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DOMESTIC GEESE: BIOLOGICAL WEED CONTROL IN AN AGRICULTURAL SETTING[1]

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Abstract. Vertebrate herbivores can be effective agents of biological weed control in certain applications. I compared the use of domestic geese for weed control in an agricultural field with the herbicide hexazinone and with hand control. Newly planted spruce seedlings acted as a prototype crop that would be unpalatable to the geese. Trampling by geese led to as much as 47% tree seedling mortality during the 1st yr; this was reduced significantly by either limiting the amount of time the geese spent in the plots or surrounding seedlings with small wire fences. When compared with plots with no weed control, weed control by geese improved the diameter growth of the surviving seedlings by over 100% during the 1st yr of the study, but had no effect in the 2nd yr. The geese controlled a variety of weed species, but were most effective against quackgrass (*Agropyron repens*). However, grazing effectively selected for unpalatable weed species (including pineapple weed, *Matricaria matricarioides,* prostrate knotweed, *Polygonum aviculare,* and wild chamomile, *Tripleurospermum phaeocephalum*) so that by the end of the 2nd yr plots weeded only by geese had 25 times as much cover of unpalatable species as plots with no weed control. In contrast, the herbicide was ineffective against grass and effective against the unpalatable weed species. A successful integrated weed management strategy would thus require combining geese with another method of weed control, and would include measures to prevent crop trampling.

Key words: biological weed control; domestic geese; hexazinone; Picea glauca.

INTRODUCTION

To date, most biological weed control efforts have involved the release of herbivorous insects or fungal or viral pathogens to control weeds spreading over large geographic areas (Samways 1981, Julien 1992). There have been some well-documented successes, such as the control of prickly pear cactus (*Opuntia inermis*) in Australia (Dodd 1940, 1959), the control of tansy ragwort (*Senecio jacobaea*) in the American West (Hawkes 1981, Harris et al. 1984), and the control of St. John's wort (*Hypericum perforatum*) in California and Australia (Huffaker and Kennett 1959, Campbell 1979).

More kinds of organisms are being considered as agents of biological control. Wapshere et al. (1989) recognized four distinct biological control strategies. Classical biocontrol is the introduction of host-specific exotic agents to control an exotic weed on a continuing basis. Inundative biocontrol is the periodic release of mass-produced native agents that control a native weed for a limited time, similar to the application of a herbicide (Harris 1991). Conservative biocontrol involves conservation efforts directed at a weed's natural enemies. The fourth type of biological control defined by Wapshere et al. (1989) is broad-spectrum biocontrol: the artificial manipulation of a natural enemy, typically a vertebrate herbivore, to control weeds.

Grazing by vertebrates is fundamentally different from other biocontrol strategies. In some grazing systems, all the vegetation is controlled, while others require a selective grazer that leaves desirable species undamaged. In many cases, the effectiveness of the agent can be controlled by altering its stocking and the timing of its release (Wapshere 1982). Populations of most vertebrate herbivores are easier to control than are populations of other biocontrol agents, so safety concerns are vastly reduced.

Though most efforts at the biological control of weeds have been made on uncultivated land (Harris 1991), interest in biological control in agricultural ecosystems is increasing (McWorter and Barrentine 1988, Pimentel 1991). Domestic geese are the only vertebrate herbivores known to have been used to control weeds in row crops.

Anecdotal evidence suggests that domestic geese have been used in China to control weeds for hundreds of years. The best-known modern use of geese for weed control was in cotton (Mayton et al. 1945, Kasasian 1969); before the development of the first organic herbicides in the 1940s, 200 000 geese weeded the cotton plantations of California's San Joaquin Valley (Johnson 1960). Geese have been used to weed strawberries (Shoemaker 1978, Doll 1981, Cramer 1992), mint, onions, raspberries, potatoes (Pacific Northwest Weed Control Handbook 1992), and Christmas trees (J. Weyandt-Fulton, *personal communication*).

Grazing by geese has successfully controlled some

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TABLE 1. Weed species in this study. Relative palatability: L = low, M = medium, H = high, U = unpalatable. No designation means species was not common enough to assess palatability.

Scientific name	Relative palatability	Common name
Achillea sibirica Ledeb.	L	yarrow
Agropyron repens (L.) Beauv.	H	quackgrass
Capsella bursa-pastoris (L.) Medic.*	H	shepherd's purse
Chenopodium album L.*	M	common lamb's-quarters
Descurainia sophia (L.) Prantl.		mustard
Epilobium angustifolium L.*	L	fireweed
Epilobium palustre L.		
Geranium erianthum DC.		geranium
Hordeum jubatum L.	H	foxtail barley
Lepidium densiflorum Schrad.*		
Linaria vulgaris Mill.		butter-and-eggs
Matricaria matricarioides (Less.) Porter*	U	pineapple weed
Medicago sativa L.		alfalfa
Plantago major L.*	M	common plantain
Polygonum achoreum Blake		
Polygonum aviculare L.	U	prostrate knotweed
Polygonum convolvulus L.		wild buckwheat
Potentilla norvegica L.	L	rough cinquefoil
Rorripa islandica (Oeder) Borb.		mustard
Stellaria media (L.) Vill.*	H	chickweed
Tripleurospermum phaeocephalum (Rupr.) Pobed.	U	wild chamomile
Vicia cracca L.*	M	vetch

* Species grown in the greenhouse and fed to goslings.

particularly troublesome weeds. Two of the world's most noxious weeds, yellow nutsedge (Mayton et al. 1945, Holm et al. 1977) and water hyacinths (Ross 1971, Wilson et al. 1977, Pieterse 1978, Damron and Wilson 1983) have been controlled by domestic geese. Geese may be best suited for weed control in situations where herbicide use is particularly problematic. During a 5-yr injunction against the use of herbicides on federal lands, domestic geese were used to weed transplant beds in the federal tree seedling nursery at Wind River, Washington (D. Dutton, *personal communication*).

Little information is available on the practical aspects of managing geese for weed control; what information there is comes primarily from unpublished reports and conversations with growers who use them. Young geese are typically used because they are thought to be more active foragers than mature birds. Geese can be herded slowly through large fields; in small areas they can be allowed to forage on their own. In the latter case, they must be protected from predators. Fields must be fenced, and if raptors are a problem, the flock must be kept in a covered pen at night. In strawberry fields, water is sometimes placed at one end of the row and commercial feed at the other, encouraging the geese to walk back and forth, eating weeds as they go (Shoemaker 1978). The flock should have access to only a limited amount of supplemental feed, as moderate hunger stress encourages grazing.

This study compared four methods of weed control in an agricultural field: (1) geese, (2) geese with supplemental hand control of unpalatable species, (3) the herbicide hexazinone, and (4) hand control by hoeing. Young white spruce (*Picea glauca* Moench. Voss) seedlings were chosen as the test crop because they were unlikely to be palatable to geese and because Christmas tree farms and seedling nurseries are among the potential users of this type of weed control.

METHODS

The study was conducted at the University of Alaska Fairbanks Agriculture and Forestry Experiment Station Farm (64°53′ N, 148°0′ W). The site has been managed for agricultural experimentation since the 1930s, and soils contain large populations of the seeds and vegetative propagules of a variety of common agricultural weeds (Table 1). The soil is Tanana silt loam, a loamy, mixed, nonacid Pergelic Cryaquept (Rieger et al. 1963, Soil Conservation Service 1975). Though growing seasons in interior Alaska are short, usually lasting ≈90 d from 1 June to 1 September, the two growing seasons of this study ranged from even shorter (1992, 80 d) to unusually long (1993, 125 d).

The experimental design was a randomized complete block, with four blocks each containing five treatment plots (3.6 × 22.6 m) and one holding pen. The same treatment was assigned to the same plots for both years of the study. In the fall of 1991, the study area was tilled and each plot planted with 20 1-yr-old containerized white spruce seedlings in two rows of 10 at 1.8-m spacing. This spacing is recommended for white spruce Christmas tree production in Alaska (Gasbarro et al. 1984). At planting, seedlings ranged in height from 16 to 21 cm.

Twelve 2-d-old White China goslings were purchased from a commercial hatchery in April of each year. They were fed poultry starter and were given several flats of young greenhouse-grown weeds daily (Table 1). The weeds were rapidly eaten.

At 5–6 wk, the flock was separated into four groups of three birds each; one group was assigned at random to each block in the field experiment. They were released into the field plots as early as weather allowed: 12 June in 1992 and 26 May in 1993. Once in the field plots, they were allowed to forage on their own, and were given a limited amount of supplemental commercial feed daily. The object was to maintain a level of hunger stress that would encourage them to forage for weeds, but not one that would cause them to become undernourished. Toward that end, I used weekly body mass measurements to determine how much commercial feed to give each group. If a goose did not gain mass from one week to the next, the amount of grain its group received was increased slightly. Plots were fenced with 1.2 m high wire fencing, had a plywood shelter at one end, and waterers at both ends.

Geese (G) and geese with hand control (GHC) treatments

During the field trials, the geese in each block were given access to either the geese (G) or the geese with hand control (GHC) treatment plots on alternate weeks. I based decisions on whether to allow access at the start of the week, and whether to continue to keep geese in the plot, on weed surveys done every Monday, Wednesday, and Friday. Surveys involved estimating percent cover on three randomly located 1-m^2 subplots in each treatment plot. In order for a group of geese to be moved into a plot at the start of any given week, or for them to remain in the plot after the Wednesday and Friday surveys, the average cover of palatable species (defined below) in the plot had to surpass a threshold. For the 1st yr of the study a threshold of weedy cover of 5% was used. Because of substantial seedling mortality due to trampling that year, I increased the threshold to 15% for the 2nd yr. If a weed survey indicated an average cover of palatable species less than the threshold value, the geese in that block were moved into their holding pen until the start of the next week.

The purpose of this treatment structure was to mimic one aspect of an operational environment. Under operational conditions, geese would be introduced to a field several times over the course of a growing season, and removed as soon as they had eaten the available weedy forage. The threshold was an objective means of determining when geese should be put into (and taken out of) a plot.

During the 1st wk in the field plots, food preferences among the geese became readily apparent. Two weed species (wild chamomile, *Tripleurospermum phaeocephalum,* and prostrate knotweed, *Polygonum aviculare*) were not eaten, even when they were the only food available. Pineapple weed (*Matricaria matricarioides*), which had been readily eaten from greenhouse flats, was clearly not preferred. Small pineapple weed plants were eaten, but the geese would not eat them if the plants were larger than ≈5 cm in diameter.

Consequently, wild chamomile, prostrate knotweed, and pineapple weed >5 cm were defined, for the purposes of this experiment, as "unpalatable." Decisions about releasing geese into G and GHC treatment plots were based on estimates of percent cover of palatable species only. In the GHC treatment plots, only unpalatable species were hoed by hand several times during the course of each growing season.

Seedlings that had died during the 1st yr of the study were replaced at the start of the 2nd yr. At that time, half of the seedlings in plots weeded by geese were surrounded with 30 cm tall wire fences.

Herbicide (H) treatment

Herbicide applications were made in late May of each year, just before bud-break on the tree seedlings. Hexazinone, a general-use herbicide recommended for weed control in Christmas trees (Pacific Northwest Weed Control Handbook 1992; M. Newton, *personal communication*), was applied with a backpack sprayer. In 1992 an application rate of 1.12 kg/ha (1 lb/ac); powder formulation, 90% active ingredient, in 120 L H_2O/ha was used. By 1993, recommendations for the use of hexazinone in white spruce had changed, and the application rate was reduced to 0.84 kg/ha (0.75 lb/ac). Spraying was done in calm weather, with the spraying wand held close to the ground to minimize drift.

Hand control (HC) treatment

Twice during the 1992 growing season, and 3 times during 1993, all weeds in each hand control (HC) treatment plot were hoed up and left in the plot. Hoeing was done on the same dates in the HC and GHC plots.

Measurements

The height and basal diameter of each seedling was recorded at the beginning and end of each growing season. Diameter was measured just above the root collar. Though seedlings trampled the 1st yr were replaced at the start of the second, the analysis of tree growth was restricted to include only trees that had been planted at the start of the study, and which survived the entire study. This prevented combining seedlings of different ages into a single growth analysis. Because of variation in seedling size at planting, relative growth rates (Hunt 1990) were used in the analysis. Both the seedlings planted the 1st yr as well as the replacement seedlings planted the 2nd yr were used in the analysis of mortality.

A comprehensive weed assessment was done weekly in all 20 treatment and no weed control (NWC) plots. The first weed assessment in 1992 was on 15 June; in 1993 the first assessment was on 26 May. The total cover, cover of grass, and cover of unpalatable species was estimated visually in three 1-m^2 subplots centered on planted seedlings for each treatment plot. Estimates were made by the same person throughout the course

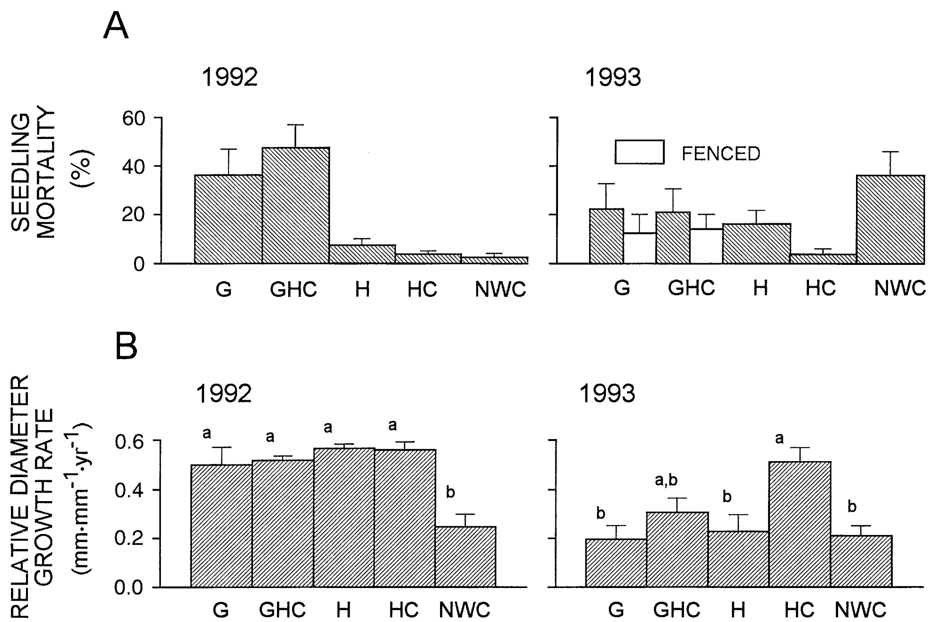

FIG. 1. (A) Percent tree seedling mortality from all sources (mean ± 1 SE), including both trees planted in fall 1991, and replacements planted in spring 1993. (B) Relative diameter growth rates of tree seedlings (mean ± 1 SE) planted in fall of 1991 over the two growing seasons of this study. Means accompanied by the same letter are not significantly ($P \geq 0.05$) different using Scheffé's test for comparison of means. G = geese, GHC = geese with hand control, H = herbicide, HC = hand control, NWC = no weed control.

of the study, after practice with calibration diagrams (Terry and Chilingar 1955). The number of broadleaf weeds were counted in a 0.25-m^2 portion of the subplot, and the number of species in the subplot recorded. The three seedlings where subplots were centered were randomly selected (with replacement) each week.

Concerns about the possible effects of geese on soil nitrogen loading and soil compaction prompted soil sampling and analysis. In June and September 1992, soil samples were collected from just below 20 cm depth in the GHC and NWC plots. In 1993 samples were collected in the 5–7 cm depth zone as well as just below 20 cm, and were collected in the G rather than GHC plots (to avoid any compaction that might occur during hand control). In both years, three samples were collected in each of two locations in each plot; the three samples were pooled before laboratory analysis. Soils were air-dried and passed through a 2-mm mesh sieve. Total nitrogen content was determined by the standard semimicro-Kjeldahl procedure (Bremner 1982). Phosphorus was extracted with a Mehlich 3 extract (Mehlich 1982, Michaelson et al. 1987) and analyzed on an autoanalyzer. Organic matter content was determined by loss-on-ignition (Black 1982).

Bulk density determinations were made at the same times and locations within the plots as soil sample collections. Because geese would be likely to cause only shallow compaction, bulk density samples were collected from the surface 2 cm of soil by pressing a sharp-edged metal ring into the soil. A spatula was used to lift the ring and the soil inside it and to scrape both the top and bottom surfaces until smooth and even with ring edges. Samples were oven-dried and weighed.

Analyses

During this experiment, weed populations changed markedly from week to week as they grew, were grazed on, and were hoed up. The sampling scheme precluded a repeated-measures analysis. For each weed control treatment, I plotted weed cover over time, and used the area under each curve as a cumulative index of weed intensity during that growing season.

Weed intensity indices, seedling growth, and soil chemistry data were subjected to analyses of variance for a randomized complete block design with a one-way structure of treatments using the SAS statistical analysis package for personal computers (SAS 1990). Scheffé's multiple comparison procedure was used; a probability value of <0.05 was considered statistically significant.

Though information on the costs of using geese for weed control is needed, the scale of this study was too small to permit an economic analysis.

RESULTS

Tree seedling growth and mortality

The effects of the weed control treatments on seedling mortality and growth varied from the 1st yr of the study to the 2nd yr. In 1992, seedling mortality in the G and GHC plots was high (Fig. 1A), and most of it could be attributed to trampling by geese. Mortality

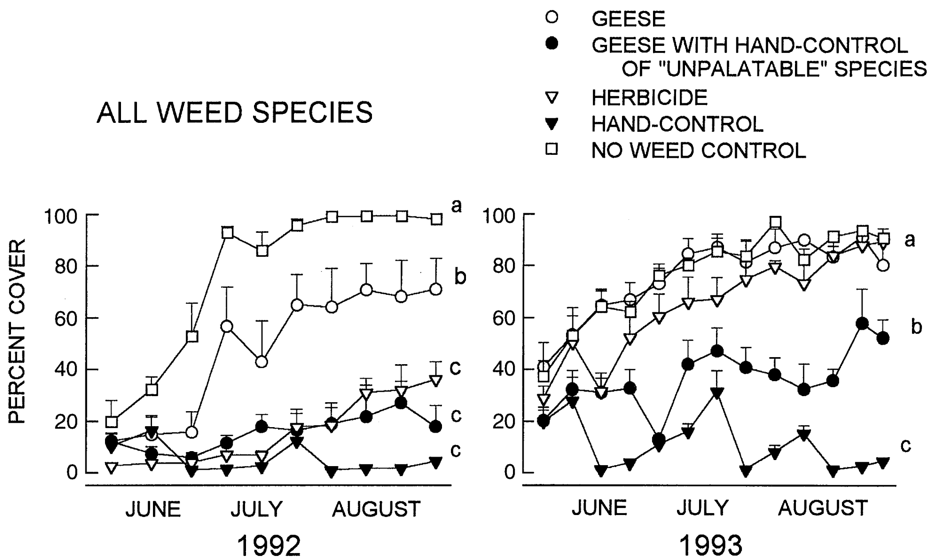

FIG. 2. Estimated percent cover of all weed species (mean ± 1 SE) over the two growing seasons of this study. Significance testing was done on the area under each curve as a cumulative measure of weed intensity during each growing season.

levels increased with the amount of time the geese spent in treatment plots and with the seedling's proximity to the plywood shelter. Mortality was reduced in 1993, both among seedlings that had been surrounded with protective wire fences and those that were left unfenced. Mortality in the G and GHC plots that was not due to trampling could not be attributed to any single cause. In the plots with no weed control, mortality increased substantially in 1993.

In 1992, all four treatments significantly improved the diameter growth of surviving seedlings relative to the seedlings in plots with no weed control (Fig. 1B). There was no difference in seedling diameter growth between the G and the GHC treatments. In 1993, however, only the hand control treatment significantly improved seedling diameter growth relative to trees in plots with no weed control. Relative diameter growth rates of seedlings in the G, GHC, and H plots declined from 1992 to 1993. None of the weed control treatments significantly affected the relative height growth of the seedlings in either year.

Weed population dynamics

Weed population trends that began in 1992 continued and were amplified in 1993. In 1992, all four weed-control treatments significantly reduced total weed cover (Fig. 2) when compared with plots with no weed control. Because of the early spring in 1993, weed control treatments and weed assessments were begun 3 wk earlier that year than they had been in 1992. Even so, at the first weed assessment in 1993, weed cover was already about twice what it had been at the first assessment in 1992. This trend of increased weed cover continued through the growing season. Only the hand control treatment maintained 1993 weed populations at levels similar to the year before.

Treatments used in this study had particularly striking effects on two groups of weed species: the group defined early in 1992 as "unpalatable" and grasses. Weeding by geese alone effectively selected for unpalatable species, which in 1992 in G plots had a weed intensity index 37% higher than in plots with no weed control (Fig. 3). This trend became statistically significant in 1993, as the importance of unpalatable species in the NWC plots continued to decline. In contrast, the herbicide was consistently effective against unpalatable species.

Grasses (mostly quackgrass, *Agropyron repens,* but also foxtail barley, *Hordeum jubatum*) were highly palatable forage: both treatments involving geese kept grass cover near zero for the duration of the study (Fig. 4). Grass cover reached ≈35% in plots with no weed control by the end of 1992, and nearly 50% the next year. The herbicide treatment was ineffective against grass; though it kept grass cover low through the first half of the 1992 growing season, the cumulative grass intensity index in herbicide-treated plots in either year was no different than that in plots with no weed control.

As the two seasons progressed, distinct boundaries were visible between herbicide-treated plots and adjoining plots. This indicated that the herbicide had neither drifted at the time of spraying nor moved laterally after being absorbed by the soil. By the final weed assessment in 1992, 2.5 mo after application, broadleaf weeds had begun to germinate in the herbicide-treated plots, suggesting either that the herbicide was breaking down or that it was moving lower in the soil column.

Soil nutrient status and compaction

The geese produced a substantial amount of feces. Its distribution on the soil surface was uneven, with the heaviest coverage near the plywood shelters. But

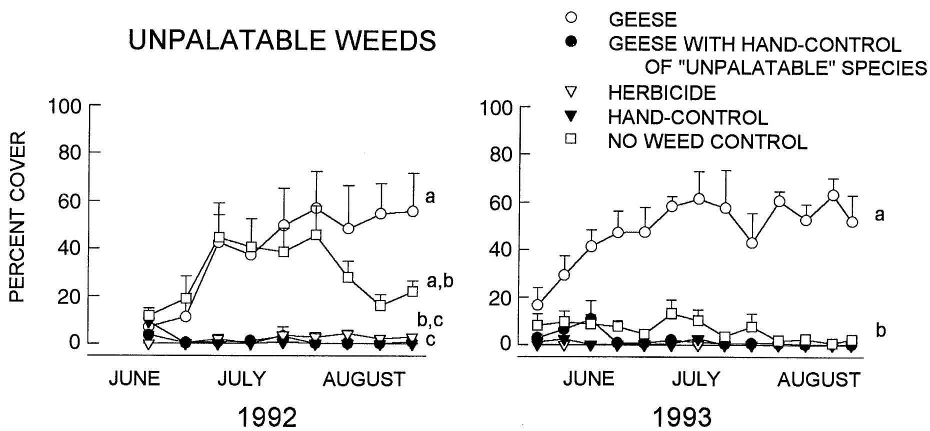

FIG. 3. Estimated percent cover of weed species defined as "unpalatable" (mean ± 1 SE) over the two growing seasons of this study. Significance testing was done on the area under each curve as a cumulative measure of weed intensity during each growing season.

by the end of the second growing season this impact on the soil surface was not apparent below the surface; there was no difference in soil chemistry between goose-weeded plots and plots receiving no weed control at either 5 or 20 cm depth (Table 2). Higher levels of nutrients and organic matter were found at 5 cm than at 20 cm, but this was consistent across treatments. There was no change in bulk density in either the G, GHC, or the NWC plots over either summer.

Geese

The amount of time the geese spent in the treatment plots (as opposed to the holding pens) varied by group, and may have been related to sex ratio differences in the different groups. Male geese were larger and appeared to be more aggressive foragers. In 1992, a group that (by chance) was made up of three males required the fewest days to keep weed cover below the 5% criterion (22 d out of a possible 71 d), while a group made up of three females required the most days (59 d out of 71 d).

Minor mass losses were recorded on several occasions among several different birds, indicating that the geese were in fact mildly hunger stressed during the experiment. By the end of the 1992 growing season, when the geese in that year's flock were 19 wk old, their mean mass was 4.2 kg.

DISCUSSION

A proper assessment of the response of tree seedlings to different treatment regimes requires consideration of both growth and mortality, yet methods for analyzing these responses together are not well developed (Binkley and Arthur 1993). In this study, I restricted the seedling growth analysis to trees that were planted at the beginning and survived to the end, in order to avoid analyzing trees of different ages together. But one of the consequences of separating growth and mortality is that it can shift the focus toward growth. In this study, however, mortality due to trampling by geese was the most significant impact that any weed control treatment had on the crop.

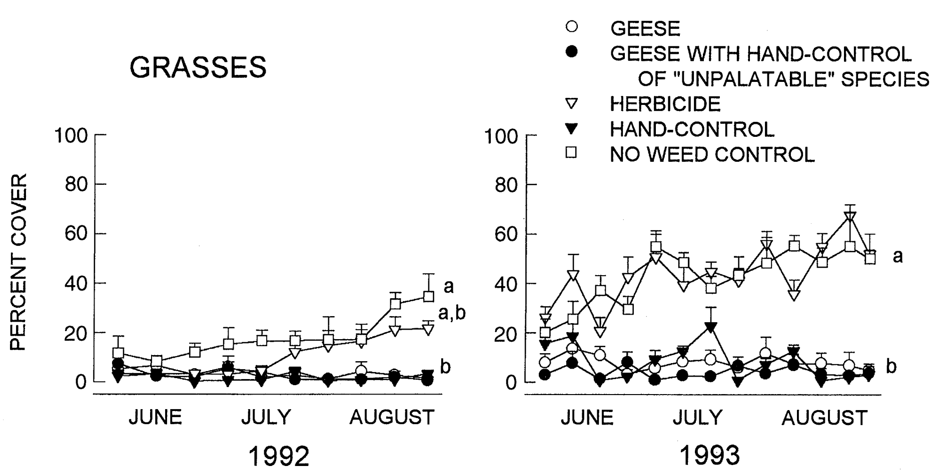

FIG. 4. Estimated percent cover of grass (mean ± 1 SE) over the two growing seasons of this study. Significance testing was done on the area under each curve as a cumulative measure of weed intensity during each growing season.

TABLE 2. Soil nutrient concentrations and organic matter content (mean, ± 1 SE in parentheses) in the G (geese) and NWC (no weed control) treatment plots during the 1993 growing season. Each value is the mean of four plot values; the sample from each plot was pooled from three locations within the plot.

Treatment	Depth (cm)	Season	Total N (%)	Total P (%)	SOM (%)
G	5	Spring	0.34 (0.01)	0.10 (0.002)	9.55 (0.54)
		Fall	0.33 (0.01)	0.10 (0.001)	9.17 (0.60)
	20	Spring	0.22 (0.01)	0.07 (0.005)	7.21 (0.39)
		Fall	0.25 (0.00)	0.07 (0.001)	7.78 (0.22)
NWC	5	Spring	0.34 (0.01)	0.10 (0.001)	9.69 (0.70)
		Fall	0.34 (0.01)	0.10 (0.004)	9.49 (0.66)
	20	Spring	0.21 (0.02)	0.07 (0.002)	6.58 (0.52)
		Fall	0.26 (0.01	0.07 (0.001)	7.72 (0.41)

Only one description of the use of geese for weed control mentions the problem of trampling (Hansen and Netzer 1984). In that study, crop tree seedlings <30 cm tall were vulnerable to being trampled. The wire fences installed in the 2nd yr of this study reduced trampling, but reducing the amount of time the geese spent in the plots (by using a higher weedy cover threshold) was more effective. With a higher threshold, the geese were taken out of the plots sooner, and had less opportunity to do damage. For larger scale operations involving crops vulnerable to trampling, periodically herding a large flock of hungry geese through a field minimizes the time spent in the field and ensures that most of the time is spent grazing. Alternately, using larger planting stock, or delaying the introduction of the geese until the crop plants are large, would make a crop less vulnerable to trampling. Geese could be allowed to forage at length. Such a strategy has been used in perennial crops such as cane berries and Christmas trees.

Virtually all the trees considered in the analysis of growth grew less the 2nd yr than the 1st. This decline is likely due to the increase in weedy cover that occurred in most plots from the 1st yr to the 2nd yr. Several factors account for the increase. The summer of 1993 was an unusually long growing season, and marked the 2nd yr since the site had been tilled. During that time perennial weeds (notably fireweed and quackgrass) increased their occupation of the site. In addition, in 1993 the herbicide application rate was reduced and the threshold of weedy cover in G and GHC plots was increased relative to 1992. Taken together, these factors led to substantially more weedy cover overall in 1993, and to reduced tree seedling growth in all but the hand control plots. The fact that trees grew well in the hand control plots both years suggests that transplant shock was not a major factor affecting the seedlings in this study. Finally, the lack of a seedling height growth response in any of the treatments is not surprising. In trees, height growth is much less affected by competition for resources than is diameter growth (Lanner 1985).

The weed control treatments used in this study led to dramatic shifts in weed species composition in just two growing seasons. In grazed plots, unpalatable weeds quickly increased in importance, while in the absence of grazing, those same species virtually disappeared from the mixture. A similar effect in the opposite direction occurred in the herbicide-treated plots, which became dominated by quackgrass, the species least affected by spraying.

But grazing did not remove all traces of palatable plants from the plots. Often, the primary effect of weed biocontrol is to reduce the competitive ability of a weed rather than to kill it (Harris 1991). That was the case here: rather than pulling and eating whole plants, the geese tended to strip the leaves from the stems. The treatment plots where geese were used were populated by many bare and partially stripped stems. Quackgrass was undoubtedly the preferred species: after stripping off the grass blades, the geese ate many of the tillers down to the ground, and dug around in the soil with their bills for roots and rhizomes.

A subjective assessment of the relative palatability of the different weeds in this study is included in Table 1. The palatability of plant tissue depends on a number of factors, including the presence of deterrent secondary metabolites, the nutritional quality of the tissue, and its toughness (Bryant and Kuropat 1980). Because these factors change over the course of a growing season, the palatable/unpalatable dichotomy used in this study was an oversimplification. The management of geese for weed control must take into account not only the weed species present and the crop's vulnerability, but also the phenology of the weeds and the potential for their palatability to change.

If the use of geese were continued in future growing seasons, unpalatable species would continue to increase in importance. The results of this study show that where unpalatable species are present, grazing cannot be relied on as the sole method of weed control for more than one growing season. Combining the use of geese with chemical weed control could result in a broader spectrum of control and would reduce the amount of herbicide needed. Or, geese could be used in conjunction with hand control measures. In this study, the lack of a significant difference in 1993 seedling growth between the G and GHC treatments reflects the fact that only weed species designated as unpalatable were hoed up. Under operational conditions there need be no such restrictions. At Wind River Nursery, a large flock of geese was herded slowly through the nursery by workers carrying hoes, who hoed up any weeds the geese left (D. Dutton, *personal communication*). Such integrated weed management is gaining acceptance in agriculture (Wapshere et al. 1989).

By the end of the second growing season, grazing by geese had had no significant effects on the soil. Even areas that were heavily used (e.g., around the plywood shelters) showed no compaction of the surface soil layers. Though goose feces are rich in nutrients (Bazely and Jeffries 1985), there was no effect on soil chemistry at 5 or 20 cm depth. The time required for nutrients from feces deposited on the soil surface to affect soil chemistry or crop yield could depend on a variety of factors, including climate, volatilization rates, soil characteristics, and crop and weed cover, uptake rates, and rooting depths. In annual crops, tillage would mix feces into the rooting zone annually, possibly making nutrients available sooner than in perennial crops. Though not a factor in this study, the incorporation of feces into cropping systems may be one of the benefits of using grazers for weed control.

The desire to reduce the use of pesticides is one of the driving forces behind the biological control movement, and attitudes on the justification of biological control measures are changing. The belief that biological control is only justified if it produces a greater rate of return on investment than other means of control (Harris 1984) is no longer universally accepted. An alternative view is that the usefulness of a biocontrol method should be gauged by the amount of pesticide it displaces (Harris 1991). But the problems involved in using geese for weed control are significant: the time and expense required to manage a flock and protect it from predators, the fact that the crop must be protected from trampling, and the need for supplemental weed control measures. Whether the amount of herbicide displaced by the use of geese justifies those burdens on a grower will vary with the crop, the weeds, and the amount and kind of herbicide needed to control them.

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This publication refers to pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended.

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