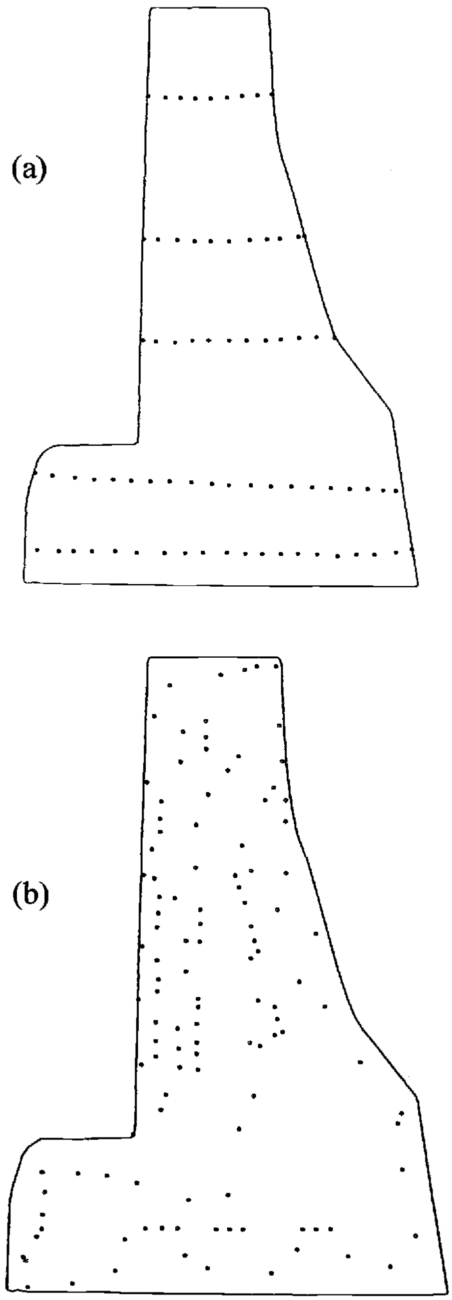


Figure 3.3. Ground-level sampling strategies were different between the first and second year of the study. Fixed transect lines were used during the first year (a). Subjective sampling locations based on goose activity and grass growth patterns provided better field coverage and more useful data in the second year (b).

Color Aerial Photography

High-resolution color aerial photographs (1:10,000) were acquired five times during the first year using a 35-mm Nikon®6006 camera, equipped with a 28-mm lens, mounted on a fixed-wing aircraft. Aerial photography was obtained while geese were present during December, January, March, April, and during July, between swathing and combining of the grass seed. The timing of each flight was planned to overlap with the ground-level monitoring periods. Using the camera and lens specifications mentioned above, several images had to be concatenated to provide full-mosaic coverage of each field, which required that the pilot maintain level flight at a consistent altitude. Mosaic images covering the whole field were then scanned and rectified using geo-positioned white targets (30 by 30 cm) placed around each field. These targets served as ground control points in aerial photographs. A minimum of 40 positional fixes was collected at each location. All points were differentially post-corrected by downloading the necessary data from the United States Forest Service GPS page maintained on the internet (United States Department of Agriculture Forest Service GPS page, 2001). Based on the output of image classification of the first year, during the second year we determined that aerial photographs were not particularly useful through the growing season until about the end of March. This was especially true for the newly seeded fields, where grass had not yet grown sufficiently to show in the aerial photographs until March. Thus, we elected to contract for one flight at higher elevation with better quality photography using a mapping camera. We obtained this aerial photograph of the study fields on April 24, 2001.

Along with vertical aerial photographs, oblique aerial photographs were taken of the entire field during each flight. Oblique aerial photographs were easier to acquire (did not require a mount attached to the aircraft) and covered a larger area. Their disadvantage was that they represented a distorted view of the field and could not be geo-corrected.

Remote Sensing

Image Processing of Ground-Level Photography

We were interested in determining the cover of these perennial grasses and documenting whether grazing by geese had occurred. Cover is defined as the vertical projection of the crown or shoot areas of a plant species on the ground surface, expressed in percent or fraction of the area measured (Stoddart *et al.*, 1975). We measured grass seed cover in 1-m^2 quadrats at ground level by analyzing digital, single-color images. The digital numbers were ratioed using the following algorithm:

$$((G-R)+(G-B))/(G+R+G+B)$$

where:

G = digital number of the green channel (0 to 255)
R = digital number of the red channel (0 to 255)
B = digital number of the blue channel (0 to255)

The resulting image (Figure 3.4) had pixel values between –1 and +1. By thresholding with a value near zero, we separated the image into two classes: green leaves and soil/nonliving. In order to get acceptable results; the observer needed to calibrate the threshold based on three to five plots per field on each sampling date. This was done by examining the original photograph and the black and white classification side by side on a computer screen. The threshold was then adjusted until it corresponded to the original color image.

(a) (b)

Figure 3.4. Grass seed cover. A color photograph of a 1-m^2 quadrat (a) has been converted to a Boolean image (b) for analysis of grass cover. Green (living) leaves were classified and displayed as black. Non-green litter and soil were classified and showed as white. Pixels were counted to determine percent of green leaves and soil/litter.

In most cases, values above zero were classified as photosynthetically active leaf and values below zero were classed as non-living. It was necessary to reset the threshold for each set of images for a field to fit the conditions of the field on that particular day. Because fields were sampled in a short time, solar shifts were minimal. At times, the moisture content of the soil surface varied throughout the field and necessitated changing the threshold value. In areas where no grazing had occurred, a threshold value of zero gave the best results. Where we had the most intense grazing and very low green cover, thresholds ranged from 0.1 to 0.25.

After establishing the threshold, percent leaf cover was calculated. To evaluate the accuracy of this process, a mask in which black represented either green leaf or soil (non-living) was applied to the original image. Estimates generated from images with pixel sizes of 0.75 to 3 mm^2 gave acceptable results. The classification process was automated via $C^{++®}$ computer language so classification of 50 photographs could be completed in less than 15 minutes. The technique worked best when grass was still short, (*i.e.,* before elongation) which is also when grass was grazed by geese.

Image Classification of Aerial Photography

Our goal was to use computer classification of color aerial photographs to classify each field into several distinct clusters. Each cluster would represent a grazing intensity class as well as any potential impacts such as water, weed infestation, etc. To accomplish this goal we used an unsupervised computer classification routine. After scanning the mosaic photograph, the resulting image was split into three bands. The red, green, and blue bands were imported into Idrisi® GIS software and used to generate a color composite. The composite image was classified using both broad and fine unsupervised classification procedures in Idrisi® (Eastman, 1997).

Depending on the year of establishment of grass seed stand, the results varied substantially. For the newly seeded grass seed field, the slow vegetative growth of these perennial grasses limited the amount of photosynthetic material capable of absorbing energy in the visible bands; therefore, these fields did not show much vegetative cover. For established fields, especially as the grass stand aged, grazing by geese did not significantly reduce the amount of green leaf cover. This was attributed mainly to the tufted vegetative growth of these bunchgrasses.

Components of Seed Yield

As stated by Elgersma (1991), seed yield in grasses is the product of seeds per unit area and individual seed weight. She also added that seed number is a function of the number of fertile tillers per unit area, the number of spikelets per tiller, the number of florets per spikelet, and floret site utilization (the proportion of florets present at anthesis that produce a seed).

Seed yield components were determined from samples taken in each exclosure and in its paired plots prior to swathing. Three random locations were selected for each paired plot: one inside the exclosure and one in each of the two paired plots. At each location an average plant height was recorded and a sample was collected using an 18-inch (45.72-cm) quadrat. During the same visit, 20 randomly selected panicles of perennial ryegrass were clipped and placed in labeled paper bags. In the laboratory, we counted the number of fertile tillers per sample for both tall fescue and perennial ryegrass. For perennial ryegrass the number of spikelets per spike and the number of florets per spikelet were recorded.

Yield Measurements

Goose exclosures were removed in early May shortly after geese migrated northward. While removing the exclosure a 0.3-m wood stake was pounded into the ground at the corner of each exclosure. The top of the stake was painted with fluorescent color.

Combines belonging to the grower were equipped with either John Deere® GreenStar® or Ag Leader® yield-mapping systems. A maximum of seven commercial combines ran simultaneously on each field. At least four combines were equipped with a DGPS/yield monitor. These combines harvested major portions of the test fields and recorded real-time position, via Global Positioning Systems (GPS) technology, and grain yield. During the second year, the two perennial ryegrass fields were harvested solely with the DGPS/yield monitor equipped combines. Unfortunately, in 2001, yield data for one field was lost because it was not saved properly.

The flagging/marker option built into the yield-mapping system provides a precise and accurate method to locate and analyze data from each exclosure. Shortly after swathing we marked, on the ground, the location of the exclosures. We used a DGPS to navigate back to exclosures' corners, which were marked by stakes. Fluorescent spray paint was used to mark the beginning and ending of each exclosure. We sprayed a strip over the top of the swathed grass. Since not all combines were equipped with a yield-mapping system, swath rows containing exclosures were marked with different color paint and with bicycle flags to ensure that yield-mapping-equipped combines harvested those rows.

The yield-mapping system provided DGPS locations recorded at one-second intervals concurrently with measurements of grass seed yield and seed moisture content. 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 by harvesting a test area with the system in calibration mode, weighing harvested seed, and adjusting to actual seed weight.

We used the data logger's flags option to collect actual data for pre-selected conditions or areas of a field. We programmed flags for exclosures and for areas impacted by water. Flags provided the ability to compare yield in a flagged area, such as inside an exclosure, to yield in the rest of the field where that condition did not exist. At times flagging was not properly set or the combine operator failed to flag the data properly. In these cases we used exclosures corners, which had been positioned using DGPS which was accurate to within 1 m. Data flags allowed us to use a search-and-delete process to isolate this information from the total data set. Because we continuously quantified and spatially tagged yield data in an electronic database, we could cross correlate it with other collected information. Ground-level photography, ground truthing, and yield maps could be examined concurrently in the search for relationships between goose grazing and grass seed production.

Data Handling and Analysis

Seed yield data were exported in ASCII format to a spreadsheet. Outliers [yield values higher than 3000 lbs acre^{-1} (3360 kg ha^{-1}) and negative yield values] were removed. Although the DGPS/yield-monitor-equipped combines were calibrated prior to harvest, differences in average yield among them were significant. Since this was a systematic error (either overestimating or underestimating), we were able to correct for the error. Based on the cumulative average of all combines, each combine was adjusted by multiplying a yield data point by a weighted average. Once the yield was adjusted, the data was imported into Arc/View® GIS software (ESRI Corp., 1996) vector format and recorded as X (latitude), Y (longitude), and Z (mean yield in lbs acre^{-1}).

Before any analysis could be performed, we had to eliminate any source of error or bias from the data set. We examined each yield data set and eliminated data points that contained errors. Error was introduced via several mechanisms.

Yield estimates at the start of a pass could be incorrect because the combine required some time to load up and begin reflecting true yields at the top of the clean grain elevator. Similarly, yield estimates could be overestimated when the combine slowed down or stopped suddenly, while the elevator still contained grain. In the latter case, the grain yield was assigned to a relatively smaller area and may not have reflected true yield. Two other potential sources of error occurred when the combine passed over ground that was already harvested or when it pivoted at corners (when the machine was turning). Once this step was completed, we removed data identified by flags as bare-ground or area impacted by water. Since it is difficult to separate the impact of goose grazing from water damage, data from any area of the field submerged by water and with low vegetative cover was clipped out. Yield could then be calculated from flagged regions of the field, or meaningful subsections within the field.

Incorporation of Geographic Information Systems

The impact of goose grazing differs from field to field and from year to year. A field grazed heavily in one year is not necessarily heavily grazed the next year, and vice versa. In order to quantify grazing impact accurately, a thorough monitoring protocol had to be established. Since all the data gathered during the monitoring were georeferenced, several themes could be overlaid in a GIS environment. Each attribute collected during field observations represented a separate layer. This would include goose grazing, number of goose droppings, plant height, and any other impact. Moreover, potential locations of flooding (ponded areas) and soil types were added as separate layers.

In order to estimate extent of area impacted by grazing, flooding, or other factors, we adopted a two-dimensional scale (spatial and temporal) analysis for each field observation:

- Spatial scale: In all circumstances, soil productivity and spatial variability exist. Therefore, our field tests had varying potential to produce grass seed yield. Spatial variability could be attributed to soil type, landscape position, and so on. For each field we tested soil impact by comparing yield in ungrazed areas for different soil types. Other spatially delineated impacts included water damage, weed infestation, and mowing. Each of these factors was delineated and analyzed separately.
- Temporal scale: The timing of goose grazing varied considerably, with associated differences in magnitude of impact on seed yield. Using yield-mapping data and ground-truthing data, we calculated yield impact due to goose grazing by extracting data in a series of steps. We extracted yields from areas grazed in April, areas grazed in March but not April, areas grazed in January but not later, areas in exclosures, and other ungrazed areas for each type of soil. The creation of these maps enabled us to assess the impact of early, late, and continuous grazing versus no grazing

This procedure allowed us to develop a more complete picture of goose grazing impact on yields and to evaluate the effects of spatial and temporal goose grazing.

Statistical Analysis

We determined the number of yield estimates necessary for an accurate mean, which we defined as 95 percent confidence that the estimate was within 5 percent of the true mean. Yield data were obtained from four adjacent combine paths as they harvested a uniform area of the field that formed a rectangle. The area was 24 by 27 m with 108 individual yield estimates. The average yield for the test area was 1873 lbs acre^{-1} (2098 kg ha^{-1}). Stein's two-stage sample procedure (Steel and Torrie, 1980) was applied to each combine individually and then to the data set as a whole. In order to generate a yield estimate within 5 percent of the mean (94 lbs acre^{-1} = 105 kg ha^{-1}) with 95 percent confidence, we needed 16, 17, 19 and 29 observations for each combine, respectively. The combine that required 29 estimates to generate an accurate estimate of yield was on one edge of the test rectangle. Examination of individual data points showed decreasing yield across the 27-m trace ($R^2 = -0.5968$). This trend in the data increased internal variability, leading to a higher number of samples (29). The other combines showed no trend in yield across the test area ($R^2 = 0.0045$ to $R^2 = 0.0999$) and the required sample size was uniform (Appendix 8). When all 108 observations were grouped, 17 samples were required to estimate within 5 percent of the yield mean with 95 percent confidence. Between four and seven samples of yield were required to estimate within 10 percent of the yield mean at 95 percent confidence. A plot of the running mean confirmed the above analysis (Appendix 9).

Given the research design (paired plots) and the nature of the data, we performed two types of statistical analysis:

Paired t-test

The yield-mapping systems we used allowed us to mark specific areas in the field with a "flagging" option. Combine operators flagged yield data collected within exclosures. This allowed us to extract exclosure data for analysis. Each exclosure was paired with two plots available for grazing. These paired plots were typically placed 20 m away at each end along the same drill rows as their respective exclosure. The yield data from both paired plots was averaged to represent the yield available for grazing. Yields within exclosures were compared to yields in paired plots. In addition, we had situations where we used one exclosure to perform multiple comparisons. For instance, if geese did not graze from either side (north and south of the exclosure) but did graze from the east side, we compared yield inside the exclosure to the easterly grazed area. All comparisons were by paired t-test in either Microsoft® Excel® (Microsoft Corp., 1998) or Statistica® (StatSoft Inc., 2002). An exclosure could serve as an ungrazed reference for nearby areas that were subjected to grazing during different periods. For analysis, exclosures and their paired plots were grouped according to when grazing occurred.

For example, areas that were grazed through February, but not later, were grouped together; areas that were grazed through March, but not later, were grouped together; and areas that were grazed through April were grouped together. In these cases, paired plots could have been more than 20 m from an exclosure and to either side as opposed to within the same drill rows. Given the limitation on the number of exclosures, most analyses were performed without taking into account soil differences.

Field Area Comparison

The strength of yield-mapping systems is its ability to collect large amounts yield data over substantial area of a field. Thousands of observations were accumulated for each field. In at least two situations we sampled the entire field (population). In these specific cases no statistical analysis was necessary. This was a census and we simply reported descriptive statistics of the population; however, in most cases we were sampling a percentage from the population.

The difference between yield values as the data were being collected by the combine allowed us to estimate error statistics for the entire data set, but this procedure was not straightforward due to the complicating factor of spatial dependence, or autocorrelation. The reason was that the values at neighboring dependent points contained less information about the error than did values of independent points; just as in classical non-spatial statistics, sequential results would be biased. Therefore, sets of points must be selected that are independent of each other. This can be accomplished using a bootstrapping technique (Efron, 1979), to subsample the data from within an area of a field.

Bootstrapping is a method of assessing the reliability of a dataset. The bootstrap procedure can be applied any number of times for increased accuracy. Unlike randomization, the assumption underlying the bootstrap is that the observations form a random sample whose distribution approximates that of the population. Thus, the conclusions drawn from a bootstrap subsample can be used to make inferences on the population. Using yield-mapping-system data from each soil class and season of grazing, we recreated (bootstrapped) the population by duplicating the sample multiple times. In any given sample, some subjects may have been selected more than once, while others may not have been selected. Next we calculated the values of the outcome statistic for each of these samples. For each data set, the mean, 95 percent confidence interval, and standard deviation were derived. We created pseudo-replicated datasets by randomly re-sampling individual yield estimates from within all areas of a field that met specified criteria. The first comparisons made were between soil types to determine if there were yield differences due to soil. We bootstrapped once (one iteration) using a sample size of 100. We then compared yields between exclosures and ungrazed portions of the field to determine if yield in areas selected by geese for grazing differed from yield in ungrazed areas. If there were no differences between soils, these categories were aggregated.

For seasonal and temporal grazing comparisons, different bootstrapping arrangements were used. Using a sample size of 15, we ran the bootstrapping twice, using 10 and 50 iterations, respectively. Fifteen observations were used because that is the number that we typically had in an exclosure. For example, field Npr-00 was partitioned so that all areas of the Amity, Dayton, and Woodburn soil types were separated. Exclosures, ungrazed areas, areas grazed January through March, and areas grazed from January through April were also partitioned within each of the soil types. The bootstrapping process used randomly selected 15 observations of yield from within the 12 partitions of the field, (three soil types by four grazing durations). Each field was different because of the number of soil types and grazing durations present. Fifty iterations of this random selection process provided us with a pseudo-replicated data set consisting of yields that could be compared to the control (exclosures) using a one-tailed t-test. We also used the same arrangement to generate a "random exclosure" where yield estimates were randomly chosen from all exclosures within the same soil type.

Bootstrapping allowed us to separate the effects of soil and grazing, and obtain a more complete picture of the effect of goose grazing on yield. This sampling routine was made possible through a subroutine programmed for use in Arc/View® GIS software called "animal movement analysis". This powerful program was developed by the United States Geological Survey - Alaska Science Center - Biological Science Office (United States Geological Survey, 1998) using avenue programming. All bootstrapping exercises were performed in Arc/View®

GIS software. Each data set was then exported to a statistical package (Statistica®) in either ASCII or dbase formats. Descriptive statistics and analyses of variance were performed to compare grazed and ungrazed areas. For differences in means between two groups, we used the *t*-test. The *p*-level reported with a *t*-test represents the probability of error involved in accepting our research hypothesis about the existence of a difference in yield due to goose grazing. This corresponded to the probability of error associated with rejecting the hypothesis of no difference between the two categories of observations in the population when, in fact, the hypothesis is true. To determine significance of differences between group means in an analysis of variance, we used one of the most conservative post hoc tests, the Scheffe's test (Ott, 1993; Ramsey and Schafer, 1997).

RESULTS AND DISCUSSION

Goose Grazing Patterns and Intensity

Goose grazing pattern and intensity in this study were not controlled by the researchers. Geese grazed where and when they wanted except when farmers hazed the geese off their fields. Farmers believed that geese caused substantial economic damage, therefore hazing was often intense. Hazing consisted of shooting towards geese with shotguns, placing propane cannons, scarecrows, electronic noisemakers, and flashers in the field, and by employees on all-terrain vehicles. Fields that were less intensively hazed tended to have more goose grazing. We did not quantify the number of geese grazing on the study fields, we simply noted where and when grazing took place, the intensity of the grazing as measured by plant height, goose droppings, and percent grass cover. If farmers had not hazed these fields, we expect the damage from goose grazing would have been greater. Thus, in this study, we were attempting to quantify grazing impacts under normal farming practices, which included hazing.

Based on field observations, there are a number of factors intrinsic to geese which affect grazing pattern and intensity. Geese prefer to graze where they have good visibility and often graze near standing water. They avoid areas of human or vehicle traffic such as highways and farmsteads. Pattern and intensity varies with:

1. Distance from roads, trees, brush, or buildings that geese perceive as a threat or which may potentially harbor predators.
2. Topography which may obstruct view.
3. Field size and shape. Narrow fields are typically grazed less intensely than large circular fields or square-shaped fields.
4. Pattern of land use and alternative food supplies. Regions proximate to wildlife refuges appear to be grazed more heavily than more distant fields and some crops are preferred over others.
5. Hazing by farmers and hunting pressure.
6. Age and height of the grass. Our observations suggest that as the grass grows above 20 cm tall it becomes less desirable for the geese.

7. Newly seeded fields are more likely to be grazed than already established fields. In addition the plant mass is less on newly seeded fields and the grazing flocks must cover more ground to meet their nutritional demands.
8. Weather conditions. During clear, sunny days geese may range further.

It is difficult to predict which fields will be grazed or when the grazing might occur. Timing of grazing differed by grass type and by year for the fields we used in this study. Perennial ryegrass was grazed into April during 2000 but only into March in 2001. Tall fescue was grazed into March during 2000 but only into February during 2001. Part of the difference was due to hazing strategy of the farms. Tall fescue was a more valuable crop and received greater hazing pressure, which reduced grazing, especially during 2001. Farmers also hazed more the second year, including winter and early spring.

Plants grazed by geese were often left with 10 cm or less of remaining leaf/stem. As the season progressed, we observed that areas that had been grazed previously were more likely to be grazed again. This could be because geese had better visibility in areas with shorter grass, regrowth from previously grazed plants was preferred, or both. In ungrazed and previously lightly grazed areas, the taller grass could be perceived as cover for predators causing a shift to more open areas (Belling, 1985). In areas previously grazed, regrowth of grass plants could have been preferred because digestibility and protein were likely higher as was found in a study by Bédard *et al.* (1986).

Effects of Goose Grazing on Plants: Factors Associated with Seed Yield

Number of Fertile Tillers

We determined the effect of goose grazing on a number of factors that have been linked to grass seed yield by other researchers. The number of fertile tillers has been shown by Green and Evans (1957) and Hebblethwaite and Clemence (1983) to be related to seed yield. We expected that grazing would increase the number of fertile tillers per plant, however only three comparisons were found to be significantly different at $P < 0.05$ (Table 3.1). In Epr-1-01, fertile tiller numbers were greater in the ungrazed paired plots, compared to exclosures, and had no meaning relative to goose grazing. In the same field, paired plots grazed through March had more tillers than associated exclosures. In field Ntf-00, fertile tiller numbers were lower in the grazed paired plots.

Analysis of data from Npr-1-00 indicated that between 50 and 100 samples were required to estimate the number of fertile tillers within 5 percent of the mean and a confidence interval of 95 percent. If we had sampled at this level, yield would have been impacted by the sampling itself in both exclosures and their paired plots. It appears that little insight is gained from the number of fertile tillers, and the damage to plots resulting from sampling just prior to harvest does not warrant the collection of these data in studies such as ours.

Table 3.1. Number of fertile tillers in perennial ryegrass and tall fescue fields from an 18-inch (46-cm) row in exclosures and adjacent paired plots.

Field*	Grazing period	Exclosure (no grazing)	Paired Plot	n	P+
	Perennial ryegrass – 2000 Harvest				
Npr-00	Lightly in March	630	608	3	0.2180
	Through March	604	675	9	0.0614
	Mid-April	625	573	5	0.2013
Epr-00	Ungrazed	696	758	1	NA
	Grazed in March	653	617	4	0.3778
	Through mid-April	648	918	2	NA
	Perennial ryegrass – 2001 Harvest				
Epr-1-01	Ungrazed	319	383	4	0.0085
	Through March	337	450	8	0.0041
	Tall fescue – 2000 Harvest				
Ntf-00	Ungrazed	253	178	1	NA
	March only – very light	122	106	5	0.0121
Etf-1-00	Through April	189	202	2	NA
Etf-2-00	Ungrazed	556	463	2	NA
	January only	532	168	1	NA
	March only	450	434	6	0.4369
	Through March	530	101	1	NA
	Tall fescue – 2001 Harvest				
Ntf-01	Through February	83	94	5	0.1370
Etf-1-01	Through February	89	100	5	0.2471
Etf-2-01	Ungrazed	76	107	4	0.2138
	Through February	72	82	4	0.2278

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; Ntf = newly seeded tall fescue; Etf = established tall fescue; -00 = harvested during 2000; -01 = harvested during 2001.

+ Probability (P) is from a one-tailed paired t-test.

NA = too few samples for analysis.

Number of Spikelets per Spike for Perennial Ryegrass

The number of spikelets per spike was more stable than the number of fertile tillers per 18 inches of a row in our study. In an area of the newly seeded perennial ryegrass field (Npr-00) grazed through March, the number of spikelets per spike was reduced from 23.5 to 21.7 (P = 0.0118) and for pairs in an area grazed through mid-April, spikelets per spike was reduced from 22.7 to 20.3 (P = 0.004) (Table 3.2). In the established perennial ryegrass fields, we detected no significant difference in the number of spikelets per spike (Table 3.2).

Table 3.2. Number of perennial ryegrass spikelets per spike for exclosures and adjacent grazed paired plots.

Field*	Grazed period	Exclosure (no grazing)	Paired Plot	n	P+
Npr-00	Lightly in March	24.3	21.8	3	0.1110
	Through March	23.5	21.7	9	0.0118
	Mid-April	22.7	20.3	5	0.0040
Epr-00	Ungrazed	27.4	22.5	1	NA
	Grazed in March	25.6	23.7	4	0.1378
	Through mid-April	25.7	21.6	2	NA
Epr-1-01	Ungrazed	23.5	23.4	4	0.4044
	Through March	23.6	24.1	8	0.2035

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; -00 = harvested during 2000; -01 = harvested during 2001.
+ Probability (P) is from a one-tailed paired t-test.
NA = too few samples for analysis.

Number of Florets per Spikelet for Perennial Ryegrass

Goose grazing from January through March or April on a perennial ryegrass field that was seeded the previous fall (Npr-00) increased the number of florets per spikelet (Table 3.3). In established fields there was no difference in the number of florets per spikelets for perennial ryegrass (Table 3.3).

Based on our very small sample it appears that grazing on new fields of perennial ryegrass has an effect on resource allocation with the plant. The plant compensates for fewer spikelets by increasing the number of florets produced on each spikelet.

Table 3.3. Number of perennial ryegrass florets per spikelet for exclosures and adjacent grazed paired plots.

Field*	Grazed period	Exclosure (no grazing)	Paired Plot	n	P+
Npr-00	Lightly in March	9.7	8.8	3	0.1870
	Through March	8.0	9.2	9	0.0280
	Mid-April	8.5	10.2	5	0.0550
Epr-00	Ungrazed	7.4	12.2	1	NA
	Grazed in March	8.0	7.5	4	0.2711
	Through mid-April	7.4	8.0	2	NA
Epr-1-01	Ungrazed	5.8	5.7	4	0.4529
	Through March	5.9	5.7	8	0.2355

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; -00 = harvested during 2000; -01 = harvested during 2001.
+ Probability (P) is from a one-tailed paired t-test.
NA = too few samples for analysis.

Effect of Goose Grazing on Plant Cover

Plant cover was estimated through image processing of 1-m^2 plots. Plots inside exclosues (ungrazed) were compared to their respective grazed paired plots. Paired plots grazed by geese any time throughout the growing season were considered grazed. The impact of goose grazing on plant cover was greater for newly established fields. New seedings of perennial ryegrass had 74 percent cover in exclosure compared to only 59 percent in paired plots (Table 3.4). Similarly, the reduction of cover in grazed paired plots for newly established tall fescue fields was 26 and 42 percent, respectively, for Ntf-00 and Ntf-01 fields (Table 3.4). No significant differences in plant cover were found in established perennial ryegrass fields. In established tall fescue, percent plant cover measurements generated variable results (Table 3.4). Non-significant results corresponded to a very patchy tall fescue field Etf-1-00/Etf-1-01 (same field harvested in 2000 and 2001). Generally, grazing reduced cover of established tall fescue.

Table 3.4. Paired plots and exclosures comparisons of plant cover (%) in April. Paired plots grazed at any time at or prior to April monitoring "ground truthing" were considered grazed.

Field Name	Grazed/Ungrazed	Exclosures (no grazing)	Paired Plot	n	P^+
		Perennial ryegrass 2000			
Npr-00	Grazed	74	59	17	0.0016
	Ungrazed			0	
Epr-00	Grazed	76	76	7	0.4573
	Ungrazed			0	

Table 3.4 (continued)

Field Name	Grazed/Ungrazed	Exclosures (no grazing)	Paired Plot	n	P[+]
		Perennial ryegrass 2001			
Epr-1-01	Grazed	86	82	11	0.2036
	Ungrazed	81	84	4	0.0527
Epr-2-01	Grazed	89	82	7	0.2045
	Ungrazed	87	84	3	0.2568
		Tall Fescue 2000			
Ntf-00	Grazed	51	38	5	0.0546
	Ungrazed	50	56	1	N/A
Etf-1-00	Grazed	61	65	2	NA
	Ungrazed			0	
Etf-2-00	Grazed	71	45	8	0.0080
	Ungrazed	79	70	2	NA
		Tall Fescue 2001			
Ntf-01	Grazed	36	21	5	0.0499
	Ungrazed			0	
Etf-1-01	Grazed	79	74	3	0.1878
	Ungrazed	77	76	2	NA
Etf-2-01	Grazed	83	75	3	0.0270
	Ungrazed	81	79	4	0.0567

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; Ntf = newly seeded tall fescue; Etf = established tall fescue; -00 = harvested during 2000; -01 = harvested during 2001.

[+] Probability (P) is from a one tail paired t-test.

NA = too few samples for analysis.

Effect of Goose Grazing on Plant Height

As would be expected, goose grazing reduced plant height of both perennial ryegrass and tall fescue. By the time geese migrated (late April), paired plots that were grazed had shorter plants (Table 3.5). It appears that the longer the grazing period the shorter the plants at harvest (Table 3.6). The same general trend holds for both perennial ryegrass and tall fescue, as well as for newly seeded and established fields. The only exception was Etf-1-01 field, which did not show a reduction in plant height prior to swathing; however, this field is an older field with high variability and patches of water damage throughout.

Table 3.5. Paired plots and exclosures comparisons of plant height (cm) in April. Paired plots grazed at any time at or prior to April monitoring "ground truthing" were considered grazed.

Field*	Grazed/Ungrazed	Exclosures (no grazing)	Paired Plot	n	P+
		Perennial ryegrass April 2000			
Npr-00	Grazed	27	13	17	<0.0001
	Ungrazed			0	
Epr-00	Grazed	39	29	7	0.0006
	Ungrazed			0	
		Perennial ryegrass April 2001			
Epr-1-01	Grazed	23	20	11	0.0237
	Ungrazed	21	22	4	0.2475
Epr-2-01	Grazed	34	26	7	0.0280
	Ungrazed	29	35	3	0.0736

Table 3.5 (continued)

		Tall Fescue 2000			
Ntf-00	Grazed	22	16	5	0.0275
	Ungrazed	25	17	1	NA
Etf-1-00	Grazed	47	25.5	2	0.0295
	Ungrazed			0	
Etf-2-00	Grazed	45	25	8	0.0004
	Ungrazed	56	49	2	0.1168
		Tall Fescue 2001			
Ntf-01	Grazed	29	21	5	0.0038
	Ungrazed			0	
Etf-1-01	Grazed	34	27.5	3	0.1027
	Ungrazed	32	35	2	0.3196
Etf-2-01	Grazed	27	23	3	0.0245
	Ungrazed	29	31	4	0.2545

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; Ntf = newly seeded tall fescue; Etf = established tall fescue; -00 = harvested during 2000; -01 = harvested during 2001.

$^+$ Probability (P) is from a one tail paired t-test.

NA = too few samples for analysis.

Table 3.6. Paired plots and exclosures comparisons of plant height (m) at swathing. Paired plots grazed at any time at or prior to April monitoring "ground truthing" were considered grazed.

Field*	Grazed period	Exclosure (no grazing)	Paired Plot	n	P+
		Perennial ryegrass – 2000			
Npr-00	Lightly in March	1.1	0.9	3	0.0942
	Through March	0.9	0.8	9	0.0034
	Mid-April	1.0	0.7	5	0.0055
Epr-00	Ungrazed	1.0	0.9	1	NA
	Grazed in March	1.1	1.0	4	0.0288
	Through mid-April	1.0	0.9	2	NA
		Perennial ryegrass – 2001			
Epr-1-01	Ungrazed	0.9	0.9	4	0.3980
	Through March	0.9	0.8	8	0.0006
		Tall fescue – 2000			
Ntf-00	Ungrazed	1.0	1.0	1	NA
	March only – very light	1.1	1.0	5	0.0175
Etf-1-00	Through March	1.3	1.1	2	NA
Etf-2-00	Ungrazed	1.3	1.3	2	NA
	January only	1.4	1.3	1	NA
	March only	1.2	1.1	6	0.0460
	Through March	1.3	0.9	1	NA
		Tall fescue – 2001			
Ntf-01	Through February	1.0	0.8	5	0.0008
Etf-1-01	Ungrazed	1.1	1.1	2	NA
	February only	1.1	1.1	2	NA
Etf-2-01	Ungrazed	1.0	1.2	4	0.1357
	Through February	1.1	1.0	4	0.0003

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; Ntf = newly seeded tall fescue; Etf = established tall fescue; -00 = harvested during 2000; -01 = harvested during 2001.

+ Probability (P) is from a one tail paired t-test.

NA = too few samples for analysis.

Effect of Goose Grazing on Grass Seed Yield as Determined by Paired-Plot Comparisons

During the first year of the study we examined one newly seeded perennial ryegrass field. Grazing by geese into March did not result in a statistically significant yield reduction when exclosures were compared to paired plots. However, grazing through mid-April resulted in a 285 lbs acre^{-1} (319 kg ha^{-1}) or 17 percent yield reduction (Table 3.7).

In fields with established perennial ryegrass, early grazing (January in 2001 and March both years) generated variable results (Table 3.7). In the area grazed through March 2000, a 131 lbs acre^{-1} (147 kg ha^{-1}) yield increase was recorded ($P = 0.006$). During 2001, yield reductions of 124, 183, and 187 lbs acre^{-1} (139, 205, and 209 kg ha^{-1}) were recorded for areas grazed through January, in March only, and through March, respectively.

Tall fescue field Etf-1-00 (-01) (an established field harvested during both 2000 and 2001) was long and narrow and very patchy due to ponded water throughout its length. We did not have enough exclosures to sufficiently capture the grazing patterns and the extreme variability within the field. Paired-plot comparisons were not possible within this field in either year, even though we increased the number of exclosures for 2001.

Table 3.7. Paired-plot comparisons of grass seed yield (lbs $acre^{-1}$) in fields grazed by wild geese.

Field*	Grazed period	Exclosure (no grazing)	Paired Plot	n	P+
		Perennial ryegrass – 2000 harvest			
Npr-00	Through March	1794	1766	7	0.3210
	mid-April	1712	1427	5	0.0115
Epr-00	Through March	1973	2104	4	0.0055
	mid-April	1861	1804	2	NA
		Perennial ryegrass – 2001 harvest			
Epr-1-01	Through January	1532	1408	3	0.0775
	March only	1602	1419	3	0.0259
	Through March	1574	1387	8	0.0027
		Tall fescue – 2000 harvest			
Ntf-00	March only – very light	1066	1078	6	0.4538
Etf-1-00	March	1330	1338	1	NA
	Through April	1283	1300	1	NA
Etf-2-00	March only	1575	1452	6	0.0075
	Through March	1647	1422	7	0.0186
		Tall fescue – 2001 harvest			
Ntf-01	Through February	1683	1545	5	0.0931
Etf-1-01	Ungrazed	926	973	2	NA
	February Only	790	884	2	NA
	Through March	681	843	2	NA
	Through April	618	758	1	NA
Etf-2-01	Through February	746	723	3	0.1885

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; Ntf = newly seeded tall fescue; Etf = established tall fescue; -00 = harvested during 2000; -01 = harvested during 2001.

+ Probability (P) is from a one-tailed paired t-test.

NA = too few samples for analysis.

The tall fescue field Etf-2-00 (a 2nd year established field) suffered a yield reduction of 123 lbs acre^{-1} (138 kg ha^{-1}) due to grazing in parts grazed only in March and a yield reduction of 225 lbs acre^{-1} (252 kg ha^{-1}) in parts grazed January through March (Table 3.7). In the tall fescue field Etf-2-01, we recorded a 23 lbs acre^{-1} (26 kg ha^{-1}) reduction due to grazing through February, which was not statistically significant (Table 3.7).

We evaluated our methods in two newly-seeded tall fescue fields, one each in 2000 (Ntf-00) and 2001 (Ntf-01). During 2000, very light grazing occurred during March only and no yield difference was recorded (Table 3.7). During 2001, grazing occurred through February only, but a yield reduction of 138 lbs acre^{-1} (155 kg ha^{-1}) was recorded (Table 3.7).

Because of the patchy nature of goose grazing, paired plots were often not located in areas of the fields where geese grazed. This placed a severe restriction on tests of significance since areas where geese grazed may not have been adequately sampled with paired plots. In an effort to separate factors that influence yield, including grazing, we applied a more sophisticated analysis of yield and landscape factors which are reported in the sections that follow.

Effect of Goose Grazing on Grass Seed Yield as Determined by Larger Areas Using Data Subsampled via Bootstrapping

We evaluated several bootstrapping combinations, i.e., number of samples and number of iterations. In general the output from these bootstrapping combinations were similar. Results presented throughout this section were based on subsample generated by 50 iterations of 15 observations each. Results of goose impact on grass seed yield using 10 iterations of 50 observations are presented in Appendices 10 to 16.

Newly Seeded Perennial Ryegrass

We had one field (Npr-00) that was newly seeded perennial ryegrass with 97,658 estimates of yield. Figure 3.5 shows the pattern of soils, exclosure locations, spatial and temporal goose grazing, and yield within the field. This field was grazed across its entire surface in January of 2000, thus there were no ungrazed areas of the field except within exclosures. The area grazed by geese became progressively smaller as the season advanced, from January to April (Figure 3.6 b). Goose grazing with the longest duration was centered in the Dayton soil.

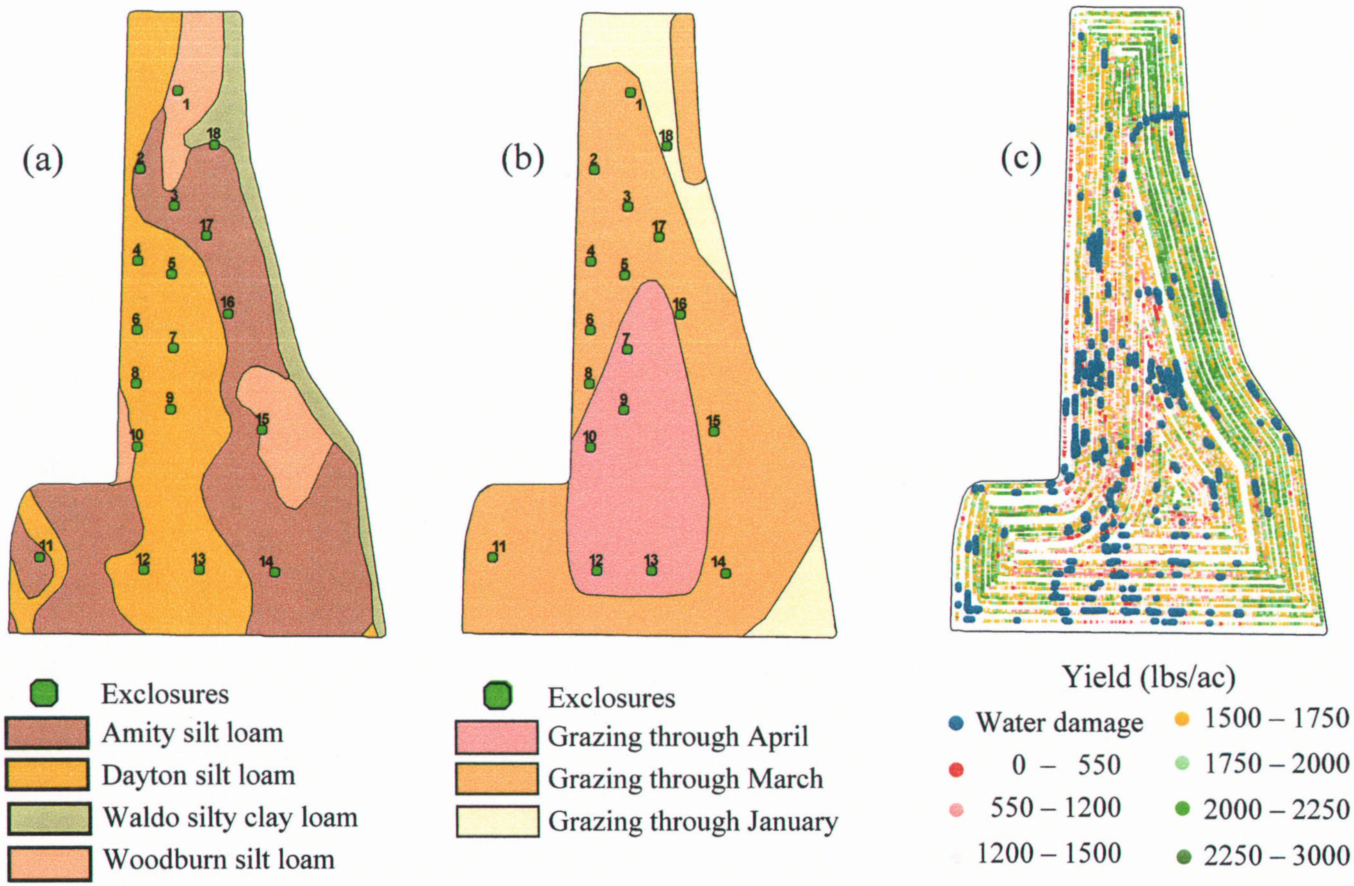


Figure 3.5. Maps for perennial ryegrass field (Npr-00/Epr-01), which was studied as a new field in 2000 and an established field in 2001. (a) soil map, (b) spatial and temporal goose grazing map, and (c) yield map.

An analysis of variance of data subsampled by bootstrapping within soil types indicated that there were seed yield differences between soil types. Exclosures on the Woodburn soil produced 2086 lbs acre^{-1} (2336 kg ha^{-1}), Amity soil produced 1692 lbs acre^{-1} (1895 kg ha^{-1}) and Dayton soil produced 1695 lbs acre^{-1} (1898 kg ha^{-1}). Yield differences between soil types were significant at $P < 0.05$. Thus, grazing impacts are reported by soil type for this field (Table 3.8).

Areas of the Dayton soil that were ungrazed (exclosures) produced seed yields of 1695 lbs acre^{-1} (1898 kg ha^{-1}) compared to 1543 lbs acre^{-1} (1728 kg ha^{-1}) for areas on this soil that were grazed from January through March, a 9 percent yield reduction. Yield reductions were greater on areas grazed from January through April. Seed yield was reduced from 1695 to 1464 lbs acre^{-1} (1875 to 1640 kg ha^{-1}) for exclosures versus grazed areas, respectively, a 14 percent yield reduction.

January through March grazing on the Amity soil resulted in a 5 percent increase in seed yield from 1692 to 1781 lbs acre^{-1} (1895 to 1995 kg ha^{-1}, respectively). The longer grazing duration of January through April, however, reduced yields 10 percent, from 1692 to 1530 lbs acre^{-1} (1895 to 1714 kg ha^{-1}, respectively).

The highest producing soil in this field (Woodburn) also showed a reduction of seed yield with grazing. Ungrazed areas (exclosures) produced 2086 lbs acre^{-1} (2336 kg ha^{-1}) as compared to 1918 lbs acre^{-1} (2148 kg ha^{-1}) for areas grazed from January through March, an 8 percent reduction.

Table 3.8. Comparisons of grass seed yield (lbs acre^{-1}) in a newly established perennial ryegrass field grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P+
Amity Soil Type					
Exclosures vs. Through March	1692	1781	89	5	<0.0001
Exclosures vs. Through April	1692	1530	162	-10	<0.0001
Dayton Soil Type					
Exclosures vs. Through March	1695	1543	152	-9	<0.0001
Exclosures vs. Through April	1695	1464	231	-14	<0.0001
Woodburn Soil Type					
Exclosures vs. Through March	2086	1918	168	-8	<0.0001

+ Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

Established Perennial Ryegrass

Established perennial ryegrass (Epr-00) in the 1999-2000 growing season was represented by one field of 75 ha. Soil type is illustrated in Figure 3.6 a. A large portion of this field was ungrazed (Figure 3.6 b). Figure 3.6 c represents the yield data as estimated by the yield-mapping system. This field was used for goose hunting and had a number of permanent "blinds" in it.

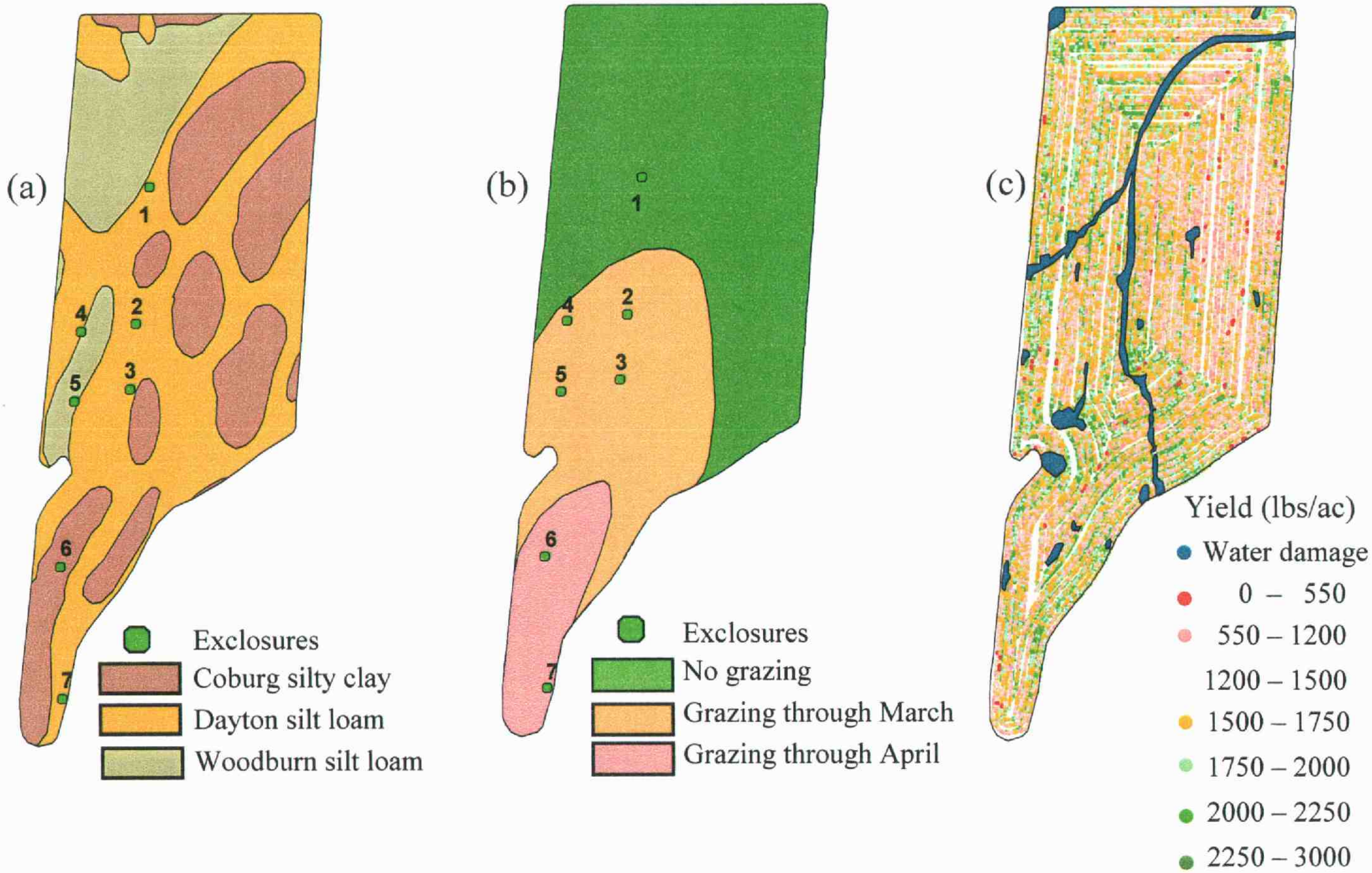


Figure 3.6. Maps for established perennial ryegrass field 2000 (Epr-00). (a) soil map, (b) spatial and temporal goose grazing map, and (c) yield map.

The field was long and was bordered on one side by a highway with heavy traffic. Much of the ungrazed portion of the field was near the highway and it was topographically higher than the grazed portion. Seven exclosures were established in areas of the field where we expected goose grazing (Figure 3.6 b).

Yield in exclosures within the grazed area was higher than the yield in the ungrazed part of the field (Table 3.9). Because of this restriction and because we only had one exclosure each on the Coburg and Woodburn soil types, we decided not to make comparisons of yield between grazed and ungrazed areas on these soils.

There were no differences in yield on the Dayton soil when exclosures were compared to grazing from January through March or April using the statistical bootstrapping (Table 3.9).

Table 3.9. Comparisons of grass seed yield (lbs $acre^{-1}$) in an established perennial ryegrass field grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^{+}
		Dayton silt loam			
Exclosures vs. Ungrazed	1952	1873	79	-4	<0.0001
Exclosures vs. through March	1952	1943	9	0	0.2425
Exclosures vs. through April	1952	1976	24	1	0.0835

$^{+}$ Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

The field that was newly established perennial ryegrass (Npr-00) in 1999-2000 was studied in its second year (2000-2001) as an established perennial ryegrass field (Epr-01). Farmers inter-seeded areas that had low perennial ryegrass density in the spring of 2000 to improve the uniformity of the stand. Ungrazed areas were mostly on the extreme northwestern and southeastern parts of the field (Figure 3.7 a). Thus we could not directly compare ungrazed and grazed portions of the field. Exclosures in this field were in the central portion of the field and had higher production than the ungrazed portions of the field. The ungrazed portions produced 7 to 12 percent less grass seed per unit area than a similar soil type in the central portion of the field. This implies that in order to adequately assess goose grazing impacts in this field we needed to compare exclosures to areas grazed by geese. Color aerial photography taken toward the end of April 2001 showed areas impacted by water (Figure 3.7 b), which were delineated using GPS unit and extracted from the yield map (Figure 3.7 c).

Goose grazing on this field in 2001 occurred only between January and March. When paired plots in the Amity and Dayton soil types were grazed early, seed yield reductions were 4 to 10 percent (Table 3.10).

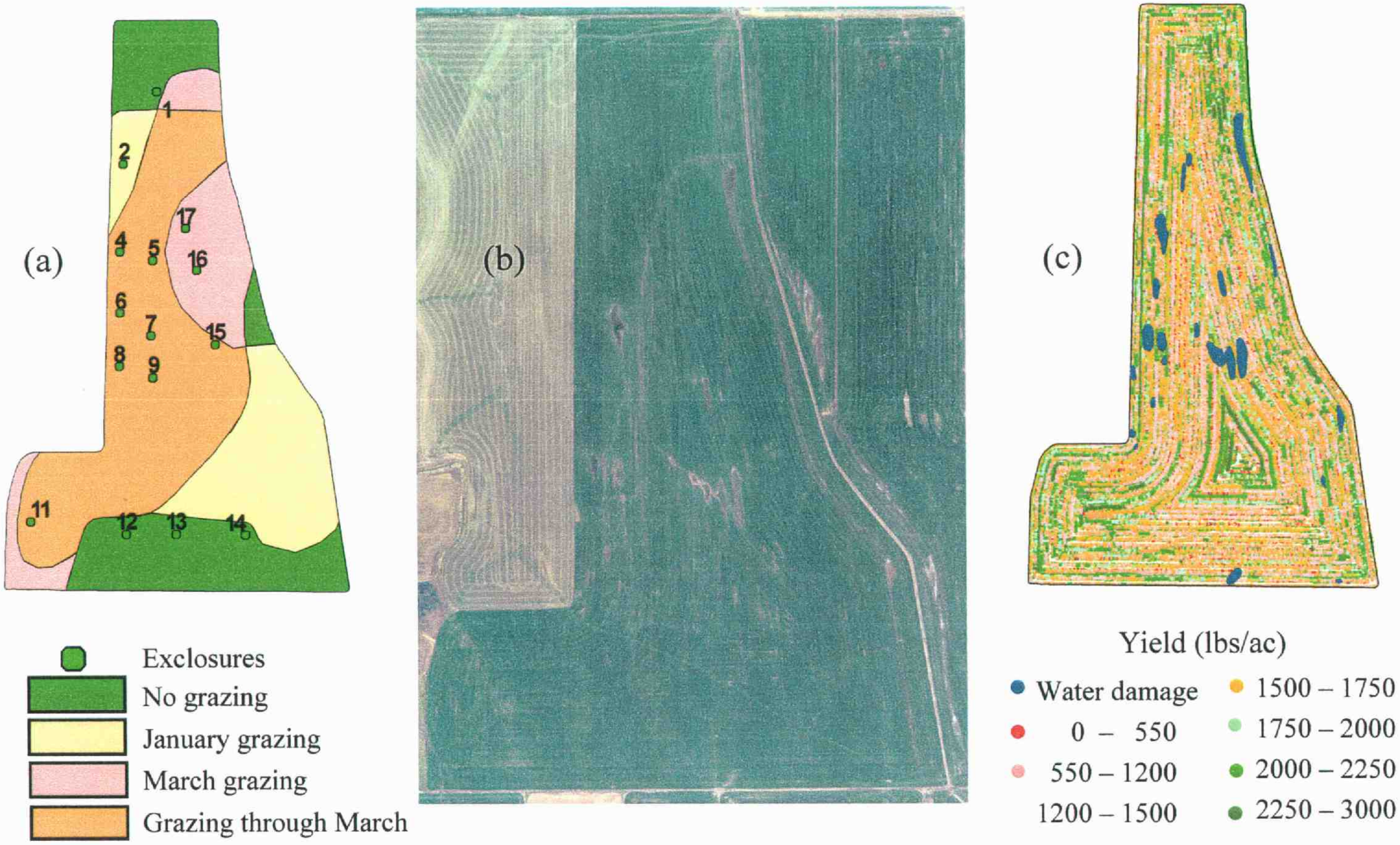


Figure 3.7. Maps for established perennial ryegrass field 2001 (Epr-01). (a) spatial and temporal goose grazing map, (b) color aerial photography taken on 24 April 2001, and (c) yield map.

Plants in the Dayton soil appeared to have greater yield reduction than the Amity soil when they were grazed between January and March. This is the same trend that was seen on this field the year before (Npr-00, Table 3.9).

Table 3.10. Comparisons of grass seed yield (lbs acre^{-1}) in a second year established perennial ryegrass field (Epr-01) grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P+
Amity silt loam					
Exclosures vs. Ungrazed	1499	1395	104	-7	<0.0001
Exclosures vs. January	1499	1406	93	-6	<0.0001
Exclosures vs. March	1499	1420	79	-5	<0.0001
Exclosures vs. through March	1499	1442	57	-4	<0.0001
Dayton silt loam					
Exclosures vs. Ungrazed	1519	1359	160	-12	<0.0001
Exclosures vs. January	1519	1379	140	-9	<0.0001
Exclosures vs. March	1519	1389	130	-9	<0.0001
Exclosures vs. through March	1519	1370	149	-10	<0.0001

+ Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

<u>**Newly Seeded Tall Fescue**</u>

In a new seeding of tall fescue studied during 2000 (Ntf-00), all exclosures and approximately 80 percent of the field was on Malabon silty clay loam soil (Figure 3.8 a). Grazing was observed to be relatively light and only occurred in March (Figure 3.8 b). When we compared grass seed yield in exclosures versus the portion of the field that was ungrazed by geese, we found higher production in the ungrazed area (Table 3.11). The difference was 110 lbs acre^{-1} (124 kg ha^{-1}) and was centered just west of the area grazed by geese (Figure 3.8 c). Thus, the area grazed by geese was a lower producing portion of the field. There was no significant difference between grazed areas and exclosures in grass seed yield (Table 3.11).

Table 3.11. Comparisons of grass seed yield (lbs acre^{-1}) in a newly seeded tall fescue field (Ntf-00) grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^{+}
Malabon silty clay loam					
Exclosures vs. Ungrazed	1084	1194	110	9	<0.0001
Exclosures vs. Grazed in March	1084	1091	7	1	0.2646

$^{+}$ Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

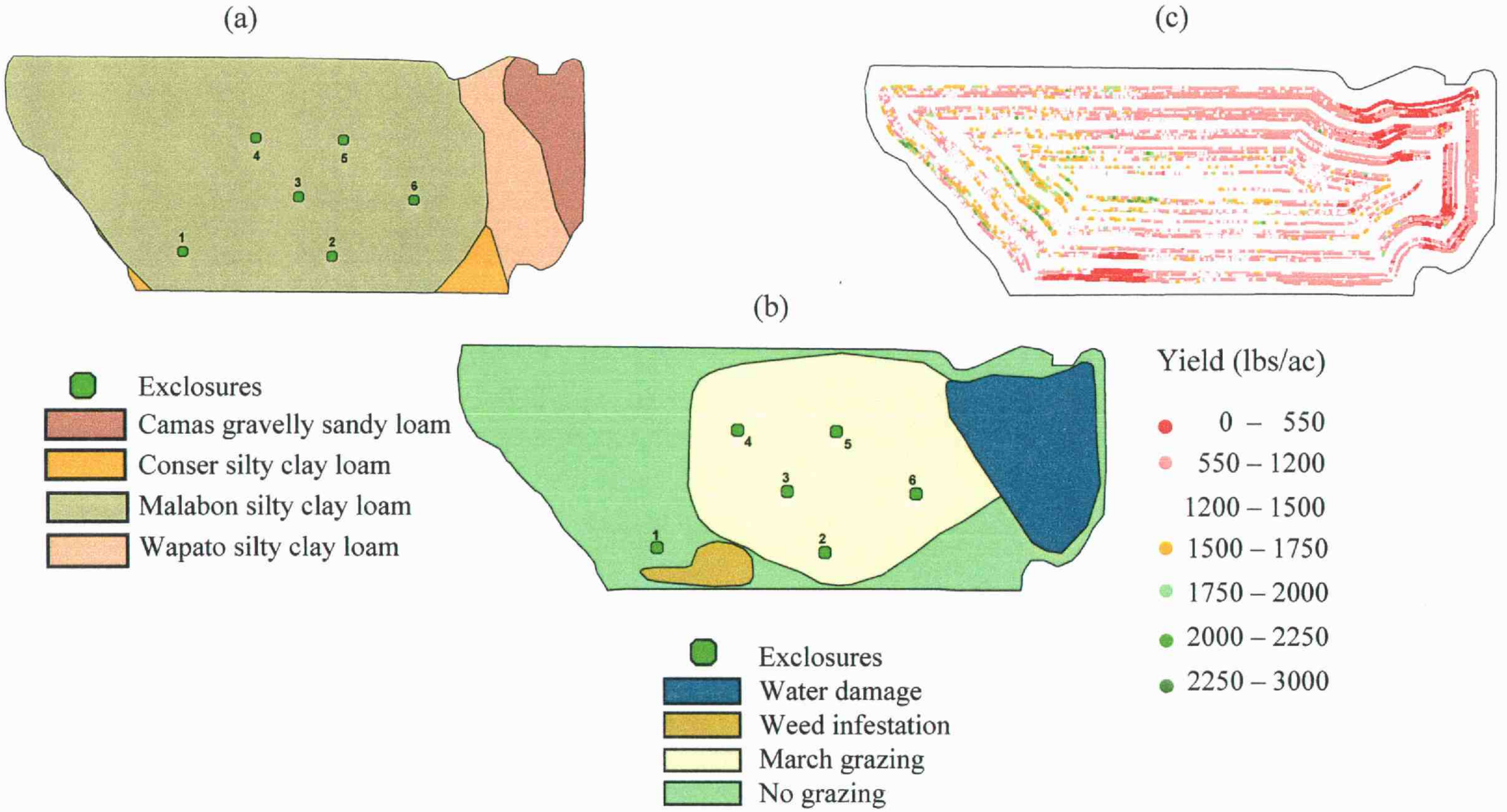


Figure 3.8. Maps for a newly established tall fescue field 2000 (Ntf-00). (a) soil map, (b) spatial and temporal goose grazing map, and (c) yield map.

A second new seeding of tall fescue was studied in 2001 (Ntf-01). Comparison of yields on Conser silty clay loam and Malabon silty clay loam (Figure 3.9 a) revealed no significant differences and therefore the yield on these two soils were combined for analysis of grazing impacts. Grazing took place primarily in the center part of the field (Figure 3.9 b). The ungrazed part of the field, which was located on the periphery, was lower producing. Comparison of seed yield inside the exclosures to the adjacent areas of the field that were grazed showed 178 lbs acre^{-1} (199 kg ha^{-1}) reduction due to grazing through February (Figure 3.9 c) (Table 3.12).

These results indicate that early grazing may have a major effect on yield during the establishment year of tall fescue, especially in a dry year such as the 2000-2001 crop year (i.e. 52 percent of average precipitation). Color aerial photograph taken on April 24, 2001, did not show much vegetative cover (Figure 3.9 d). In spite of the fact that goose grazing was light and only occurred through February, grazed tall fescue plants were slow to develop when compared to those protected from grazing (Tables 3.4 and 3.5). Thus, it appears that first year tall fescue is more sensitive to goose grazing than first year perennial ryegrass.

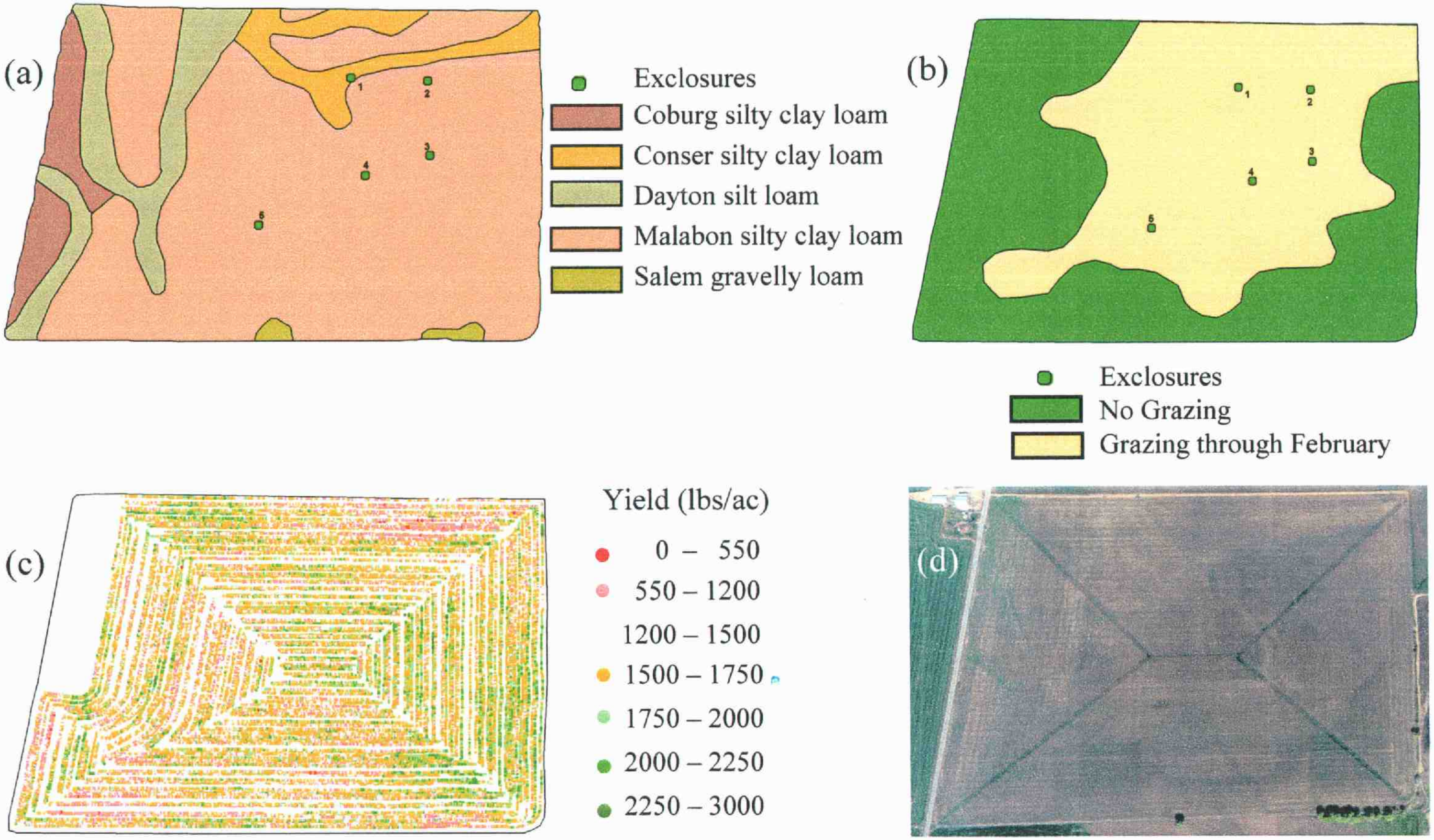


Figure 3.9. Maps for a newly established tall fescue field 2001 (Ntf-01). (a) soil map, (b) spatial and temporal goose grazing map, (c) yield map, and (d) color aerial photography taken on April 24, 2001.

Table 3.12. Comparisons of grass seed yield (lbs acre^{-1}) in a newly seeded tall fescue field (Ntf-01) grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P+
Exclosures vs. Ungrazed	1650	1502	148	-9	<0.0001
Exclosures vs. through February	1650	1472	178	-11	<0.0001

+ Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

Established Tall Fescue

One tall fescue field was studied for two years: 1999-2000 (Etf-1-00) and 2000-2001(Etf-1-01). The distribution of soil for this field is shown in Figure 3.10. Soil is predominantly classified as Dayton silt loam with a small area of Coburg silty clay loam at the north end of the field and a small area of Willamette silt loam at the south. This field was heavily impacted by water, which resulted in a very patchy network of bare ground (Figure 3.11). The grazing pattern was substantially different in 2000 compared to 2001 (Figure 3.12). Yield maps of this field for 2000 and 2001 are provided as Figure 3.13.

This field was not as uniform as other fields in the study. It was not possible to make inferences because of the high degree of variability which resulted from:

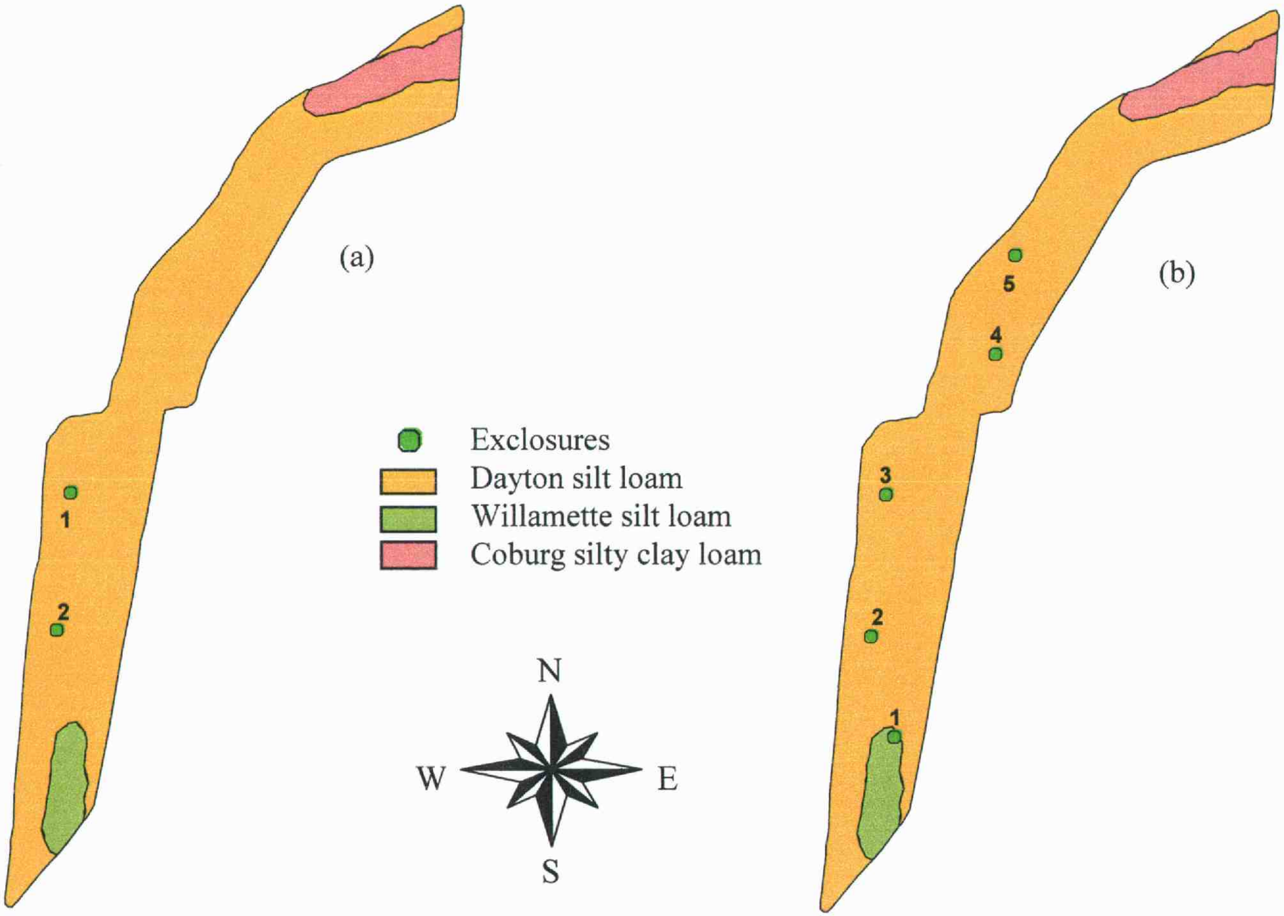


Figure 3.10. Soil map for an established tall fescue field, which was studied for two years: 1999-2000 (Etf-1-00) and 2000-2001 (Etf-1-01). Exclosure locations were overlaid for both years: first year (a) and second year (b).

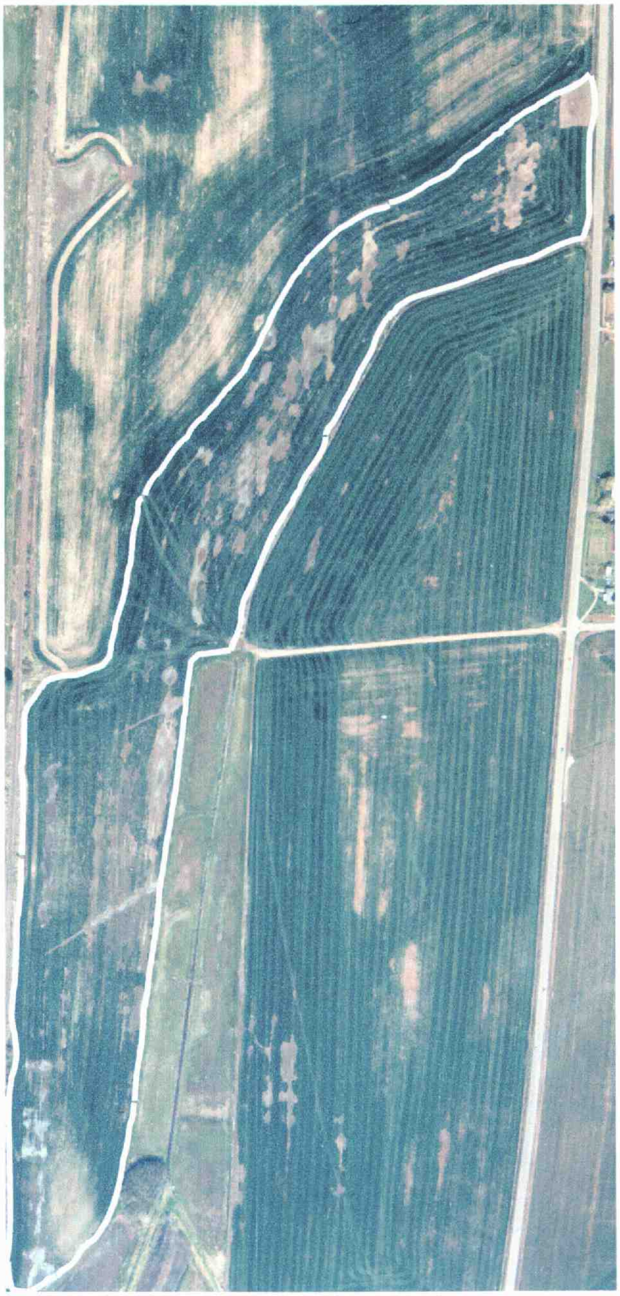


Figure 3.11. Color aerial photography taken on April 24, 2001 for an established tall fescue field (Etf-1-01).

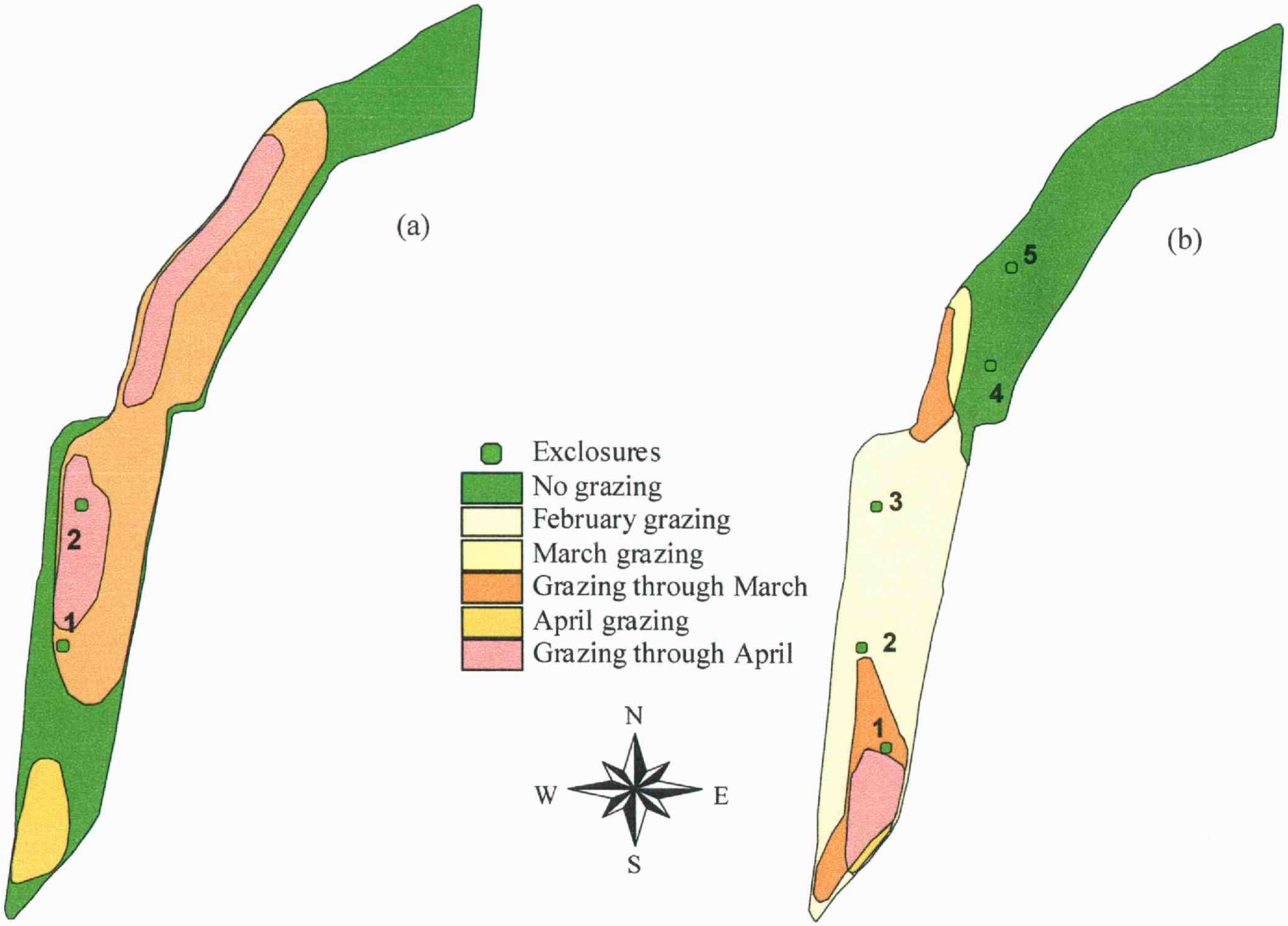


Figure 3.12. Spatial and temporal goose grazing for an established tall fescue field, which was studied for two years: 1999-2000 (Etf-1-00) (a) and 2000-2001 (Etf-1-01) (b).

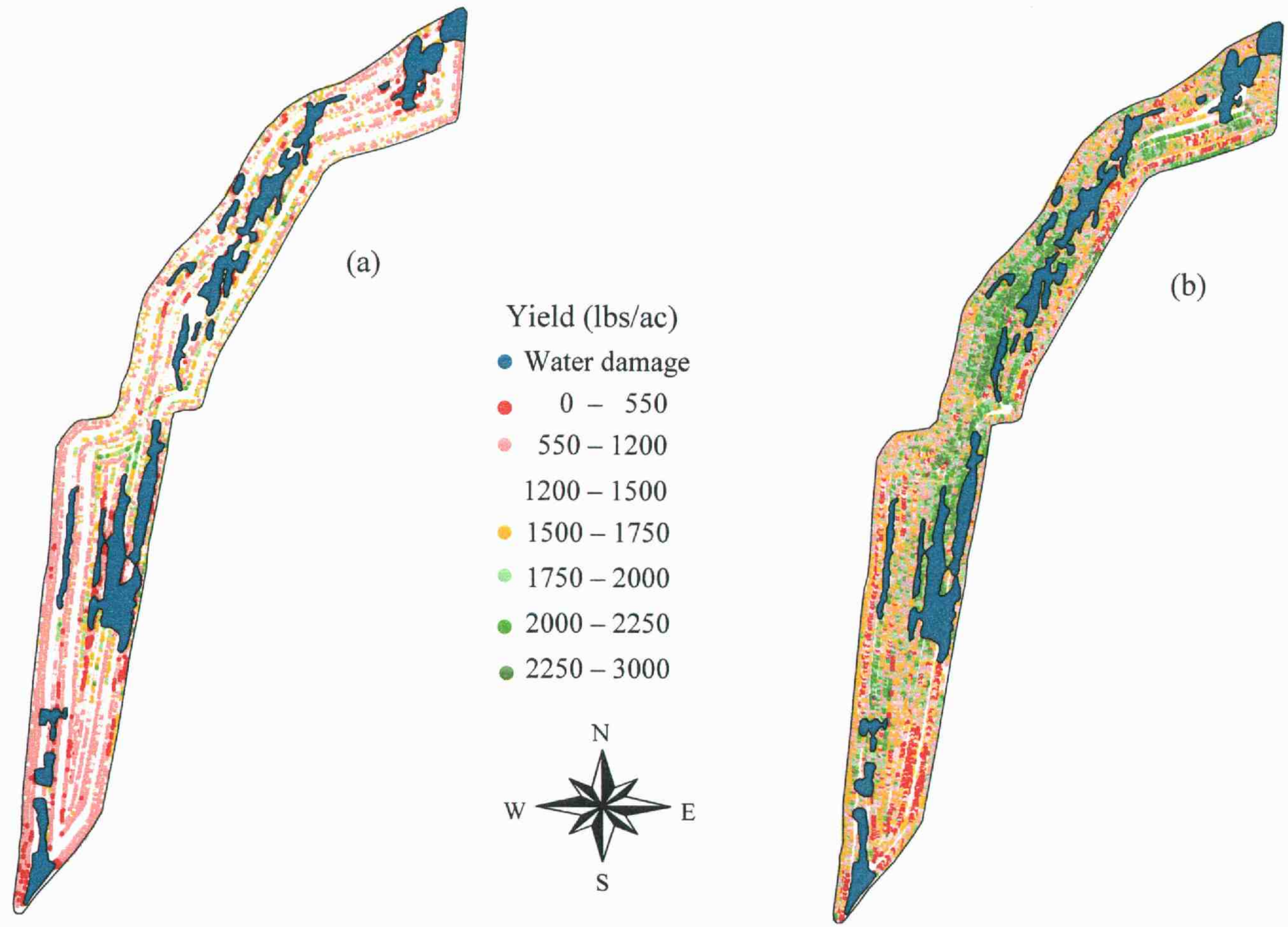


Figure 3.13. Yield map for an established tall fescue field, which was studied for two years: 1999-2000 (Etf-1-00) (a) and 2000-2001 (Etf-1-01) (b).

- The grass stand was very patchy causing the yield to fluctuate over short distances.
- The shape of the field was long and narrow, which was likely to introduce environmental differences along the field.
- The ungrazed portion of the field was located at one end of the field was close to a heavily traveled highway.

During 2000 we had only two exclosures in the field and it was impossible to assess grazing impacts. Yield inside these exclosures were significantly different than yield in ungrazed portions of the field (Table 3.13). Thus, we elected to not compare grazed portions of the field to ungrazed areas.

Although we established five exclosures during the second year, only three of the exclosures were placed where grazing occurred (Figure 3.12 b) (Table 3.14). Seed yields in ungrazed portions of the field (near highway) and within exclosures were significantly different; therefore, comparisons of grazed areas to ungrazed areas near the highway were inappropriate. Also, yield in exclosures versus areas subjected to February or March grazing were confounded because the grazed area was small and interspersed with water damage. Therefore, the variability within plots was too high for us to attribute yield differences to grazing.

Table 3.13. Comparisons of grass seed yield (lbs acre^{-1}) in an established tall fescue field (Etf-1-00) grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P+
Exclosures vs. Ungrazed	1289	1241	48	-4	0.0013

+ Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

Table 3.14. Comparisons of grass seed yield (lbs acre^{-1}) in an established tall fescue field (Etf-1-01) grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P+
Exclosures vs. Ungrazed	875	1003	128	13	<0.0001
Exclosure vs. February	875	925	50	5	0.0004
Exclosures vs. through March	875	883	8	1	0.2771

+ Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

A second established tall fescue field was studied for goose grazing impacts during 1999 - 2000 (Etf-2-00). This field consisted of only two soil types: Conser silty clay loam and Malabon silty clay loam (Figure 3.14 a). However, our observations lead us to believe that there were greater variations in soil than suggested by two similar soil types. The central portion of the field had gravel and stones at the soil surface, and color and texture varied across the field. Most of the goose grazing occurred in the center of the field (Figure 3.14 b). Figure 3.14 c shows the pattern of yield in the field and that the Conser soil was more productive than the Malabon soil; ungrazed Malabon soil produced 1675 lbs acre^{-1} (1876 kg ha^{-1}) of grass seed compared to 1860 lbs acre^{-1} (2083 kg ha^{-1}) in ungrazed areas of the Conser soil. Because there was a yield difference associated with soil type, the effect of grazing was analyzed separately (Table 3.15).

Within the Malabon soil area, exclosures produced 73 lbs acre^{-1} (82 kg ha^{-1}) less seed than ungrazed areas. Therefore, yield in exclosures was compared to yield in areas grazed in March and through March. Goose grazing on the Malabon soil reduced grass seed yield by 2 to 3 percent (Table 3.15).

Conser silty clay loam areas had no significant difference in yield between exclosures and other ungrazed areas of the field. Comparisons of exclosures to both grazed and ungrazed portions of the field are presented in Table 3.15. When yield in exclosures was compared to areas that had been grazed through February, yield was 4 percent higher ($P = 0.0003$) in the grazed area.

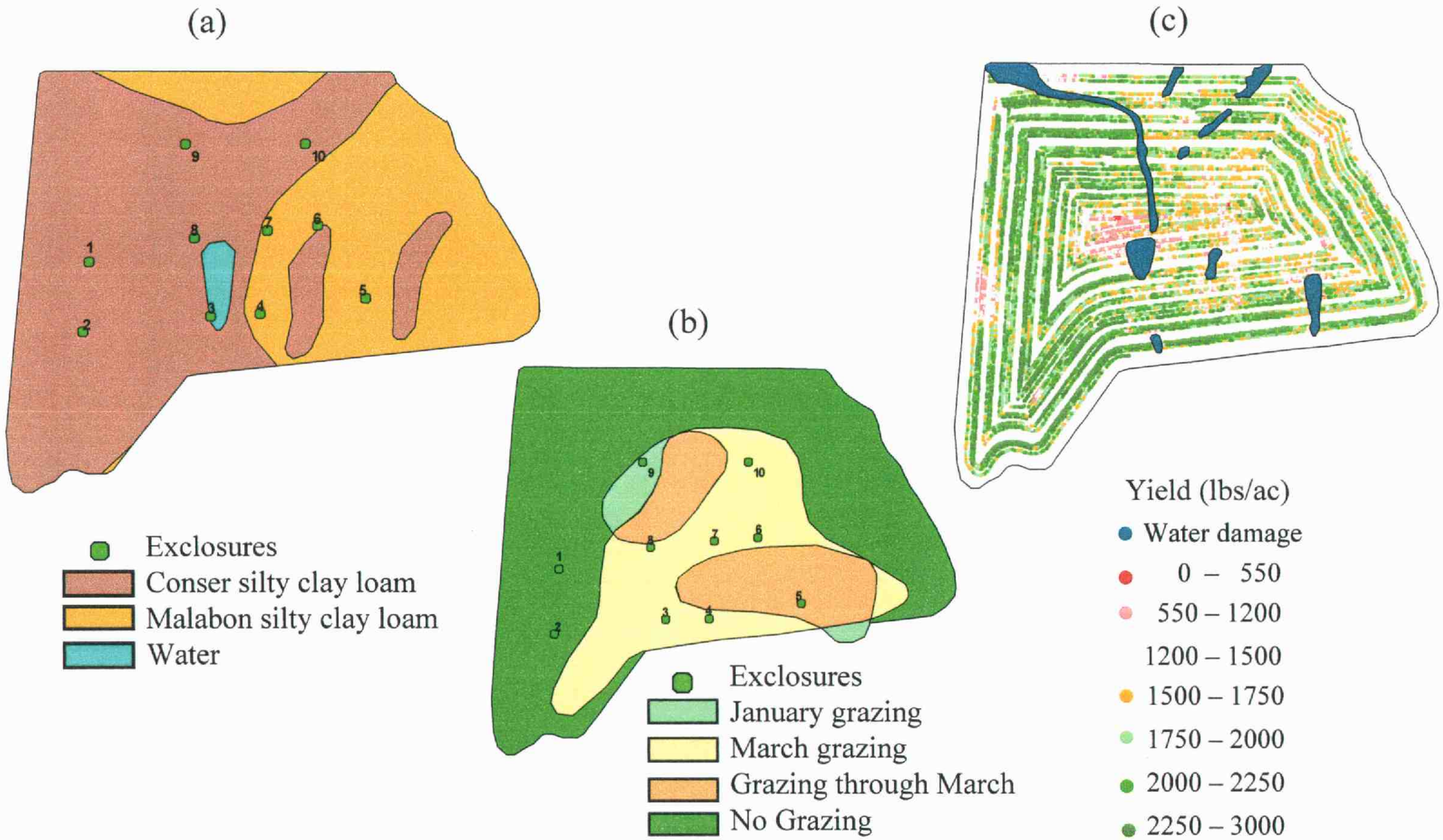


Figure 3.14. Maps for an established tall fescue field 2000 (Etf-2-00). (a) soil map, (b) spatial and temporal goose grazing map, and (c) yield map.

Table 3.15. Comparisons of grass seed yield (lbs acre^{-1}) in an established tall fescue field (Etf-2-00) grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^{+}
Malabon silty clay loam					
Exclosures vs. Ungrazed	1602	1675	73	4	<0.0001
Exclosures vs. March	1602	1562	40	-3	0.0006
Exclosures vs. through March	1602	1573	29	-2	0.0104
Conser silty clay loam					
Exclosures vs. Ungrazed	1832	1860	28	2	0.0870
Exclosures vs. through February	1832	1899	67	4	0.0003
Exclosures vs. March	1832	1723	109	-6	<0.0001
Exclosures vs. through March	1832	1482	350	-19	<0.0001
Ungrazed vs. Jan/Feb	1860	1899	39	2	0.0142
Ungrazed vs. March	1860	1723	137	-7	<0.0001
Ungrazed vs. through March	1860	1482	378	-20	<0.0001

$^{+}$Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

Areas grazed only in March had a 6 percent yield reduction in grass seed compared to yield inside exclosures. Areas grazed January through March produced 19 percent less grass seed yield than exclosures. The ungrazed portion of the field yielded 2 percent more grass seed than areas grazed in January/February (P = 0.0142). Those areas grazed in March produced 7 percent less grass seed and those grazed through March produced 20 percent less seed than similar ungrazed areas ($P \leq 0.0001$). Longer and later grazing by geese resulted in lower yields (Table 3.15). Tall fescue plants in the Conser soil appeared to be more sensitive to grazing. We do not know why this occurs. A higher resolution soil map for this field might enable us to separate soil and grazing effects. This field was also heavily grazed during 1998 – 1999, which was the year of establishment. Consequently, there may have been multiple year grazing effects.

In the 2000-2001 growing season, we studied an established tall fescue field with Coburg, Dayton, and Malabon soil types (Figure 3.15 a). Because the Malabon soil type was a narrow strip along the edge of the field and adjacent to the highway, it was not grazed by geese (Figure 3.15 b) and therefore excluded from the analysis. Yield impacted by water damage and/or bareground (Figures 3.16 a and b) were also excluded from the analysis. There were no significant differences between grass seed yield on Coburg and Dayton soil types, so they were combined. We found no significant differences between exclosures and the ungrazed part of the field ($P = 0.3881$) (Table 3.16). Those areas that were grazed by geese through February produced 17 percent less seed than grazed parts of the field when compared to either exclosures or ungrazed portion of the field (Figure 3.16 c).

We were surprised to see that goose grazing in February but not later resulted in such a substantial reduction in yield. Factors that may have exacerbated early grazing on yield included an extremely dry winter (Appendix 6), carry over damage from previous years' grazing, or a combination of the two.

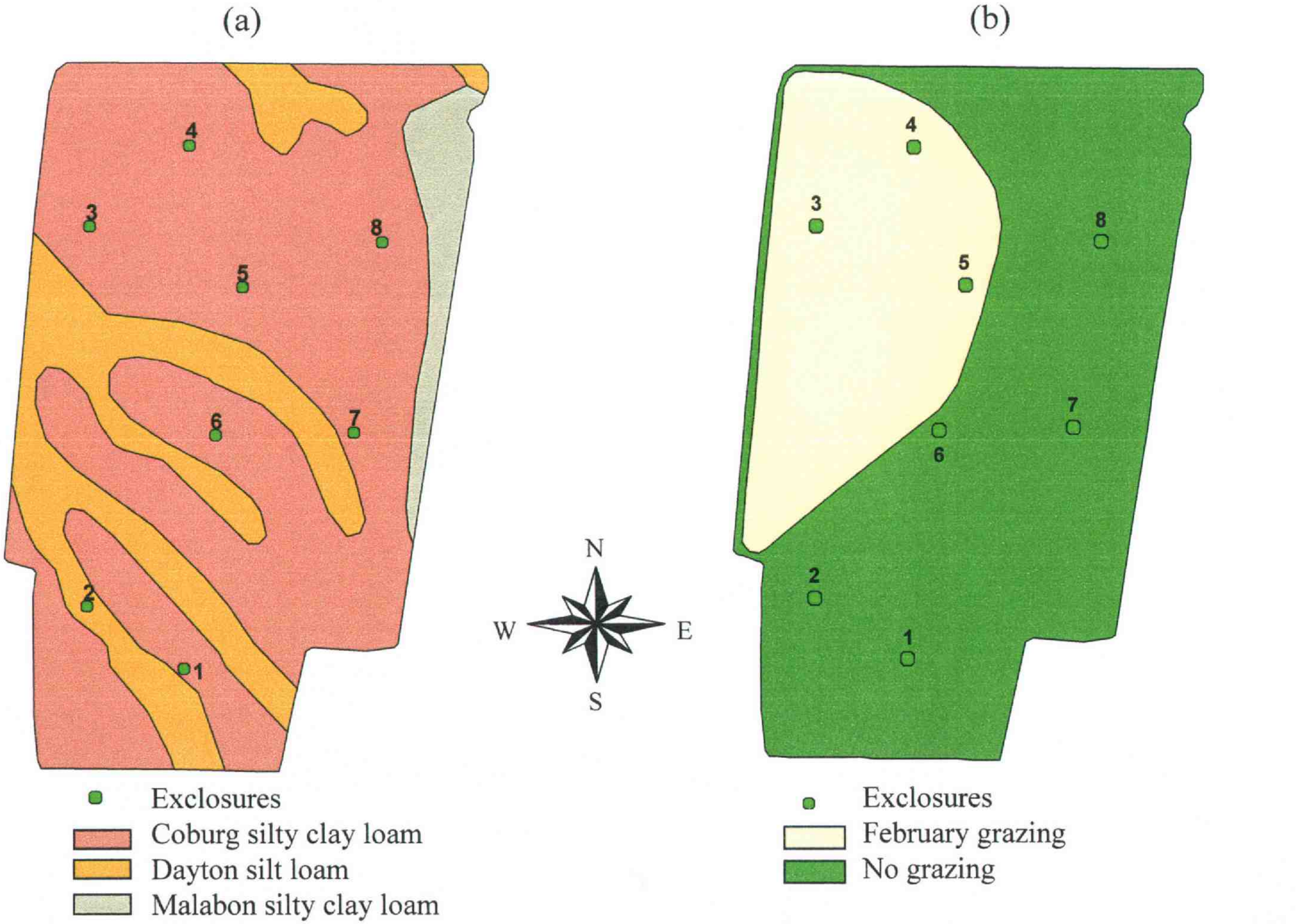


Figure 3.15. Maps for an established tall fescue field 2001 (Etf-2-01). (a) soil map and (b) spatial and temporal goose grazing map.

(a) (b) (c)

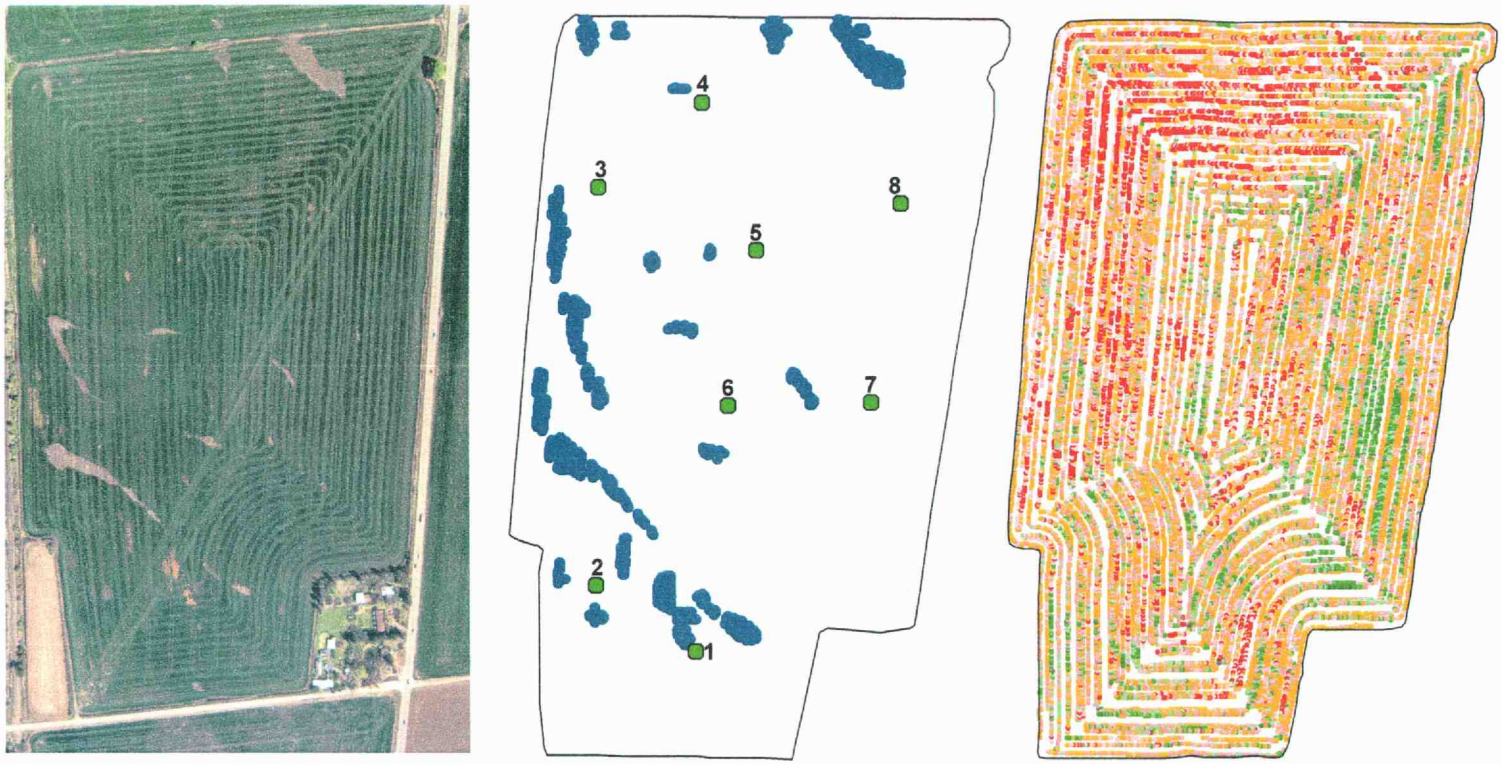


Figure 3.16. Maps for an established tall fescue field 2001 (Etf-2-01). (a) color aerial photography taken on April 24, 2001 showing bareground areas, (b) delineated ponded areas, (c) yield map.

Table 3.16. Comparisons of grass seed yield (lbs $acre^{-1}$) in an established tall fescue field (Etf-2-01) grazed by wild geese.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^+
Exclosures vs. Ungrazed	811	807	3.5	-0.43	0.3881
Exclosure vs. February	811	672	139	-17.15	<0.0001
Ungrazed vs. Through February	807	672	135.5	-16.8	<0.0001

$^+$ Probability (P) is from a one-tailed t-test using statistical bootstrapping algorithm with 50 iterations of 15 observations.

SUMMARY AND CONCLUSIONS

Documenting goose-grazing impacts proved more difficult for grass-seed fields than for winter-wheat fields, which was reported by Louhaichi (1999). Different harvest techniques, more within-field variability, and a perennial crop with both newly planted and already established fields resulted in more challenges for documenting grazing impacts on grass-seed fields than on wheat fields. We also encountered equipment failures during the second year of the grass-seed study that we had not encountered when monitoring wheat. Yield-mapping-system failures and possible operator errors resulted in substantial amounts of lost data that, in some cases, limited our ability to evaluate grazing impacts on seed yields. However, even with the additional complexity and problems encountered, we were still able to document seed-yield differences between ungrazed exclosures and their paired plots that had been grazed and among areas of fields that received grazing at various times during the growing season.

Results of paired-plot comparisons varied; including several cases of no difference due to grazing, a single case of a yield increase attributable to grazing, and several cases of yield reductions due to grazing. Analyses comparing entire areas (as opposed to fixed-plot size) of fields with different timing of grazing to exclosures and to field areas not grazed also yielded variable results. Results included no apparent difference, increased yields, and yield reductions due to grazing. Yield reductions tended to be associated with periods of later grazing, but there were exceptions such as early grazing during a dry crop year.

Both exclosures and photography were essential components to verify goose-grazing impacts. The exclosures were very effective in providing ungrazed areas as comparisons to the grazing impacts around them.

Aerial photography was not as useful for the grass-seed fields as it was for wheat fields. The dramatic differences in aerial photographs of grazed wheat fields were not apparent in grass fields. Later and slower growth of newly seeded grass fields compared to wheat fields resulted in little to no visible vegetation in aerial photographs until about mid-March. In established grass fields, grazing could significantly reduce leaf biomass, but dramatic bare ground increase was not as apparent because the crowns of the established plants were still in place.

Ground-level photography provided verification of goose grazing activity when and where it was occurring; thereby creating a visual record of grazing.

Ground-level photographs allowed us to identify when the various fields were being grazed and to verify cause and effect.

The yield-mapping system developed for commercial combines proved to be an effective method for obtaining yield data. We were able to obtain yields for entire areas of a field. The flagging option allowed us to document yields in specific areas that could be compared to yields in comparison areas. For example, we were able to compare yields from within exclosures to paired plots outside the exclosures by turning on the exclosure flag when entering and turning it off when exiting an exclosure. In some cases the yield-mapping system allowed us to actually census a field, or part of a field, rather than subsample it. The differences were actual differences not subject to sampling error. Thus, statistical analysis was not necessary to determine whether or not differences were real. We were also able to subsample larger field areas and use bootstrapping to subsample the data to allow appropriate statistical analysis.

During the second year of the grass-seed study, we lost data for an entire field because of an apparent malfunction of the yield-mapping-system equipment. Yields recorded by the yield-mapping system were about half the actual weight recorded when the seed was independently weighed out of the field. In another field, either the flagging option was not properly set or the operators did not use the flagging option for exclosures. Substantial additional work was required to identify exclosure data. Important lessons learned were that calibration of the yield-mapping system is important, independently weighing seed out of the field is important for verification of yield-mapping-system recorded data, and the flagging option must be correctly set and used to facilitate data extraction, especially for exclosures.

Global Positioning System (GPS) data allowed us to tie together data collected during the growing season to yield data at specific locations on the ground. A specific location with standing water or goose grazing impact from a photograph earlier in the year could be tied to the yield at that same location. GPS data allowed us to identify cause-and-effect relationships.

The combination of exclosures to serve as ungrazed controls, photography, yield-mapping-system data collection, and global positioning system (GPS) technology has proven very effective in quantifying seed yield differences due to grazing and verifying cause-and-effect relationships.

LITERATURE CITED

Allen, H.A. Jr., D. Samsons, R. Brinsfield, and R. Limpert. 1985. The effects of Canada goose grazing: an experimental approach. Proceedings of the Eastern Wildlife Damage Control Conference 2:135-141. Wildlife Review 206.

Anderson, G. 1996. The application of spatial technologies for rangeland research and management: state of the art. Geocarto International 11(3):5-11.

Bédard, J., A. Nadeau, and G. Gauthier. 1986. Effects of spring grazing by greater snow geese on hay production. Journal of Applied Ecology 23:65-75.

Belling, K. M. 1985. Winter wheat depredation by Canada geese in central New York State. M.S. Thesis, State University of New York, Syracuse. 108p.

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

Carr, P.M., G.R. Carlson, J.S. Jacobson, G.A. Nielsen, and E.O. Skogley. 1991. Farming soils, not fields: A strategy for increasing fertilizer profitability. Journal of Production Agriculture 4(1): 57-61.

Chilcote, D., E.P. Peloquin, and R.S. Rodgers. 1973. Goose grazing in relation to seed yield of annual ryegrass. Proceedings 33rd Annual Meeting of the Oregon Seed Growers League, Eugene, Oregon.

Clark, S.L. and R.L. Jarvis. 1978. Effects of winter grazing by geese on yield of ryegrass seed. Wildlife Society Bulletin 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, Massachusetts. 386p.

Efron, B. 1979. Bootstrap methods: another look at the jackknife. Annals of Statistics 7:1-26.

Efron, B. and R.J. Tibshirani. 1993. An Introduction to the Bootstrap. Chapman and Hall, New York. 436p.

Elgersma, A. 1991. Floret site utilization in perennial ryegrass (*Lolium perenne* L.). Journal of Applied Seed Production 9 (suppl.):38-43.

ESRI (Environmental Systems Research Institute). 1996. Getting to Know Arc View. Environmental Systems Research Institute. Redlands, California.

Fridgen, J.J., C.W. Fraisse, N.R. Kitchen, and K.A. Sudduth. 2000. Delineation and analysis of site-specific management zones. Second International Conference on Geospatial Information in Agriculture and Forestry. Lake Buena Vista, Florida. January 10-12th, 2000.

Green, J.O. and T.A. Evans. 1957. Grazing management for seed production in leafy strains of grasses. Journal of the British Grassland Society 12:4-9.

Hebblethwaite, P.D. and T.G.A. Clemence. 1983. Effect of autumn and spring defoliation and defoliation method on seed yield of *Lolium perenne*. Proceeding of the XIX international Grassland Congress 257-260.

Johnson, D.E., M.M. Borman, M. Louhaichi, D.J. Smith, and N.R. Harris. 1998. What's good for the grower. GPS World 9(3):30-36.

Knox, R.G. and R.K. Peet. 1989. Bootstrapped ordination: a method for estimating sampling effects in indirect gradient analysis. Vegetation 80:153-165.

Lillesand, M.T. and W.R. Kiefer. 1994. Remote Sensing and Image Interpretation. John Wiley and Sons, Inc. 750p.

Louhaichi, M., M.M. Borman, and D.E. Johnson. 2001. Spatially located platform and aerial photography for documentation of grazing impacts on wheat. GEOCARTO International (16)1:63-68.

Louhaichi, Mounir. 1999. Assessment of impacts of Canada geese on wheat production. M. S. thesis, Oregon State University, Corvallis. 104p.

Microsoft Corporation. 1998. Microsoft Excel. Microsoft Information Center, One Microsoft Way, Redmond, Washington 98052-6399.

Oregon Climate Service page. 2001. Online. Oregon State University Climate Data/Reports for Hyslop Farm Experimental Station, Oregon. http://www.ocs.orst.edu/ocs.shtml (Accessed May 25, 2002)

Ott, R.L. 1993. An introduction to Statistical Methods and Data Analysis. 4th edition. Duxbury Press, California. 1051p.

Patterson, I.J. 1991. Conflict between geese and agriculture: does goose grazing cause damage to crops? ARDEA 79(2):179-186.

Pillar, V.D. 1999. The bootstrapped ordination re-examined. Journal of Vegetation Science 10:895-902.

Ramsey, F.L. and D.W. Schafer. 1997. The Statistical Sleuth: A Course of Methods of Data Analysis. Duxbury Press, California. 742p.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Science 41:1884-1888.

Roberts, M.H. 1965. The effect of defoliation on the seed-producing capacity of bred strains of grasses. III. Varieties of perennial ryegrass, cocksfoot, meadow fescue and timothy. Journal of British Grassland Society 20:283-289.

Sawyer, J.E. 1994. Concepts of variable rate technology with considerations for fertilizer application. Journal of Production Agriculture 7(2):195-201.

Schabenberger, O. and F.J. Pierce. 2002. Contemporary Statistical Models for the Plant and Soil Sciences. CRC Press, New York. 738p.

StatSoft Incorporation. 2002. Statistica Entreprise Systems. Version 6. Tulsa, Oklahoma.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd Edition. McGraw-Hill Book Co. New York. 633p.

Stoddart, L.A., A.D. Smith, and T.W. Box. 1975. Range Management. McGraw-Hill Book Company, New York.

Terry, K.S. and A.S. Bury. 1997. Texas Orthoimagery Program-DOQQ processing techniques and applications for the state of Texas. Earth Observation Magazine 6(3):24-27.

United States Department of Agriculture Forest Service Global Positioning Systems page. 2000. Online. http://www.fs.fed.us/database/gps (accessed August 21, 2001).

United States Department of Agriculture Soil Conservation Service and Oregon Agricultural Experiment Station. 1975. Soil survey of Benton County Area, Oregon. 119p.

United States Geological Survey page. 1998. Online. Animal movement analysis Arc View extension. BRD, Alaska Science Center - Biological Science Office. http://www.absc.usgs.gov/glba/gistools/animal_mvmt.htm (Accessed April 12, 2002)

Wibawa, W.D., D.L. Dludlu, L.J. Swenson, D.G. Hopkins, and W.C. Dhanke. 1993. Variable fertilizer application based on yield goal, soil fertility and soil map unit. Journal of Production Agriculture 6 (2):255-261.

Young III, W.C., M.E. Mellbye, and G.A. Gingrich page. 1997. Online. The Oregon Grass Seed Industry. http://www.css.orst.edu/seed-ext/pub/industry.htm (Accessed May 15, 2002).

CHAPTER 4: SUMMARY AND CONCLUSIONS

Increasing populations of wintering Canada geese (*Branta canadensis*) in the lower Columbia and Willamette Valleys have resulted in discernible farm crop damage, including reductions of grass-seed production. Several studies have been conducted on the relationship between defoliation (grazing or cutting) and grass-seed production. Results from these studies were sometimes conflicting and sometimes monitoring and sampling design were insufficient to adequately represent field-scale variation. This study was designed to test methods to quantify and statistically analyze goose-grazing impacts on seed yields of tall fescue (*Festuca arundinacea* Schreb.) and perennial ryegrass (*Lolium perenne* L.). Study objectives included:

- develop methods that provide reliable estimates of goose impact on grass-seed yield;
- develop methods to separate goose damage from other factors that lower yield, such as poor soil or waterlogging;
- identify timing of goose use of selected grass-seed fields;
- provide an estimate of goose impact on grass-seed yield on specific fields during the research period;
- test the assumption that early grazing by geese is not detrimental to plant growth and production;

- determine the optimum exclosure size to collect enough samples to accurately measure yield;
- identify optimum timing for taking aerial photography (single flight);
- develop and test a new technique for generating high-resolution digital elevation models for research plots and agronomic fields;
- develop a sound and efficient data sampling and analysis strategy for the yield-mapping-system data.

Integration of geographical information systems, ground-truth data collection via geopositioned (DGPS) platform photography with selected measurements, and yield-mapping systems provided a method to document impacts on grass seed yields. This combination of tools was effective in documenting, quantifying and spatially delineating wild goose grazing impacts on grass-seed yields.

Separating goose grazing from other impacts was critical in ensuring good results. As an example, stress associated with water damage or weed infestation, must be separated from goose grazing. This process required frequent field visits. Also, crops do not grow evenly across the field and consequently crop yield can vary greatly from one spot in the field to another. These growth differences may be a result of soil nutrient deficiencies or other forms of stress.

Through a combination of GPS-located ground photographs, geo-positioned field observations, and geo-referenced yield mapping, we were able to verify and quantify the impact of wild geese on grass seed fields. We believe the analysis presented in this thesis is relevant to the broader agricultural community. Yield results reported in this study are supported by a large body of research on herbivory and are consistent with our understanding of ecological processes. This approach should provide farmers and wildlife agency personnel with reliable information as they work together to evaluate goose impacts. Following are summaries of procedures.

PROCEDURES TO QUANTIFY AND STATISTICALLY ANALYZE GOOSE-GRAZING IMPACTS ON GRASS SEED YIELDS

Base Maps

Base maps were a necessary component of our protocol. They included all pertinent information about each field. As the growing season progressed, subsequent data were overlaid on these base maps.

Ground-Truth Data

Ground-truth data were collected concurrently with platform photographs, 1.7 m above the ground. Photographs were taken to estimate vegetation cover and to identify factors associated with differences in cover. Associated data, such as grazed leaves and goose droppings, were recorded at each photo point to document presence or lack of goose impact. Each point was spatially located with a GPS unit so that it could be accurately associated with yield data at that point. The sequential ground-truth verification of geese as the impact agent allowed us to monitor the level and extent of goose grazing throughout their residence in the area. We were able to map zones (spatial map) of impact in January, March, and April (temporal map). Heavily grazed areas were reduced in size as the season progressed.

Other factors such as standing water or some soil types were also associated with low cover. We believe that soil maps at higher resolution than the conventional soil survey maps from the Natural Resource Conservation Service could improve the analysis of soil influences on grass seed yield.

Yield-Mapping System

The commercially available yield-mapping system provided complete and useful information when combined with the spatial-temporal maps. The yield-mapping system recorded yield at approximately 1.2 to 1.3 m intervals. We were able, in a series of steps, to extract yield data from within zones of impact. We extracted yields from areas grazed in April, areas grazed in March but not April, areas grazed in January but not later, areas in exclosures, and other nongrazed areas. This procedure allowed us to develop a complete picture of goose grazing impact on yields and to evaluate the effects of seasonal grazing. Although April grazing appeared to have the greatest negative impact per unit area, earlier season grazing also impacted grass seed yields either negatively or positively and must, therefore, be quantified to accurately assess goose impacts.

Aerial Photography

Image classification of vertical color aerial photography (1:10,000) was not as useful for the grass-seed fields as we hoped. No discernible differences in aerial photographs between grazed and ungrazed parts of a field were apparent in grass fields. Later and slower growth of newly seeded grass fields resulted in little to no visible vegetation in aerial photographs until late March to mid-April. In established grass fields, grazing could significantly reduce leaf biomass, but dramatic bare ground increase was not as apparent because the crowns of the established plants were still in place. For these reasons oblique aerial photographs were more convenient. They were easier to acquire (did not require a mount attached to the aircraft) and covered a larger area. Their disadvantage was that they represented a distorted view of the field and could not be geo-corrected.

Analysis Procedure

Data from yield monitors are auto-correlated because they map continuously. To avoid autocorrelation, a bootstrapping procedure for sub-sampling spatially contiguous seed yield data was used to organize the data for appropriate use of a standard t-test analysis. First we sorted yield data by areas of the field with similar patterns (soil type, intensity and timing of grazing). Then from each of these areas, groups or cluster data were extracted in a series of iterations. Each iteration contained a randomly selected subsample from the population. We also used a standard paired-plot procedure, involving exclosures and associated plots available for grazing.

For both techniques, exclosures were a necessary component for the analysis. They served as controls of ungrazed grass seed and could be compared directly with paired plots accessible to goose grazing or with other nonexcluded portions of the field. These exclosures had to be large enough to be harvested by a commercial combine. Exclosure width should be at least as wide as the swather and its length should be at least 20 m.

Grazing Impacts

Because of the patchy nature of goose grazing, sufficient numbers of paired plots were often not located in areas of the fields where geese grazed. This placed a restriction on tests of significance since areas where geese grazed may not have been adequately sampled with paired plots. The bootstrapping procedure for subsampling data from larger field areas allowed us to compare larger, similarly grazed areas of a field to yields from representative exclosures, and, if appropriate, to other ungrazed areas of a field. Yields from those larger areas, representing similar timing of grazing, better represented grazing impacts on seed yields. Results from those larger area comparisons are summarized below.

During 2000, a newly seeded perennial ryegrass field was grazed across its entire surface in January. The area became progressively smaller as the season advanced through April. Ungrazed seed yields were greater on Woodburn soil compared to Dayton and Amity soils, which were similar. Grazing impacts were analyzed by soil type. Grazing through March resulted in a 5 percent yield increase on Amity soil. Grazing through March resulted in 9 and 8 percent yield decreases on Dayton and Woodburn soils. Grazing through April resulted in a 10 percent yield decrease on Amity soil and a 14 percent yield decrease on Dayton soil.

During 2000, an established perennial ryegrass field had no yield differences due to grazing, whether through March or April. During 2001, a second-year established perennial ryegrass field (the same field as described in the paragraph immediately above) did suffer seed yield losses due to grazing. Grazing occurred only during January, March, and January through March. Yield losses ranged from 4 to 10 percent with the greatest losses on Dayton soil compared to Amity soil. Results were similar to the previous year even though hazing effectively stopped grazing in April. We suspect that the impact of earlier grazing was more severe after early grazing in 2001 because it was a much drier year and the ryegrass was not able to recover as well as it had in 2000.

A newly seeded tall fescue field evaluated in 2000 had no yield difference due to grazing, which was light and occurred only in March. A second newly seeded tall fescue field was evaluated in 2001, a very dry year. Grazing through February resulted in an 11 percent seed yield reduction. Early grazing may have a negative impact on seed yield during the establishment year of tall fescue, especially during a dry year. Grazed tall fescue plants were slow to develop compared to ungrazed plants.

Two established tall fescue fields were evaluated. One was long and narrow and had substantial variability due to a network of standing water. Due to the configuration of the field and high variability within the field, it was not possible to make inferences about grazing impacts on seed yield. A second established tall fescue field was evaluated in 2001. It contained two soil types, which appeared to have different production potential. Grazing through February on the more productive soil resulted in seed yield increases of 2 to 4 percent. Grazing only in March resulted in seed yield reductions of 2 to 7 percent. Grazing during January through March resulted in yield reductions of 2 percent on the lower producing soil to 20 percent on the higher producing soil.

Generally, our results suggest that later and longer grazing by geese will tend to suppress seed yields to a greater extent than will earlier and shorter grazing periods. Grazing during a very dry year appears to reduce the recuperative ability of both grass species, especially tall fescue, compared to grazing during an average precipitation year. Our results suggest that newly seeded tall fescue was more sensitive than newly seeded perennial ryegrass to goose grazing. Perennial ryegrass may be generally more resilient than tall fescue following defoliation.

Results presented in this study do not reflect potential goose grazing impact on grass seed yield. The intensity of the hazing and hunting pressure likely decreased the impact of goose grazing.

COMPARISON BETWEEN PAIRED PLOTS AND ANALYSIS OF LARGER FIELD AREAS

GIS, GPS, and yield monitor technologies are changing the way agronomic research is being done. In the past, researchers collected samples by hand or by using small plot harvesters that provided few estimates of yield. Today thousands of estimates of yield can be generated during the harvest. In many cases, the whole population is sampled. If the entire population has been sampled, no statistical analysis is needed. Differences are real. If less than the entire population has been sampled, statistical analysis is needed. Automated data collection provides greater power to determine factors that influence yield yet traditional statistical methods fail because of autocorrelation and over-sampling. This presents a dilemma, either discard data so that traditional statistics can be performed or develop new methods to account for the increased sample size.

We evaluated the use of a traditional approach using paired plots versus a bootstrapping procedure to organize data for analysis of larger field areas. Table 4.1 highlights the advantages and disadvantages of each procedure. Results of both techniques are in general agreement (Table 4.2). Where there were differences between the analysis methods, it was generally explained by the soil patterns that existed on the field. Both techniques require exclosures to ensure that some reference areas of no grazing are present. Both systems also require a yield monitor on the combine. Paired-plot analysis was computationally simpler, since it requires yield estimates only from exclosures and their pairs. For a field with 10 exclosures this could be as few as 600 individual measurements of yield. This would not provide a spatial perspective of yield throughout the field. Thus, information relevant to factors that limit or enhance yield may not be observed.

In contrast the bootstrapping approach of data extraction allows us to compare yield in any pre-selected area of the field. For example, if we wanted to examine the effect of topography on yield, we could use a digital elevation model to define lowlands, hillsides, and hilltops. We would then randomly select individual yield estimates from areas that were contained in each type and statistically compare them. The challenge is to separate each factor that influences yield so that its contribution is adequately assessed. If we use the example above and estimate yield based on topographic position, our results would be erroneous if goose grazing only occurred in lowlands and grazing depressed yield. Thus, it is important to control variables when possible on portions of the field. In our test, fields, goose grazing was controlled via exclosures, soil pH was controlled via liming, and ponded or water damaged areas were eliminated from consideration by removing them from the data set. Statistical bootstrapping was advantageous because a subset of data that was random and not autocorrelated could be obtained easily. Paired-plot analysis uses a much more restricted data set and probably provides a more conservative test as compared to analysis of larger areas. We found both paired-plots and comparison of larger field areas to be enlightening and recommend that both be used.

Table 4.1. Advantages and disadvantages of paired plots and larger-area comparisons for assessing the impact of goose grazing.

Paired Plots		Larger-Area Comparisons	
Advantages	Disadvantages	Advantages	Disadvantages
- Exclosures can be placed in the field to exclude grazing. - Because exclosure and paired plots are adjacent, meaningful comparisons can be made. - Paired t-test is a simple and powerful test.	- We cannot predict where goose grazing is going to take place, so proper placement is difficult. - Grazing does not always occur where we have paired plots, so some grazing treatments are not represented. - If grass seed yield is influenced by soil type, each soil type must have enough exclosures to adequately sample grazing impact. - If we install too many exclosures, we may indirectly lessen the intensity of grazing.	- The entire field is sampled. - Sub-samples used to characterize yield are randomly selected. - There is no autocorrelation between samples when data are subsampled via bootstrapping. - Yield can be sampled from any part of the field. - If field is uniform and yield inside exclosure and ungrazed parts are similar, we can increase the power of statistical comparisons. - This technique is more robust and allows greater flexibility in examining factors influencing crop yield.	- Areas ungrazed versus areas grazed can be some distance apart and yield differences can result from causes other than goose grazing. Comparisons would therefore not be meaningful.

Table 4.2. Comparison between paired plots and larger-area comparisons for assessing the impact of goose grazing.

Field Name*	Grazing Period	Percent difference and Statistical Significance Level			
		%	Paired-t-test	%⁺	Bootstrapping
		Perennial ryegrass – 2000 harvest			
Npr-00	Through March	-2	0.3210	5 To -9	<0.0001
	Mid. April	-17	0.0115	-10 to -14	<0.0001
Epr-00	Through March	6	0.0055	0	0.2425
	Mid. April	NA		1	0.0835
		Perennial ryegrass – 2001 harvest			
Epr-01	Through January	-8	0.0775	-6 to -9	<0.0001
	Grazed in March	-11	0.0259	-5 to -9	<0.0001
	Through March	-12	0.0027	-4 to -10	<0.0001
		Tall fescue – 2000 harvest			
Ntf-00	Grazed in March	1	0.4538	1	0.2646
Etf-1-00	Through April	NA		NA	
Eft-2-00	Grazed in March	-8	0.0075	-3 to -6	0.0006
	Through March	-14	0.0186	-2 to -20	0.0104
		Tall fescue – 2001 harvest			
Ntf-01	Through February	-8	0.0931	-11	<0.0001
Etf-1-01	Grazed in February	NA		5	0.0004
	Through March	NA		1	0.2771
	Through April	NA		NA	
Etf-2-01	Through February	-3	0.1885	-17	<0.0001

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; Ntf = newly seeded tall fescue; Etf = established tall fescue; -00 = harvested during 2000; -01 = harvested during 2001.

⁺ Percent difference for large areas comparisons varies due to soil differences.

NA = Too few samples for analysis.

RECOMMENDED EQUIPMENT AND PROTOCOLS

Throughout this study we have developed protocols and methods to monitor goose grazing impacts on grass seed fields, and we have observed factors influencing yield. There are pitfalls that can easily be avoided with proper planning. This section highlights some major areas that require special attention to ensure that reliable information is collected, processed, and analyzed.

Selection Criteria for Cooperating Farmers and Fields

- Fields should have a recent history of goose grazing. Monitoring fields for goose damage has a cost and cannot be justified if impacts are minimal.
- It is best if farmers are already equipped and familiar with yield monitoring systems and their calibration. Specialists will likely perform data transfer, storage protocols, and statistical analysis. These techniques require a level of technical sophistication that is only gained by experience.
- Greater uniformity within a field, of soils, fertility, topography, pH, and microenvironment, reduces the probability of confusion in results.
- Compact fields are easier to evaluate. Square or circular fields tend to have less variability than long, narrow fields.
- Farmers should lime their fields above a threshold amount to minimize the effect of pH on yield and promote uniformity in yield.

- Farmers should be aware of the cost, in time and money, of measuring and verifying goose grazing impacts on their fields. In particular, farmers need to:
    - Be able to adjust farming practices to accommodate the presence of exclosures.
    - Be tolerant of limits that are imposed on farming practices by exclosures. Once exclosures are placed in a field, the pattern of spraying, potential reseeding, and harvest are often limited because spray booms must clear the exclosures and swathers/combines must pass exactly over them. This requires planning.
    - Communicate well with his/her field crews to ensure that all operations occurring in the field are uniform throughout and that yield data is properly collected. It is best if a single coordinator supervises all harvest operations.
    - Carefully follow instructions for the yield-mapping-systems employed.
    - Be willing to spent time and energy to keep track of hazing activity, to set up and remove goose exclosures, and to monitor grazing with a differentially correctable global positioning system.
    - Be willing to provide ancillary information pertinent to the fields such as prior farming practices, soil or chemical amendments, and aerial photography. This information can be kept confidential, but it

may be needed to interpret seed yield differences within a field (e.g. are yield differences due to goose grazing, soil differences, difference in fertilizer or herbicide application, etc.). Some farmers have yield maps from previous seasons. This information provides an idea about field variability and helps with the layout of exclosures.

Base Maps

In order to use spatial analysis techniques to assess impacts on yield, accurate electronic maps must be made. We used DGPS to delineate field boundaries. These maps were correct to the nearest meter. Aerial photographs were also obtained, scanned into electronic format with a pixel size of 20 cm, and rectified by using ground control points, visible in the images, with known coordinates. This permitted us to create a base map with a standard projection and datum (UTM Zone 10, WGS1984). In the absence of current aerial images, we employed USGS Digital Orthophotographic Quarter Quad (DOQQ) files. Electronic data that were used during the course of this study were:

- USGS Digital Elevation Models (DEMs).
- USGS Digital Line Graphs (transportation, hydrography, hypsography, etc.).

- USGS Digital Orthophoto Quarter Quadrangles (DOQQs). The DOQQ's are digital images produced by the USGS. They contain orthorectified aerial photography at a resolution of 1 m.
- Soils maps from the USDA NRCS.
- USGS Digital Raster Graphics (DRG). The DRGs are scanned images of a U.S. Geological Survey standard series topographic map. They are georeferenced to the Universal Transverse Mercator (UTM) grid and may be used as a source or background layer in a geographic information system.
- DGPS generated maps of field boundaries.
- DGPS generated maps of goose grazed areas.
- DGPS generated maps of areas within the field with standing water.
- DGPS generated maps of exclosures and paired plots.
- DGPS generated maps of other notable features in the fields.
- Yield maps from a combine-mounted yield-monitoring system.
- Yield-monitor flags

Because USGS digital elevation models were imprecise, we also created our own elevation models with much higher accuracy for some of the fields.

Exclosures

The number of exclosures that are placed in a field is dependant upon the size of the field, the size of the area that geese are expected to impact, and the cost in both time and money that it takes to establish exclosures and maintain them. More exclosures give more estimates of yield uninfluenced by grazing geese and more paired plots. With larger sample sizes it is easier to accurately assess impact. We tried to have several exclosures on each soil type that was present in the field. Sometimes this is not possible due to time constraints or because a soil type occupied only a small area. We suggest that:

- Minimum exclosure length should be 20 m. During harvest we obtained 15 to 18 estimates of yield within a 20 m exclosure length. We determined that 15 to 18 data points were needed to generate yield estimate within yield 5 percent of the mean with 95 percent confidence.
- Exclosure width should match or exceed the width of the swather or combine. Wider is better, but width should not prevent chemical and fertilizer applications.
- Exclosures should be distributed to represent all parts of the field.
- It is best to stratify a field into two or three units based on anticipated grazing intensity (e.g. more intensive, less intensive, and no grazing).
- Within each unit, assign treatments (exclosures) randomly.
- Put most exclosures in strata of the field that are expected to be heavily grazed.

- Avoid placing exclosures where swathers and combines turn.
- Exclosures may influence which fields or parts of fields are grazed. Too many exclosures in one area may cause geese to shift to other parts of the field.
- As soon as geese leave the area (migrate north in the spring), exclosures should be removed. Removal is much easier before the grass grows up and into the wire.

Hazing Activity

This study was done with normal farming practices, including goose hazing. Hazing activities are a cost of production. Farmers should keep track of all his/her hazing activities and associated costs, such as:

- How many working hours.
- Purchase and operating cost of devices such as propane cannons, scarecrows, flash tape, atv use, etc.

Swathing

When swathing, drivers should keep the header full at all times and avoid merging swathed lines to the fullest extent possible, especially in the vicinity of exclosures. They should be as consistent as possible and avoid winding around exclosures.

Pre-Harvest

After swathing is completed, it is necessary to mark, on the ground and/or on the top of the swathed grass row, the beginning of each swathed row where there are exclosures, and the beginning and ending point of each exclosure.
At this time it is important that the combine/yield-monitoring-system is in good working order and ready for harvest. If possible, test the YMS setting in another field. This will ensure that the yield data will be recorded properly. Data loggers should be preprogrammed with the crop species/cultivars, field names, preferred units (lbs. $acre^{-1}$), and flags. Flags are used to note data points that have a specific condition such as: position within an exclosure, weeds present, a bare area due to water damage, or other field conditions of importance. At this time it is also important to calibrate the combine and yield monitoring system. Calibration data should be recorded for each combine and grass species so that errors can be calculated. If possible, recalibrate for each field.

Harvest

During harvest it is important that all combine drivers be comfortable with the data collection system and the use of flags. They should proceed through the field at a uniform pace and not stop in exclosures or on paired plots. When encountering bare spots they should lift the header slightly without disengaging or stopping the yield monitoring system. This will ensure that data continues to be collected and will provide us with a more complete picture of yield across the field.

During harvest, farmers should record the weight of each truckload of seed removed from the field. At the end of harvest this information is useful for determining error and variation in the yield monitoring system. If more than one type of yield monitor is used and if loads are stratified keeping each system separate, the each yield monitoring system can be compared and corrected.

Post-Harvest

Farmers should download yield data from PCMCA flashcards as soon as the field is harvested using laptop equipped with PCMCA card reader. This data should be stored on a computer hard drive and also archived to permanent media such as a compact disk. Analysis is time consuming and is usually not done until later in the year so any notes or written records should be organized and stored in a secure location.

BIBLIOGRAPHY

Allen, H.A. Jr., D. Samsons, R. Brinsfield, and R. Limpert. 1985. The effects of Canada goose grazing: an experimental approach. Proceedings of the Eastern Wildlife Damage Control Conference 2:135-141. Wildlife Review 206.

Anderson, G. 1996. The application of spatial technologies for rangeland research and management: state of the art. Geocarto International 11(3):5-11.

Avery, T. A. 1977. Interpretation of Aerial Photographs, Third Edition. Burgess Publishing Company, Minneapolis, Minnesota. 392p.

Bakhsh, A., T.S. Colvin, D.B. Jaynes, R.S. Kanwar, and U.S. Tim. 2000. Using soil attributes and GIS for interpretation of spatial variability in yield. Transactions of the American Society of Agricultural Engineers 43:819-828.

Barrett, E.C. and L.F. Curtis. 1992. Introduction to Environmental Remote Sensing. Chapman and Hall, New York. 426p.

Bédard, J., A. Nadeau, and G. Gauthier. 1986. Effects of spring grazing by greater snow geese on hay production. Journal of Applied Ecology 23:65-75.

Belling, K. M. 1985. Winter wheat depredation by Canada geese in central New York State. M.S. Thesis, State University of New York, Syracuse. 108p.

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

Brady, N.C. and R.R. Weil. 2001. The Nature and Properties of Soils. 13th edition. Prentice Hall, Upper Saddle River, New Jersey.

Brooks, K.N., P.F. Ffolliott, H.M. Gregersen, and L.F. DeBano. 1997. Hydrology and the Management of Watersheds. Second edition. Iowa State Univ. Press, Ames, Iowa.

Brown, K.R. 1980. Seed production in New Zealand ryegrasses: I. Effect of grazing. New Zealand Journal of Experimental Agriculture 8:27-32.

Carr, P.M., G.R. Carlson, J.S. Jacobson, G.A. Nielsen, and E.O. Skogley. 1991. Farming soils, not fields: A strategy for increasing fertilizer profitability. Journal of Production Agriculture 4(1): 57-61.

Casady, W., D. Pfsot, C. Ellis, and K. Shannon page. 1998. Online. Precision Agriculture: Yield Monitors. University of Missouri, Columbia. http://www.fse.missouri.edu/mpac/pubs/wq0451.htm (Accessed May 22, 2002).

Chastain, T. G. 2000. Precipitation and Grass Seed Yield in the Willamette Valley. Seed Production Research at Oregon State University USDA-ARS cooperating. Oregon Seed Publications.

Chilcote, D., E.P. Peloquin, and R.S. Rodgers. 1973. Goose grazing in relation to seed yield of annual ryegrass. Proceedings 33rd Annual Meeting of the Oregon Seed Growers League, Eugene, Oregon.

Clark, R.L. and R. Lee. 1998. Development of topographic maps for precision farming with kinematic GPS. Transactions of the American Society of Agricultural Engineers 41:909-916.

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

Conover, M.R. 1988. The effect of grazing by Canada geese on the winter growth of rye. Journal of Wildlife Management 52(1):76-80.

Davis C.H. and X. Wang. 2001. High-resolution DEMs for urban applications from NAPP photography. Photogrammetric Engineering and Remote Sensing 67(5):585-592.

Deckard, C. and P. Bolstad. 1996. Forest canopy, terrain, and distance effects on global positioning point accuracy. Photogrammetric Engineering and Remote Sensing 62(3):317-321.

Driscoll, R.S. 1992. Remote sensing – An invaluable ally for assessing and managing renewable natural resources. GIS World 5(4):66-69.

Dueker, K.J. and D. Kjerne. 1989. Multipurpose Cadastre Terms and Definitions. American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, Virginia.

Eastman, J.R. 1997. Idrisi for Windows, User's Guide, version 2.0. Clark Labs for Cartographic Technology and Geographic Analysis, Worchester, Massachusetts. 386p.

Efron, B. 1979. Bootstrap methods: another look at the jackknife. Annals of Statistics 7:1-26.

Efron, B. and R.J. Tibshirani. 1993. An Introduction to the Bootstrap. Chapman and Hall, New York. 436p.

Elgersma, A. 1991. Floret site utilization in perennial ryegrass (*Lolium perenne* L.). Journal of Applied Seed Production 9 (suppl.):38-43.

ESRI (Environmental Systems Research Institute). 1996. Getting to know Arc View. Environmental Systems Research Institute. Redlands, California.

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

Fox, A.D., N.J. Kristiansen, D.A. Stroud, and H. Boyd. 1998. The effects of simulated spring goose grazing on the growth rate and protein content pf *Phleum pratense* leaves. Oecologia 116:154-159.

Fridgen, J.J., C.W. Fraisse, N.R. Kitchen, and K.A. Sudduth. 2000. Delineation and analysis of site-specific management zones. Second International Conference on Geospatial Information in Agriculture and Forestry. Lake Buena Vista, Florida. January 10-12th, 2000.

Friedl, M.A., J. Michaelsen, F.W. Davis, H. Walker, and D.S. Schimel. 1994. Estimating grassland and leaf area index using ground and satellite data. International Journal of Remote Sensing 15:1401-1420.

Green, J.O. and T.A. Evans. 1957. Grazing management for seed production in leafy strains of grasses. Journal of the British Grassland Society 12:4-9.

Hall, F.G., J.R. Townshend, and E.T. Engman. 1995. Status of remote sensing algorithms for estimation of land surface state parameters. Remote Sensing of Environment 51:138-156.

Harris, N.R. 1998. Spatial patterns of tree effects on pasture production in open canopied agroforest. M. S. thesis, Oregon State University, Corvallis. 109p.

Hebblethwaite, P.D. and T.G.A. Clemence. 1983. Effect of autumn and spring defoliation and defoliation method on seed yield of *Lolium perenne*. Proceeding of the XIX international Grassland Congress. pp 257-260.

Herring, T.A. 1996. The global positioning system. Scientific American 274(2):44-50.

Howard, J.A. 1991. Remote Sensing of Forest Resources. Chapman and Hall, London, England. 417p.

Hubert, A. Jr., D. Dammons, R. Brinsfield, and R. Limpert. 1985. The effects of Canada goose grazing on winter wheat: an experimental approach. Proceedings: Eastern Wildlife Damage Control Conference 2:135-141.

Jewiss, O.R. 1972. Tillering in grasses: Its significance and control. Journal of British Grassland Society 27:65-82.

Johansen, D.P., D.E. Clay, C.G. Carlson, K.W. Stange, S.A. Clay, D.D. Malo, and J.A. Schumacher. 2001. Vertical accuracy of two differentially corrected global positioning satellite systems. Journal of Soil and Water Conservation 56:198-201.

John Deere Corp. 1997. John Deere Yield Mapping System. JDmap GreenStar™. Version 2.1. User's Guide.

Johnson, D.E., M.M. Borman, M. Louhaichi, D.J. Smith, and N.R. Harris. 1998. What's good for the grower. GPS World 9(3):30-36.

Kahl, B.R. and F.B. Samson. 1984. Factors affecting yield of winter wheat grazed by geese. Wildlife Society Bulletin 12: 256-262.

Kauth, R.J. and G.S. Thomas. 1976. The Tasseled Cap - a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. Proceedings of Symposium on Machine Processing of Remotely Sensed Data. IEEE, New York. pp 41-49.

Knox, R.G. and R.K. Peet. 1989. Bootstrapped ordination: a method for estimating sampling effects in indirect gradient analysis. Vegetation 80:153-165.

Langley, R.B. 2000. Navigation 101: Basic navigation with a GPS receiver. GPS World 11(10):50-54.

Leica Geosystems AG. 1999. GPS Surveying – system 500. Leica Geosystems AG. Heerbrugg, Switzerland.

Lillesand, M.T. and W.R. Kiefer. 1994. Remote Sensing and Image Interpretation. John Wiley and Sons, Inc. 750p.

Lotz, L. 1997. Yield Monitors and Maps: Making Decisions. Ohio State University Extension Fact Sheet AEX-550-97. The Ohio State University. 4p.

Louhaichi, M., M.M. Borman, and D.E. Johnson. 2001. Spatially located platform and aerial photography for documentation of grazing impacts on wheat. GEOCARTO International (16)1:63-68.

Louhaichi, Mounir. 1999. Assessment of impacts of Canada geese on wheat production. M. S. thesis, Oregon State University, Corvallis. 104p.

McCormac, J.C. 1991. Surveying Fundamentals. Prentice Hall, Englewoods Cliffs, New Jersey. 608p.

Microsoft Corporation. 1998. Microsoft Excel. Microsoft Information Center, One Microsoft Way, Redmond, Washington 98052-6399.

Misra, P. and P. Enge. 2001. Global Positioning Systems: Signals, Measurements, and Performance. Ganga-Jamuna Press. Lincoln, Massachusetts. 408p.

National Geodetic Survey. 1996. Data sheets on CD-ROM for the Western United States and Pacific Territories: AK, CA, HI, ID, OR, WA, and Pacific Territories. Silver Spring, Maryland.

National Mapping Division, U.S. Geological Survey. 1998. National Mapping Program Technical Instructions: Standards for Digital Elevation Models. Version 01/1998. Silver Spring, Maryland.

Oregon Climate Service page. 2001. Online. Climate data/Reports. http://www.ocs.orst.edu/ocs.shtml (Accessed May 25, 2002)

Oregon Department of Agriculture page. 1997. Online. Oregon wildlife damage survey. Oregon Agricultural Statistics Service. http://www.oda.state.or.us/oass/wildlife.htm (Accessed July 3, 2002).

Oregon Department of Fish and Wildlife and Washington Department of Fish and Wildlife. 1997. Pacific Northwest Goose Management. Portland, Oregon.

Oregon Department of Fish and Wildlife. 1998. Oregon's Access & Habitat Board News, Fall 1998, Vol. 3, No. 4.

Ott, R.L. 1993. An Introduction to Statistical Methods and Data Analysis. 4th edition. Duxbury Press, California. 1051p.

Patterson, I.J. 1991. Conflict between geese and agriculture: does goose grazing cause damage to crops? ARDEA 79(2):179-186.

Pillar, V.D. 1999. The bootstrapped ordination re-examined. Journal of Vegetation Science 10:895-902.

Ramsey, F.L. and D.W. Schafer. 1997. The Statistical Sleuth: A Course of Methods of Data Analysis. Duxbury Press, California. 742p.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Science 41:1884-1888.

Roberts, M.H. 1958. The effect of defoliation on the seed-producing capacity of bred strains of grasses. I. Timothy and perennial ryegrass 13:255- 261.

Roberts, M.H. 1965. The effect of defoliation on the seed-producing capacity of bred strains of grasses. III. Varieties of perennial ryegrass, cocksfoot, meadow fescue and timothy. Journal of British Grassland Society 20:283-289.

Roughgarden, J., Running, S.W., Matson, P.A. 1991. What does remote sensing do for ecology? Ecology 72(6):1918-1922.

Salisbury, F. and C. Ross. 1992. Plant Physiology, Fourth edition. Wadsworth Publishing Company, Belmont, California. 600p.

Sawyer, J.E. 1994. Concepts of variable rate technology with considerations for fertilizer application. Journal of Production Agriculture 7(2):195-201.

Schabenberger, O. and F.J. Pierce. 2002. Contemporary Statistical Models for the Plant and Soil Sciences. CRC Press, New York. 738p.

Scheaffer, R.L., W. Mendenhall III., and R.L. Ott. 1996. Elementary Survey Sampling. Duxbury Press, New York. 501p.

Sellers, P.J., S.O. Los, C.O. Justice, D.A. Dazlich, G.J. Collatz, and D.A. Randall. 1994. A Global 1 x 1 NDVI data set for climate studies. Part 2: The generation of global fields of terrestrial biophysical parameters from NDVI. International Journal of Remote Sensing 15:3519-3545.

Sharrow, S.H. 1990. Defoliation effects on biomass yield components of winter wheat. Canadian Journal of Plant Science 70: 1191-1194.

Spencer, D.R., M.A. Green, and P.H. Biggs. 1997. Integrating eucalupt forest inventory and GIS in Western Australia. Photogrammetric Engineering and Remote Sensing Vol. LXIII, Number 2:114-216.

StatSoft Incorporation. 2002. Statistica Entreprise Systems. Version 6. Tulsa, OK.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd Edition. McGraw-Hill Book Co. New York. 633p.

Stoddart, L.A., A.D. Smith, and T.W. Box. 1975. Range Management. McGraw-Hill Book Company, New York.

Stoeckel D.M. and M.S. Miller-Goodman. 2001. Seasonal nutrient dynamics of forested floodplain soil influenced by microtopography and depth. Soil Science Society of America Journal 65:922-931.

Summers, R.W. and G. Hillman. 1990. Scaring brent geese (*Branta bernicla*) from fields of winter wheat with tape. Crop Production 9:459-462.

Sumpter, C.W. and G.W. Asher. 1994. Real-time kinematic GPS for cadastral surveys. Proceedings of the American Congress on Survey and Mapping. American Society for Photogrammetry and Remote Sensing International Meeting 1994. Reno, Nevada.

Terrapoint page. 2000. Online. Lidar Advantages and Approach. TerraPoint, LLC, The woodlands, Texas. http://www.terrapoint.com/tfc/Real_Estate/TerraPoint/Technology/default.asp (Accessed May 18, 2002).

Terry, K.S. and A.S. Bury. 1997. Texas Orthoimagery Program-DOQQ processing techniques and applications for the state of Texas. Earth Observation Magazine 6(3):24-27.

Trimble Navigation. 1996. Trimble Pathfinder Office™, Software Reference Guide. Trimble Navigation, Ltd., Sunnyvale, California. 432p.

Trimble Navigation. 2001a. GPS Pathfinder Systems. Trimble Navigation Limited. Sunnyvale California.

Trimble Navigation. 2001b. Trimble 5700 Receiver. Trimble Navigation Engineering and Construction. Dayton, Ohio.

Trimble Navigation page. 2002. Online. GPS Satellites. http://www.trimble.com/gps/satellites.html (Accessed June 10, 2002).

Tucker, C.J. 1977. Spectral estimation of grass canopy variables. Remote Sensing of the Environment 6:11-26.

Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment 8:127-150.

Tucker, C.J. 1980. A critical review of remote sensing and other methods for non-destructive estimation of standing crop biomass. Range and Forage Science 35:177-182.

United States Department of Agriculture Soil Conservation Service and Oregon Agricultural Experiment Station. 1975. Soil survey of Benton County Area, Oregon. 119p.

United States Fish and Wildlife Service. 1998. Waterfowl Population Status, 1998. U.S. Fish and Wildlife Service, Department of Interior. I 49.100/3: 998.

United States Department of Agriculture Forest Service Global Positioning Systems page. 2000. Online. http://www.fs.fed.us/database/gps (Accessed August 21, 2001).

United States Geological Survey. 1987. Digital Elevation Models. U.S. Geological Survey Data User's Guide 5. 38p.

United States Geological Survey page. 1998. Online. Animal movement analysis Arc View extension. BRD, Alaska Science Center - Biological Science Office. http://www.absc.usgs.gov/glba/gistools/animal_mvmt.htm (Accessed April 12, 2002)

United States Geological Survey page. 2002. Online. USGS Digital Elevation Model. http://edcwww.cr.usgs.gov/glis/hyper/guide/usgs_dem (Accessed June 3, 2002).

Warner, W.S., R.W. Graham, and R.E. Read. 1996. Small Format Aerial Photography. American Society for Photogrammetry and Remote Sensing. Whittles Publishing, Scotland, UK. 348p.

Watson, C.E., Jr. and V.H. Watson. 1982. Nitrogen and date of defoliation effects on seed yield and seed quality of tall fescue. Agronomy Journal 74:891-893

Webster, R. and M.A. Oliver. 1990. Statistical Methods in Soil and Land Resource Survey. Oxford University Press, New York. 316p.

Wells, D.E., N. Beck, D. Delikaraoglou, A. Kleusberg, E.J. Krakiwsky, G. Lachapelkle, R.B. Langley, M. Nakiboglu, K.P. Schwarz, J.M. Tranquilla, and P. Vanicek. 1987. Guide to GPS Positioning. 2nd edition. Canadian GPS Associates, Fredericton. New Brunswick, Canada. 600p.

Wibawa, W.D., D.L. Dludlu, L.J. Swenson, D.G. Hopkins, and W.C. Dhanke. 1993. Variable fertilizer application based on yield goal, soil fertility and soil map unit. Journal of Production Agriculture 6 (2):255-261.

Wiegand, C.L., A.J. Richardson, and P.R. Nixon. 1986. Spectral components analysis: a bridge between spectral observations and agro-meterological crop models. IEEE Transactions on Geoscience and Remote Sensing GE-24(1):83-89.

Wiegand, C.L. and A.J. Richardson. 1990. Use of spectral vegetation indices to infer leaf area, evapotranspiration and yield: I. Results. Agronomy Journal 82:623-629.

Young, F.J. and R.D. Hammer. 2000. Soil-landform relationships on a loess-mantled upland landscape in Missouri. Soil Science Society of America Journal 64:1443-1454.

Young III, W.C., D.O. Chilcote, and H.W. Youngberg. 1996. Annual ryegrass seed yield response to grazing during early stem elongation. Agronomy Journal 88:211-215.

Young III, W.C. 1997. *Festuca arundinacea* Schreb. (Tall Fescue) in the USA. In: Forage Seed Production. Volume 1: Temperate Species. Edited by Fairey, D.T and J.G. Hampton. CAB International, New York. pp 287-296.

Young III, W.C., M.E. Mellbye, and G.A. Gingrich page. 1997. Online. The Oregon Grass Seed Industry. http://www.css.orst.edu/seed-ext/pub/industry.htm (Accessed May 15, 2002).

APPENDICES

Appendix 1. Field area and number of exclosures by field.

Field*	Area Hectares (Acres)	Number of Exclosures
Npr-00	97 (240)	18
Epr-00	75 (186)	7
Etf-1-00	24 (59)	2
Ntf-00	17 (41)	6
Etf-2-00	35 (87)	10
Epr-1-01	97 (240)	15
Epr-2-01	75 (186)	10
Etf-1-01	24 (59)	5
Ntf-01	78 (193)	5
Etf-2-01	35 (87)	8

* Field identification is as follows: Npr = newly seeded perennial ryegrass; Epr = established perennial ryegrass; Ntf = newly seeded tall fescue; Etf = established tall fescue; -00 = harvested during 2000; -01 = harvested during 2001.

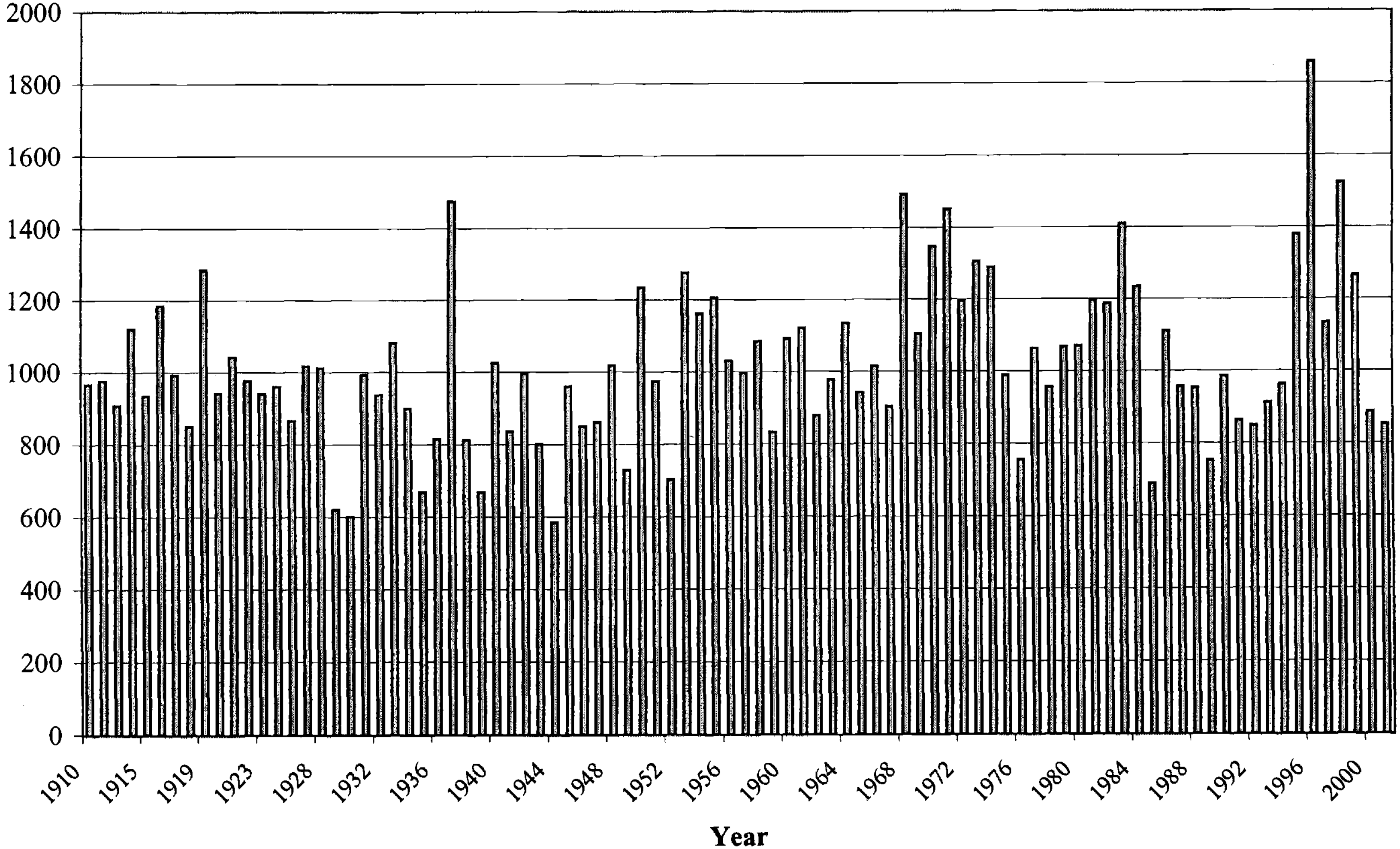
Appendix 2. Estimated soil properties for soil series present in the field study.

	Estimated Soil Properties						
Soil series	Depth to bedrock (Inch)	Depth to seasonal high water table (Inch)	Classification (Dominant USDA texture)	Permeability (Inch/hour)	Available water capacity (Inch/inch)	pH Reaction	Shrink-swell potential
Amity	>72	12-24	Silt loam	0.2-0.6	0.19-0.21	5.6-6.5	Moderate
Camas	>72	>60	Gravelly sandy loam	0.2-0.6	0.07-0.09	5.6-6.0	Low
Coburg	>72	20-36	Silty clay loam and silty clay	0.2-0.6	0.15-0.21	5.6-6.5	High
Conser	>72	0-6	Silty clay loam	0.6-2.0	0.19-0.21	6.1-6.5	Moderate
Dayton	>72	0-6	Silty loam and silty clay loam	0.2-0.6	0.23-0.25	5.6-6.0	Low
Malabon	>72	>60	Silty clay loam	0.2-0.6	0.15-0.21	5.6-6.5	Moderate
Salem	>72	>72	Gravelly loam	0.6-2.0	0.12-0.17	6.1-6.5	Low
Waldo	>60	0-6	Silty clay loam	0.2-0.6	0.17-0.21	5.1-5.5	Moderate
Wapato	>72	0-6	Silty clay loam	0.2-0.6	0.19-0.21	5.6-6.5	Moderate
Willamette	>72	>72	Silt loam	0.2-0.6	0.19-0.21	4.5-5.0	Low
Woodburn	>72	18-36	Silt loam	0.6-2.0	0.19-0.21	5.6-6.0	Low

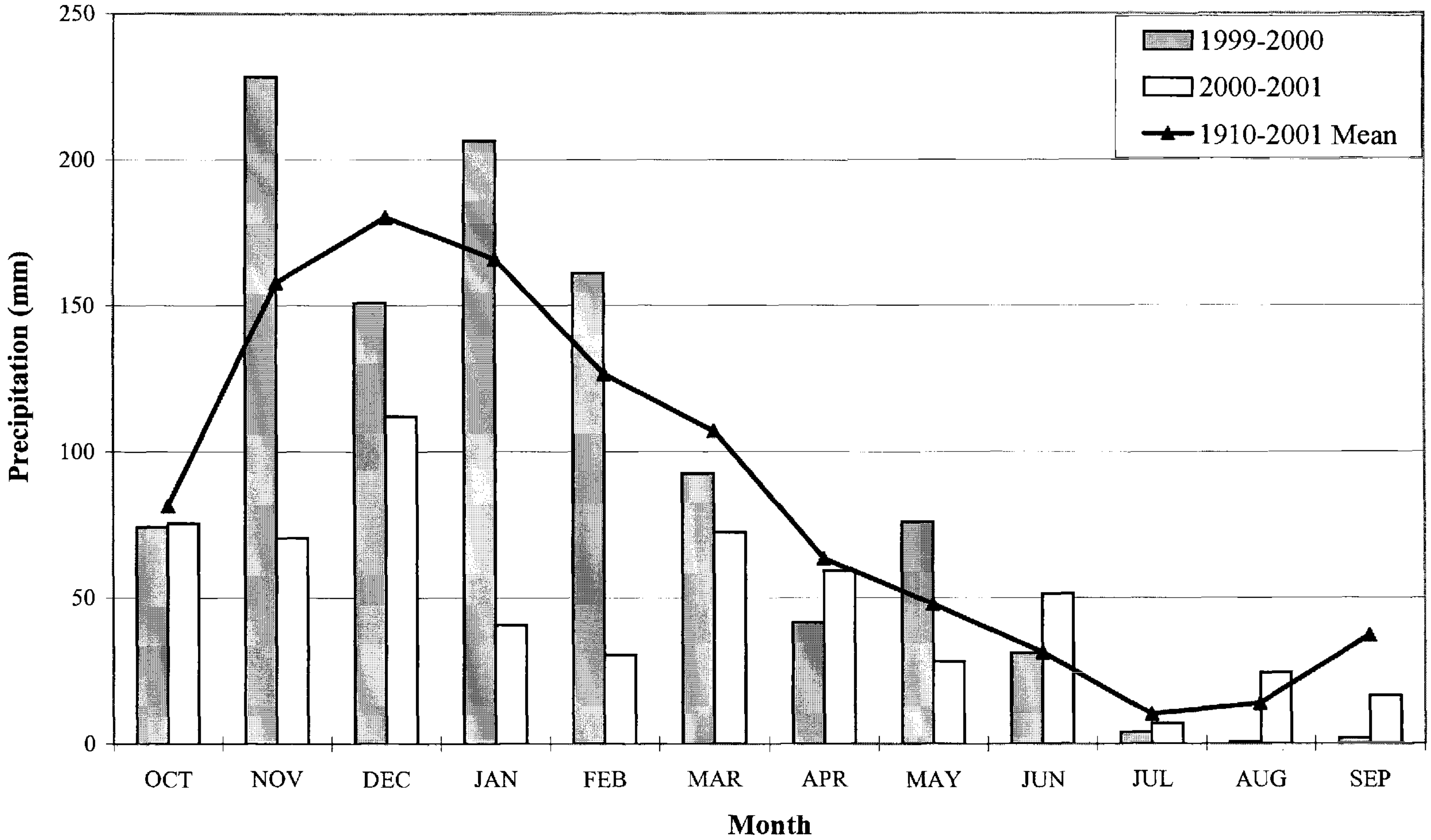
Appendix 3. Classification of soil series.

Soil series	Family	Subgroup	Order
Amity	Fine-silty, mixed, mesic	Argiaquic Xeric Agialbolls	Mollisols
Camas	Sandy-skeletal, mixed, mesic	Fluventic Haploxerolls	Mollisols
Coburg	Fine, mixed, mesic	Pachic Ultic Argixerolls	Mollisols
Conser	Fine, mixed, mesic	Typic Argiaquolls	Mollisols
Dayton	Fine, montmorillonitic, mesic	Typic Albaqualfs	Alfisols
Malabon	Fine, mixed, mesic	Pachic Ultic Argixerolls	Mollisols
Salem	Fine-loamy over sandy or sandy-skeletal, mixed, mesic	Pachic Ultic Argixerolls	Mollisols
Waldo	Fine, mixed, mesic	Fluvaquentic Haplaquolls	Mollisols
Wapato	Fine-silty, mixed, mesic	Fluvaquentic Haplaquolls	Mollisols
Willamette	Fine-silty, mixed, mesic	Pachic Ultic Argixerolls	Mollisols
Woodburn	Fine-silty, mixed, mesic	Aquultic Argixerolls	Mollisols

Appendix 4. Mean annual precipitation (mm) at Hyslop Farm Experimental Station, Corvallis, OR. Range from 1910 to 2001.



Appendix 5. Average monthly precipitation (mm) for both crop years compared to long-term average monthly precipitation at Hyslop Farm Experimental Station, Corvallis, OR. Range from 1910 to 2001.



Appendix 6. Comparison of precipitation (mm) received during the growing season to long-term average monthly precipitation at Hyslop Farm Experimental Station, Corvallis, OR.

(a) Amount and distribution of precipitation (mm) received during the growing season for the study area.

Growing Season Precipitation During the Study											
Growing Season	Fall			Winter			Spring			Total	Percent of 90-Year Mean
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May		
1990-2000	1.8	74.2	228.3	150.9	206.5	161.0	92.4	41.4	75.9	1032.4	107%
2000-2001	16.2	75.4	70.4	112.0	40.6	30.5	72.4	59.2	28.2	504.9	52%
90-Year Mean	37.1	81.3	157.8	180.2	165.9	126.5	107.0	63.4	47.8	967.0	

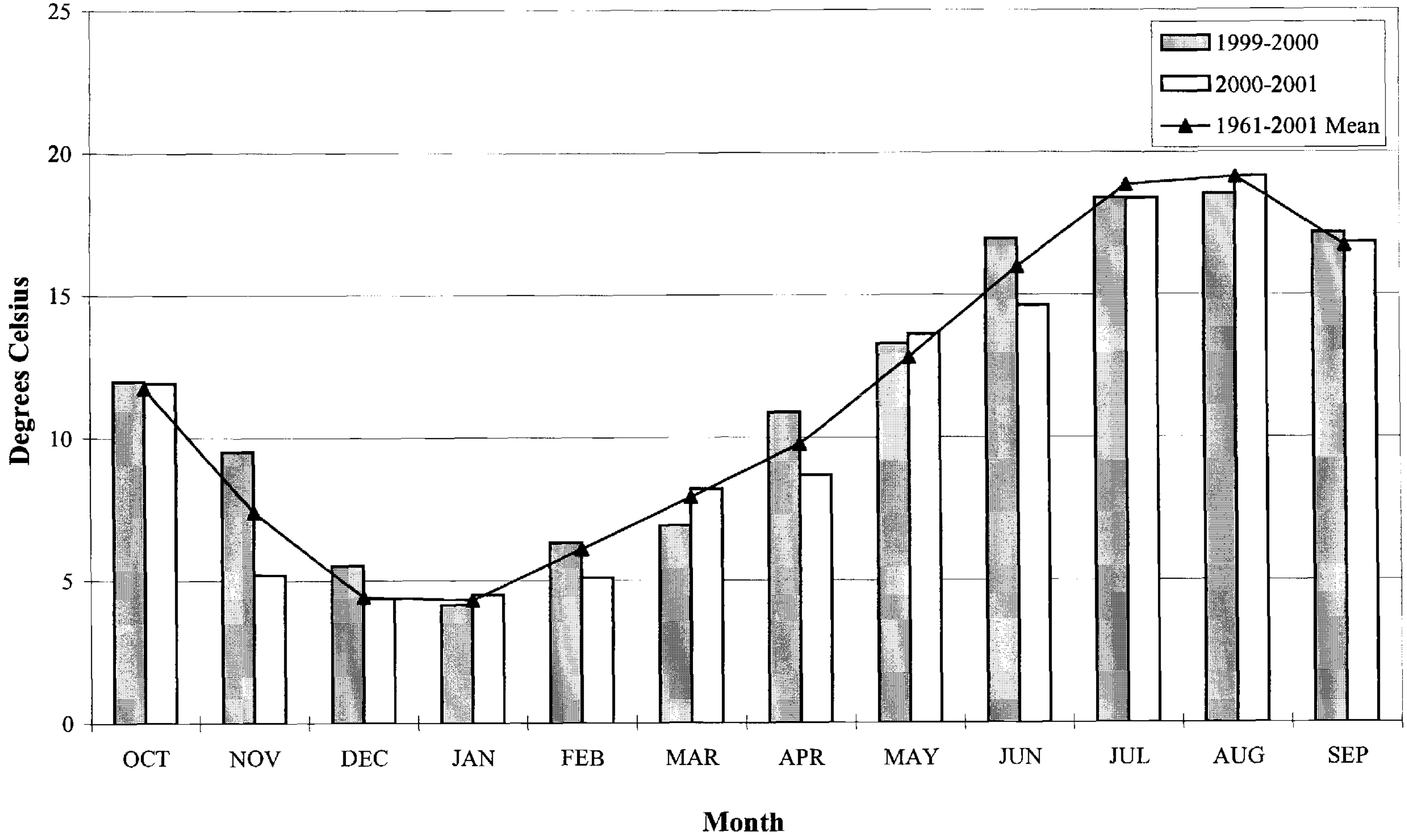
(b) Summary of precipitation for the study area during the growing season. (Measurements in percentage).

Year	Fall		Winter		Spring	
	Class*	% of 90-Year Mean	Class	% of 90-Year Mean	Class	% of 90-Year Mean
1999-2000	Dry	80%	Normal	112%	Normal	104%
2000-2001	Very Dry	60%	Extremely Dry	37%	Dry	73%

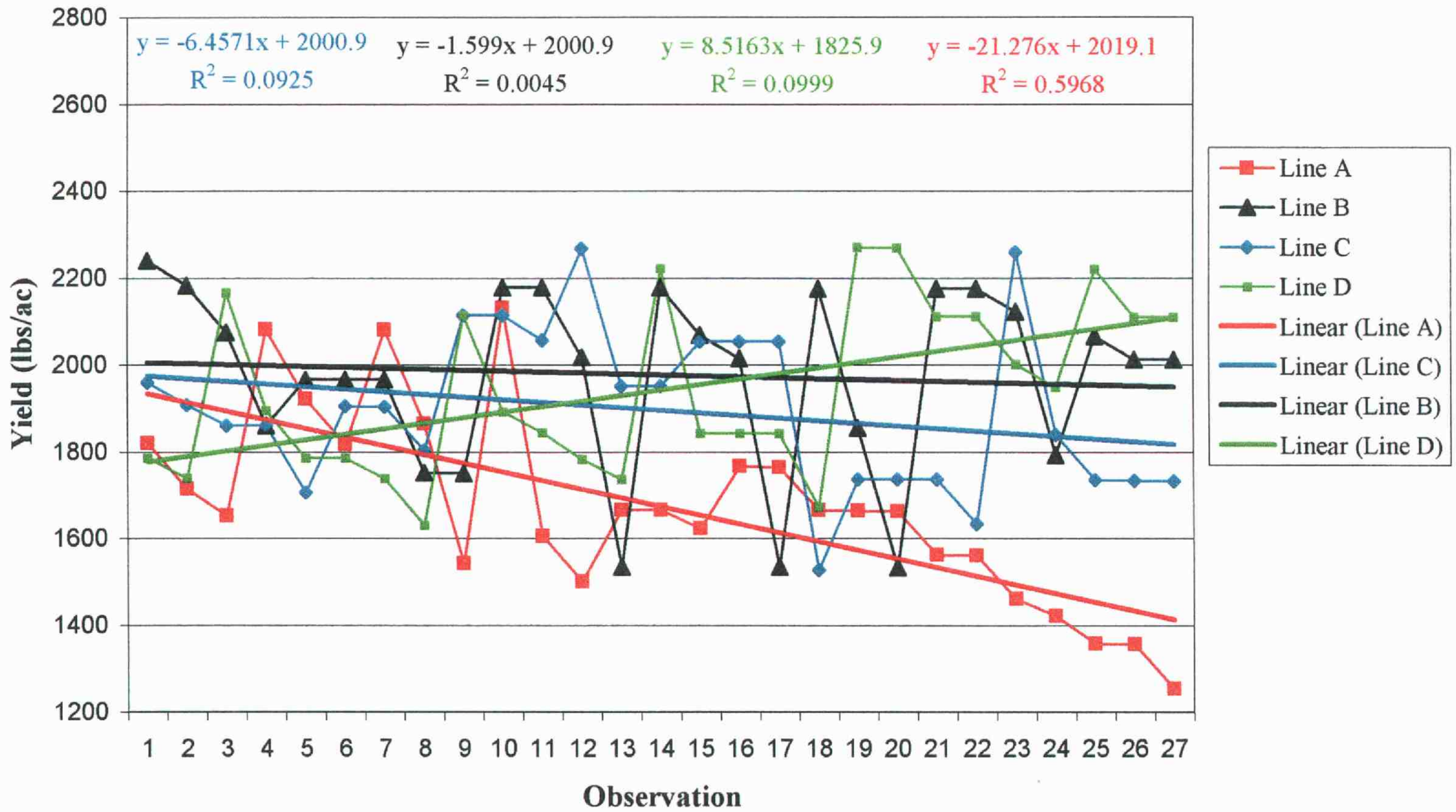
* Distribution of class range:

> 162.5	Extremely wet
137.5 – 162.5	Very wet
112.5 – 137.5	Wet
87.5 – 112.5	Normal
62.5 – 87.5	Dry
37.5 – 62.5	Very dry
< 37.5	Extremely dry

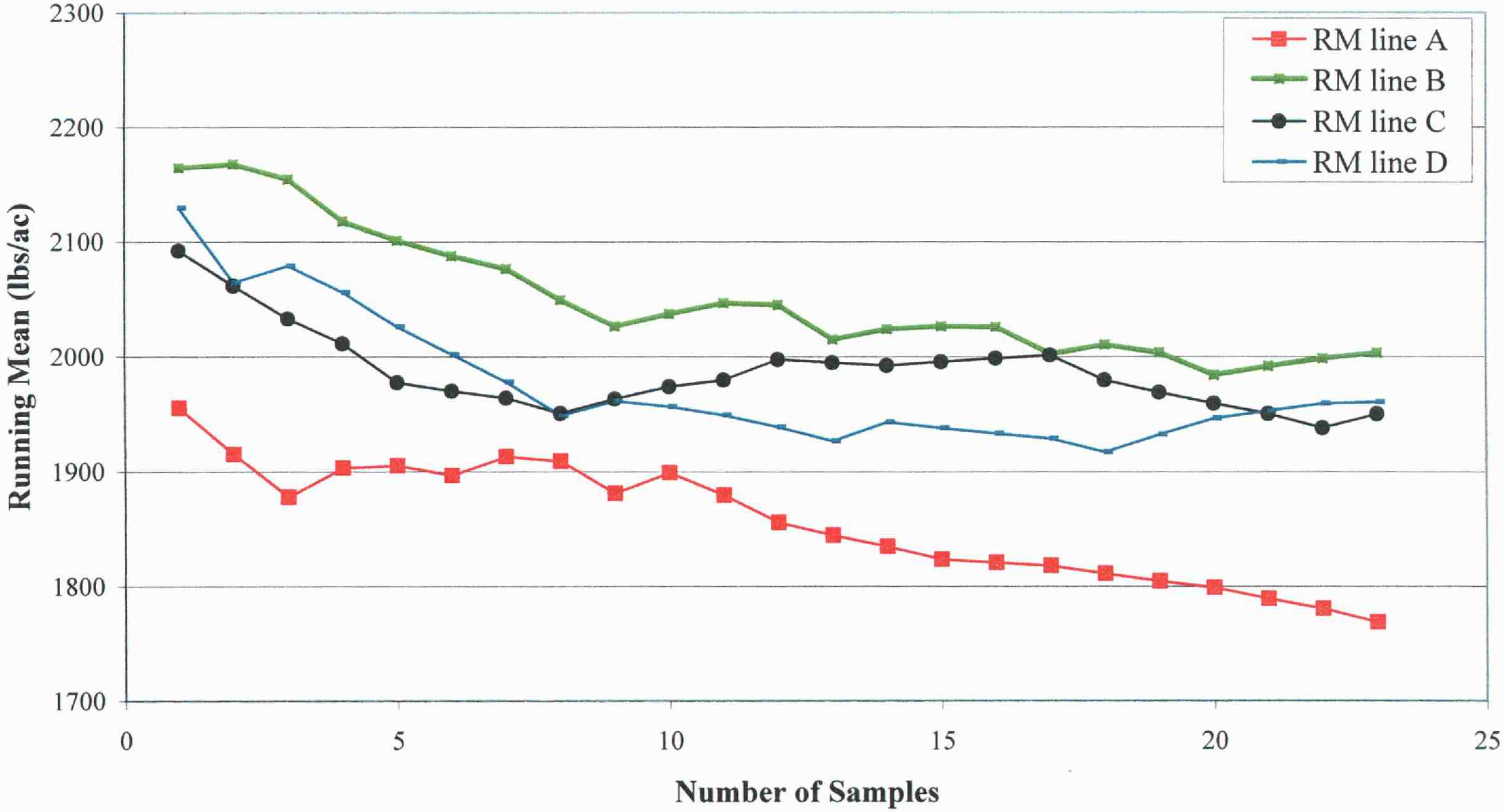
Appendix 7. Average monthly temperature (°C) for both crop years compared to long-term average monthly temperature for Hyslop Farm Experimental Station, Corvallis, OR. Range from 1961 to 2001.



Appendix 8. Variability in individual yield estimates obtained from four adjacent combine paths as they harvested a uniform area of the field. Area was 24 by 27 m with 108 individual yield estimates.



Appendix 9. Plots of the running mean recorded by the yield mapping system of of four adjacent combine paths as they harvested a uniform area of the field.



Appendix 10. Comparisons of grass seed yield (lbs $acre^{-1}$) in a newly seeded perennial ryegrass field (Npr-00) grazed by wild geese, based on sub-sampled data using bootstrapping algorithm with 10 iterations of 15 observations.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P+
		Amity Soil Type			
Exclosures vs. Through March	1712	1790	68	4	<0.0439
Exclosures vs. Through April	1712	1513	-198	-12	<0.0008
		Dayton Soil Type			
Exclosures vs. Through March	1675	1574	101	-6	<0.0262
Exclosures vs. Through April	1675	1469	206	-12	<0.0001
		Woodburn Soil Type			
Exclosures vs. Through March	2098	1928	170	-8	<0.0001

+ Probability (P) is from a one-tailed t-test.

Appendix 11. Comparisons of grass seed yield (lbs $acre^{-1}$) in an established perennial ryegrass field (Epr-00) grazed by wild geese, based on sub-sampled data using bootstrapping algorithm with 10 iterations of 15 observations.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^{+}
Exclosures vs. Ungrazed	1968	1912	56	-3	<0.0724
Exclosures vs. Through March	1968	1947	21	-1	0.2752
Exclosures vs. Through April	1968	1945	23	-1	0.3149

[+] Probability (P) is from a one-tailed t-test.

Appendix 12. Comparisons of grass seed yield (lbs acre^{-1}) in a second year established perennial ryegrass field (Epr-01) grazed by wild geese, based on sub-sampled data using bootstrapping algorithm with 10 iterations of 15 observations.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P[+]
		Amity silt loam			
Exclosures vs. Ungrazed	1495	1384	111	-7	<0.0002
Exclosures vs. January	1495	1406	89	-6	<0.0010
Exclosures vs. March	1495	1425	70	-5	<0.0089
Exclosures vs. through March	1495	1474	21	-1	<0.2677
		Dayton silt loam			
Exclosures vs. Ungrazed	1520	1364	156	-10	<0.0001
Exclosures vs. January	1520	1347	173	-11	<0.0001
Exclosures vs. March	1520	1383	137	-9	<0.0001
Exclosures vs. through March	1520	1364	156	-10	<0.0001

[+] Probability (P) is from a one-tailed t-test.

Appendix 13. Comparisons of grass seed yield (lbs $acre^{-1}$) in a newly seeded tall fescue field (Ntf-00) grazed by wild geese, based on sub-sampled data using bootstrapping algorithm with 10 iterations of 15 observations.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^+
Exclosures vs. Ungrazed	1087	1198	-111	10	<0.0008
Exclosures vs. Grazed in March	1087	1079	8	-1	0.3846

$^+$ Probability (P) is from a one-tailed t-test.

Appendix 14. Comparisons of grass seed yield (lbs $acre^{-1}$) in a newly seeded tall fescue field (Ntf-01) grazed by wild geese, based on sub-sampled data using bootstrapping algorithm with 10 iterations of 15 observations.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^+
Exclosures vs. Ungrazed	1640	1540	100	-6	<0.0058
Exclosures vs. through February	1640	1488	152	-9	<0.0001

$^+$ Probability (P) is from a one-tailed t-test.

Appendix 15. Comparisons of grass seed yield (lbs $acre^{-1}$) in an established tall fescue field (Etf-1-00) grazed by wild geese, based on sub-sampled data using bootstrapping algorithm with 10 iterations of 15 observations.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^{+}
Exclosures vs. Ungrazed	1282	1215	67	-5	0.0136

$^{+}$ Probability (P) is from a one-tailed t-test.

Appendix 16. Comparisons of grass seed yield (lbs $acre^{-1}$) in an established tall fescue field (Etf-1-01) grazed by wild geese, based on sub-sampled data using bootstrapping algorithm with 10 iterations of 15 observations.

Grazing treatment	Exclosure Yield	Comparison Yield	Yield Difference	Percent Difference	P^+
Exclosures vs. Ungrazed	845	976	-131	165	<0.0008
Exclosure vs. February	845	928	-83	10	0.0082
Exclosures vs. through March	845	868	-23	3	0.1753

$^+$Probability (P) is from a one-tailed t-test.

Appendix 17. Timeline for monitoring and documenting goose impacts on grass seed production.

Creation of base map	August/September

- Create a base map for each field:
  - Delineate the field using GPS unit
  - Create soil map either by digitizing soil survey map or by acquisition from NRCS
  - Acquire USGS digital orthophoto quadrangles and USGS topographic maps

- Gather information about the field from previous years:
  - Yield map
  - Aerial photography

- Determine the number and location of exclosures for each field

Set up exclosures	September – November

- Shortly after seeding (newly established field) and before geese start grazing the field farmers will set up exclosures on his/her field

- Put a 1-foot wooden stake into the ground at each enclosure's corner. This stake will help us later relocate the exclosure

- Record the location of each exclosure (four corners) using DGPS

- Establish and record GPS locations of ground control points using white targets (30 by 30 cm). These targets will be used to geo-correct aerial photography

Ground-truthing	October- April

- As soon as grazing by geese starts to occur, frequent visits of the field are required. This is to document areas of the field being impacted by goose grazing as well as other impacts. This step is performed using:
  - Platform photography
  - GPS unit
  - Record ground truthing data:
    - average plant height
    - number of goose droppings/m^2
    - water impact (ponded area)
    - weed infestation
    - wildlife grazing other than geese
    - gopher activity
    - rodent activity
    - slug presence
    - change in soil texture
    - any unusual circumstance

Aerial photography	January - April

- If possible schedule aerial photography during January – April. Due to high cost and difficulty of acquiring and processing vertical aerial photography we take oblique aerial photography

Hazing activity	October- April

- Hazing geese to reduce the negative impact on yield is an additional expense. To calculate the cost of hazing, it is necessary to document hazing activities.
  - How many working hours over the season
  - Manner and cost of devices used:
    - propane cannon
    - reflecting tape
    - gas, repair, and depreciation costs for all-terrain vehicles ...etc.

GIS analysis January-June

- Convert all the data collected into digital format.
  - Scan images
  - Determine percent green leaf cover for each photo
  - Enter data into a spreadsheet (database)
  - Perform GIS overlay
  - Create a grazing intensity index/field/season based on:
    - Plant height
    - Percent leaf cover
    - Number of goose droppings and/or presence of foot prints

- Computer classification of aerial photography
  - If possible try to stratify field into clusters based on goose grazing intensity
  - Perform an accuracy assessment

- Create a goose grazing map for each period
  - Early grazing map (January though February)
  - Late grazing map (through April)

Remove exclosures May

- As soon as geese migrate north, exclosures should be removed

- Paint the top of each wooden stake placed at the corners of each exclosure with fluorescent spray paint

Pre-harvest (swathing) July

- Swathing operation should be conducted with no adjustment for exclosures

- After swathing is completed we need to mark the location of the exclosure on the ground and/or on the top of the dry grass:
  - The beginning of each swathed row where we have exclosures (using fluorescent spray paint, bicycle flag, or other means)
  - The beginning and ending of each exclosure (using a different color fluorescent spray paint)

We can use the GPS to navigate back to each exclosure to conduct these activities

Harvest	July – Early August

Yield mapping system (YMS)

- Set up the options in the data logger of the YMS
    - o Species/cultivar
    - o Field name
    - o Unit should be pounds per acre (not bushels)
    - o Flagging (exclosures, weeds, bare spots)

Flag ID	Description
1	Inside exclosure
2	Bare spots
3	Weeds

- Instruct combine drivers
    - o Flagging options should be written and kept inside the combine cab
    - o Location on the ground (map)

- Combine calibration: calibration data should be recorded for each combine and trial

Combine Identification	Trial Number	Reading (YMS)	Actual weight	Difference (+/-)

Post Harvest	August

- Record actual yield per field (total field yield). This information is useful in:
    - Determining the variability of the YMS
    - Comparing GreenStar to AgLeader System

- As soon as field is harvested, download the yield data from card.

- Export data as ASCII format

GIS / Statistical analysis

- GIS analysis
    - Spatial scale yield maps
        - Intensity of goose grazing (heavy, moderate, no grazing)
        - Soil type
        - Weed infestation
        - Water damage
    - Temporal scale yield maps
        - Areas impacted only early in the season (January/February)
        - Areas impacted late in the season (Mid-March through end of April)
        - Areas impacted continuously

- Statistical analysis
    - Paired Plots
    - Area comparisons (grazed versus exclosures or ungrazed areas as appropriate)

- Write final report
    - Summarize findings