Management Strategies for the Control of Northern Pocket Gophers (*Thomomys talpoides*) in Agro-Manitoba

by Marcia DeWandel

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MANAGEMENT STRATEGIES FOR THE CONTROL OF NORTHERN POCKET GOPHERS (*Thomomys talpoides*) IN AGRO-MANITOBA

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ABSTRACT

Damages due to the activities of the northern pocket gopher (*Thomomys talpoides*) are estimated to cost Manitoba forage producers over $15 million annually, with similar losses estimated in Saskatchewan and Alberta. Losses across North America likely total several hundred million dollars annually. Pocket gophers consume forage plants below and above ground, and excavate subterranean tunnel systems, bringing excess soil to the surface, producing mounds. These mounds suffocate crops, damage machinery and cause immeasurable frustration for prairie forage producers. Objectives of this study were to (1) determine loss in alfalfa yield due to pocket gopher consumption and damage, and whether this loss is economically significant; (2) analyse the effectiveness of grass, cultivated and treated buffer zones of varying widths on the control of pocket gopher invasion; and (3) provide a method to determine the most cost-effective option(s) to farmers to control pocket gopher damage. Decreases in harvestable yield on plots occupied by pocket gophers were significant, with average losses of 22.9%. Effectiveness of buffer zones varied between treatments; however, their use as configured in this study cannot be recommended at this time. A management strategy is outlined, incorporating the average yield loss of 22.9% and the cumulative costs of three control options; leaving the stand untreated, applying a rodenticide and re-establishing the stand every three years, over a period of 5 harvest years. When compared to the costs of no treatment, applying a rodenticide proved to be an economically viable option on the study site, whereas the costs of re-establishing the stand every three years was economically inefficient.

ACKNOWLEDGEMENTS

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The conclusions of this study are for the benefit of the forage producers in Manitoba. Through the funding received from the MFC, pocket gopher research in Manitoba will provide information to farmers across the country. Within the province, CMAAS, Manitoba Agriculture, and the Prairie Farm Rehabilitation Administration (PFRA), continue to explore new research directions and potential strategies to assist in the search for management options.

The field component of this study would not have been possible without the assistance and cooperation of the VanderKroon family. Their commitment, knowledge, cooperation and enthusiasm was greatly appreciated! Special thanks is also extended to Roger Bruneau and the Ste. Claude Pocket Gopher Committee who assisted by providing valuable economic information.

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Thanks and appreciation is extended to my committee: George Bonnefoy, project coordinator, whose loyalty to the project and drive to find solutions were never ending; Jack Dubois, the editor-in-chief with a passion for pocket gophers, who always found time to help me view the project from a "big picture" standpoint; Dr. Rick Baydack, student advisor, who provided the guidance and encouragement throughout the practicum process; Dave Campbell, crop specialist, who provided input on behalf of Manitoba Agriculture and forage producers across the province; and Dr. Betsy Troutt, economist and e-mail correspondent, whose enthusiasm and expertise assisted in putting the pieces of the project together. Together, their combined areas of expertise were invaluable to the project and I thank them for their time and contributions.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

Wildlife damage control has become an integral part of wildlife management. Intensified land-use practices and an expanding human population have produced conflicts with various species. Due to the difficulties associated with organizing, implementing and sustaining rodent damage management programs, agricultural pest control (namely weeds, insects and disease) has taken precedence in North America (Elias 1988). Within Manitoba, agricultural damages caused by the northern pocket gopher (*Thomomys talpoides*) require immediate attention, as estimated economic losses are rising with growing rodent populations.

The northern pocket gopher (*Thomomys talpoides*), one of the 1600 species in the order Rodentia, is a relatively small secretive animal (Nowak 1991) valued ecologically as a food source for several species, and in the modification of plant succession and species composition (Witmar et al. 1995). Contrary to its positive function in the ecosystem, the pocket gopher is most noted for economic problems arising from human interaction: damage to forage crops, pastures and nursery trees.

Found throughout agricultural regions in Manitoba, the northern pocket gopher is a fossorial herbivore distinguished by the presence of two fur-lined cheek pockets used for food storage (Case 1983). Although the pocket gopher feeds on a variety of native plants, economic damage is seen primarily in monocultures of concentrated agricultural crops, such as alfalfa (*Medicago sativa*) (Elias 1988, Quick 1991). In the process of building subterranean burrow systems to access succulent root growth, excess soil is pushed to the surface, producing mounds. The rate of mound building is highly variable and depends primarily on soil texture and moisture conditions (Andersen and MacMahon 1981, Case 1983). Richens (1966) data estimates that the *T. talpoides* burrowing rate is approximately 3 cm/min. This activity brings an estimated 1130 kg of soil per gopher to the surface each year (Case 1983). These surface mounds plug and dull swathing knives and decrease harvestable yields, thereby lowering revenues (Mupondwa 1993). Collective losses due to pocket gopher damage have previously been estimated at $15 million annually (Manitoba Agriculture 1987).

In North America, documentation of the effects of pocket gopher damage and subsequent management techniques date as far back as 1923 (Tiejen 1973). The prairie landscape has changed since the first encounters of farmers with the northern pocket gopher. Prior to European settlement, Manitoba's Red River Valley was a mosaic of prairie grasslands and fresh water lakes. Taking advantage of the rich organic soils, early settlers transformed the valley into prime agricultural land. Natural ecosystems, particularly the diverse plant and animal communities, were drastically altered. Monoculture, coupled with a decrease in natural predators, may have contributed to the increase in pocket gopher populations over time. At present, the northern pocket gopher is estimated to occupy over 500 thousand hectares across agro-Manitoba.

The Manitoba Forage Council launched a Northern Pocket Gopher Control study in 1991. Two control mechanisms were tested, trapping and rodenticides (Deniset 1994) with pocket gopher biology comprising a portion of the study as well. Documented conclusions indicated that cost-effective trapping would only be seen on small acreages or home gardens, as the labour component required for efficiency was too intensive. Seventy-five percent of the rodenticides tested, however, proved somewhat effective during either spring or fall applications. Deniset (1994) suggested that annual rodenticide application, with a purpose-built machine, should be used until populations are sufficiently reduced. Both control methods, trapping and rodenticide use, could not prevent gopher re-invasion within months of treatment and created a great deal of frustration for producers.

Research on the northern pocket gopher in Alberta has provided further information on effective control methods (Proulx 1993). Tentative conclusions on bait testing in Alberta bait tests show that pocket gophers prefer soft foods, over hard and appear to have the ability to detect poison in baits. Although it is very labour intensive, Proulx (1993) suggests that trapping is the only reasonable means to control pocket gophers. Further results of these studies, and others, will be reviewed in the following chapter.

A second stage of the Manitoba Forage Council Pocket Gopher Control Study was launched in June, 1994, focusing primarily on the development of a cost-effective management strategy. This report provides information on the results of these investigations.

1.1 The Problem

Forage producers across the province encounter numerous problems resulting from pocket gopher activity. Reduced crop yield and quality, pre-mature cultivation, machine damage and soil/water erosion are among the largest contributors to revenue loss and frustration. Trapping and rodenticide application have been somewhat effective in treating gopher populations, however, effective strategies to *maintain* low populations have yet to be determined. A management strategy, combining methods of control, when to use them, and the associated benefits and costs, is required.

1.2 Objectives

The primary objective of this project was to develop and promote the use of a management strategy for control of northern pocket gophers in forage crops. Specific objectives were:

1. to determine loss in alfalfa yield due to pocket gopher consumption and damage and whether this loss is economically significant.

2. to analyse the effectiveness of various treatments and widths of buffer zones on the control of pocket gopher re-invasion to alfalfa fields.

3. to recommend cost effective options to farmers with respect to pocket gopher damage and control.

1.3 Hypothesis

1. Alfalfa yield is decreased due to the activities of the northern pocket gopher in fields where they occur compared to fields where they do not.

2. After initial populations have been managed by means of trapping or rodenticides, provision of a buffer zone around fields will effectively lower the rate of gopher re-invasion.

1.4 Limitations

This study focused on the effects of pocket gopher activity on alfalfa yield, the effectiveness of a buffer strip to deter pocket gophers after initial populations have been managed and the development of a strategy, based on the study results and previous research, aimed at assisting forage producers in making more informed management decisions. Some losses associated with pocket gopher activity are very difficult to measure: extra time and labour in the field, the level of producer frustration during harvest, varying degrees of machine damage, soil/ water erosion, and harvested forage quality losses. Articulating costs associated with these factors would provide forage producers with a more definitive idea of the overall costs of pocket gopher activity in alfalfa fields. In devising a strategy, some of these costs were estimated to provide more informed suggestions for management. Providing hard data on the costs associated with these variables was beyond the scope of the study.

Even more challenging was associating pocket gopher density to related losses on forage fields. In order to determine economic threshold levels (ie. the cost effectiveness of treatments based on the level of infestation of individual fields), a reliable census method for pocket gophers was required. At study commencement, census development was very preliminary, restricting its use as a management tool at that time. The proposed control strategy relies on the use of mound densities as an index to gopher numbers and assumed saturation points (i.e. maximum number of gophers per unit area) as the basis for optimal strategy development.

Development of the eighteen treated plots began in the fall of 1994. The cultivated buffer strips were easily installed, however the grassed and rodenticide zones required specific environmental conditions. The spring and early summer of 1995 were very dry, retarding rodenticide application (moist soils are required) and the germination of grassed buffers. Due to the delay, simultaneous monitoring of buffer effectiveness did not commence until the end of July 1995. Successful buffer establishment and commencement of monitoring in the early spring may have yielded different results.

The buffers were statistically analysed in relation to one another, not to other plots void of buffer strips. Postulations can be made on their overall effectiveness as a control method, however these observations are not backed by concrete statistical testing.

Chapter 2

Literature Review

2.1 The Biological Bases for Management

2.1.1 Distribution and Natural History

The pocket gopher family, *Geomyidae* (*Rodentia*), is broadly distributed from south-central Canada through middle America (Russell 1968). *Geomyidae* is noted as the major vertebrate taxon consuming and storing subterranean plant materials (Andersen and MacMahon 1981). Within this family, *Thomomys* is the most widely distributed genus, with a range extending from the Canadian prairies to northern California (Runnells 1988) (Figure 1).

In Manitoba, two known genera, *Thomomys* and *Geomys* are found. The northern pocket gopher is the only species belonging to the *Thomomys* genus found in agro-Manitoba. The species has 58 subspecies identified, with *Thomomys talpoides rufescens* the subject of this study. As expressed by Dubois (1996), diet-related morphometric variations may explain the relative abundance of subspecies in North America. Over time, morphological modifications have been extensive in geomyids, particularly in body and skull dimensions. Runnells (1988) found that these modifications were a result of adaptations to a burrowing existence, as well as to habitat variations. Smaller pocket gophers seem able to tolerate shallow, compact soils at higher elevations (Kennerly 1954, Miller 1964), whereas larger subspecies are found in nutrient-rich, looser soiled localities (Miller 1964, Hansen and

Reid 1973).

The plains pocket gopher (*Geomys bursarius*), a larger species, is distributed throughout the Eastern Great Plains region of North America (Banfield 1974), extending from the north central States (along the Canadian border) to the Gulf of Mexico (Marsh 1985). In Canada, the plains pocket gopher is extremely localized, restricted to a small area in southeastern Manitoba. Past distribution records by Wrigley and Dubois (1973) indicate that general distribution ranges from a small area east of Manitoba's Red River, and extends north to the Roseau River. As noted by Oberpichler (1989) and Dubois (pers. comm. 1995), the range of the plains pocket gopher is expanding, causing further displacement of *Thomomys* in Manitoba.

Thomomys, widespread throughout the grasslands of southern Manitoba, occupies the area surrounding the *Geomys* range (Figure 2). Comparative histories of both species suggest that *Thomomys* dispersed generally from the southwest, whereas *Geomys* generally moved in from the southeastern United States. The larger *Geomys* was able to exclude *Thomomys* from its preferred habitat. Distributions of both species in Manitoba are considered parapatric (Wrigley and Dubois 1973).

The observed distribution patterns of the plains pocket gopher and the northern pocket gopher evolved along with the vegetation changes that occurred in the North American Great Plains during the Holocene (Wrigley and Dubois 1973). Soil type is not an absolute limiting factor in the dispersal of *Geomys*, as individuals have been found in both sand and glacial till. The tall-grass and the mixed grass prairies are typical habitats (Wrigley and Dubois 1973), however, with the intensive agriculture that has replaced these habitats in agro-Manitoba, forage crops (namely alfalfa) seem to support the largest populations.

The *Geomyidae* family are noted for their adaptability to various habitats. Pocket gopher populations are present in boreal and tropical vegetation areas, as well as locations above the treeline and below sea level. Preferences include areas supporting nutrient rich vegetation (e.i. alfalfa), loose soils, and marginal slopes (Runnells 1988). Pocket gophers have been known to spread into areas modified by clearing and grazing and have crossed barriers as large as the South Saskatchewan River (Adams 1994). The vast distribution range of *Thomomys talpoides* can be attributed to its ability to tolerate both coarse textured and compact soil types (Miller 1964), as well as survive on a variety of vegetation. This great adaptability probably accounts for their wide distribution.

2.1.2 Fossorial Activity

The northern pocket gopher is morphologically and physiologically adapted to fossorial activity. The head is broad and flattened, equipped with small eyes and ears, and long sharp grooved incisor teeth; the shoulders are broad, the short forelimbs are equipped with long claws, the hind legs are weak and the tail is short and relatively hairless (Adams 1994).

Figure 1: Distribution of the northern pocket gopher, *Thomomys talpoides*: 1. *T.t. andersoni*, 2. *T.t. bullatus*, 3. *T.t. cognatus*, 4. *T.t. fuscus*, 5. *T.t. incensus*, 6. *T.t. medius*, **7. *T.t. rufescens***, 8. *T.t. saturatus*, 9. *T.t. segregatus*, 10. *T.t. talpoides* (Banfield 1974)

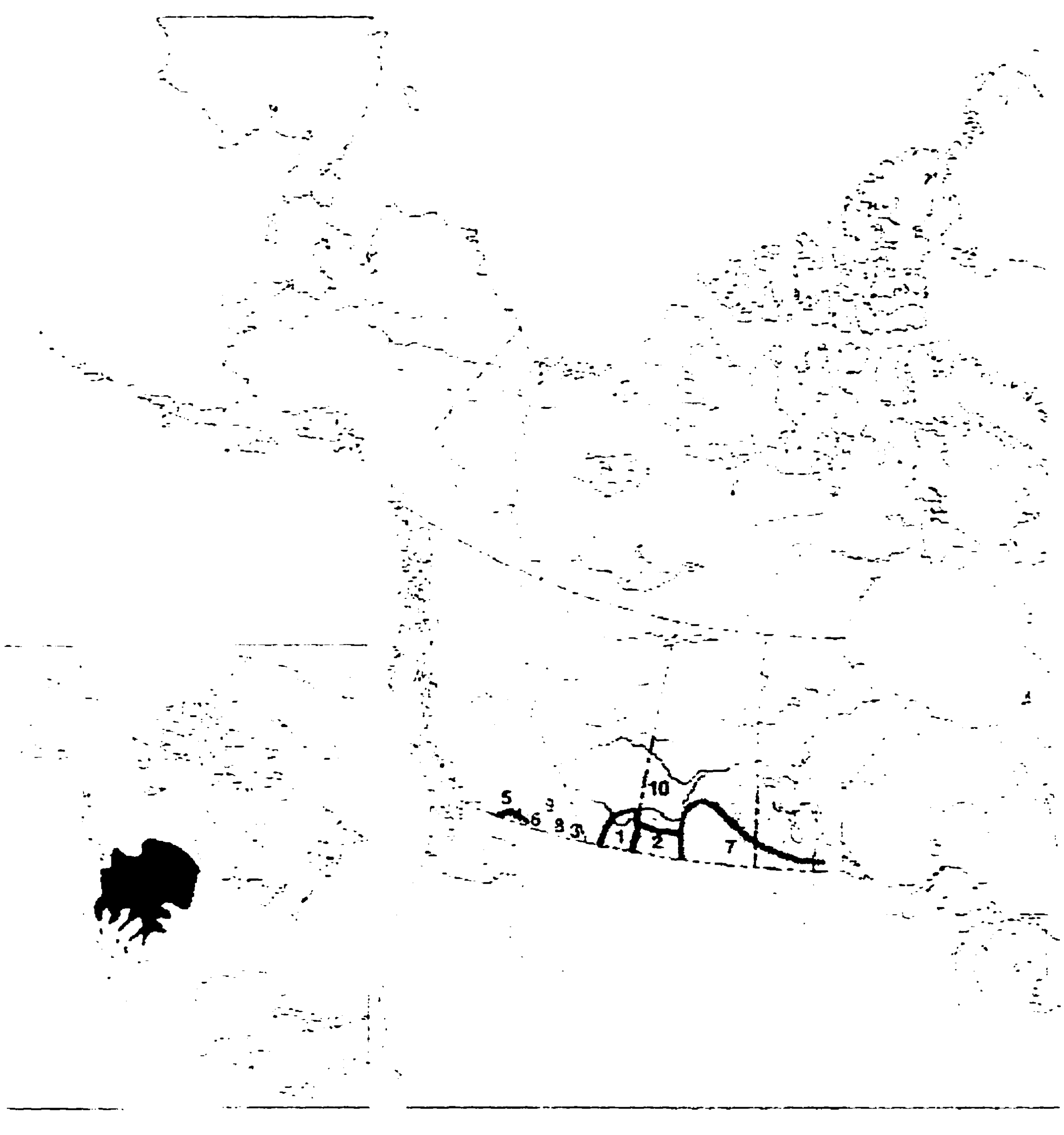
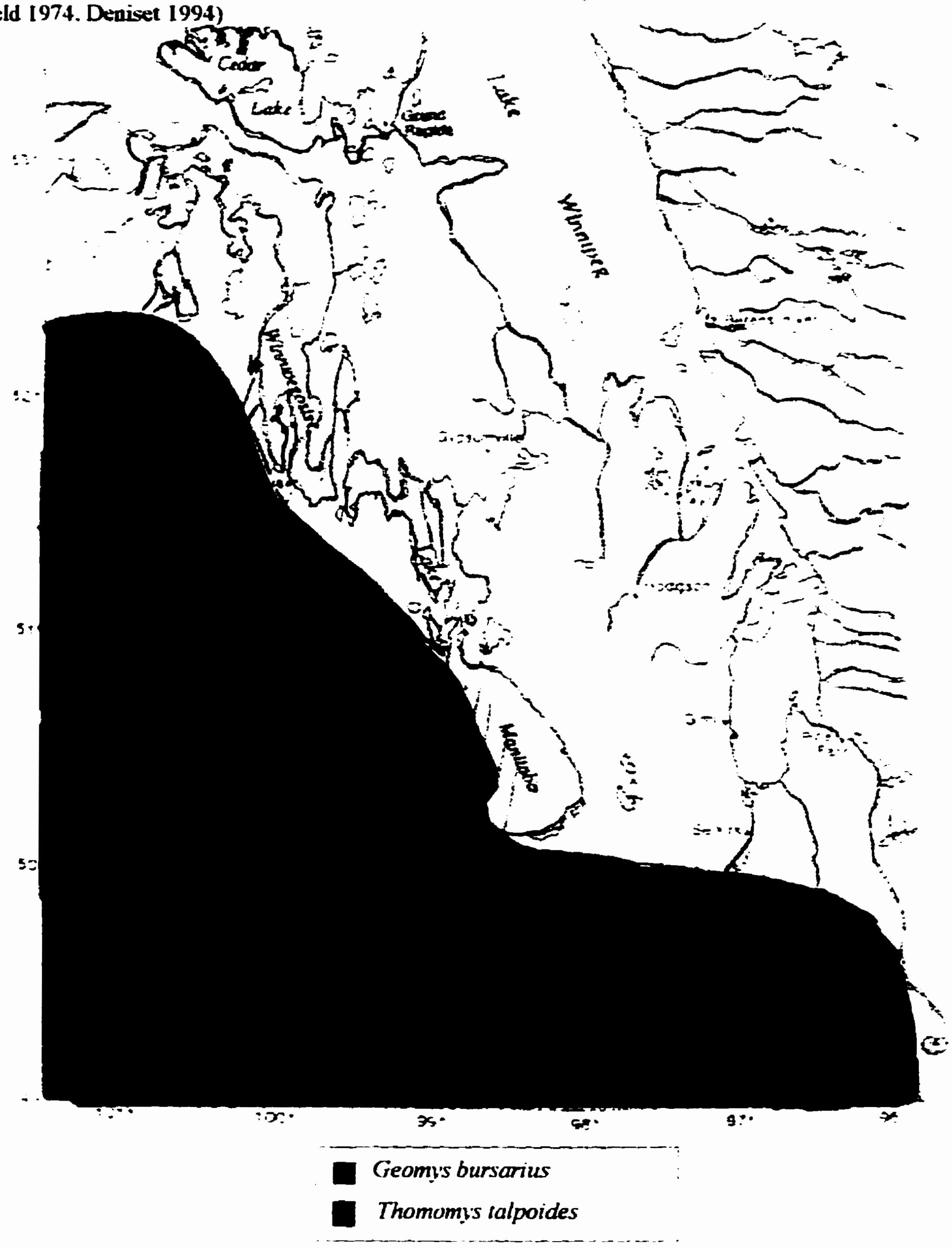


Figure 2: *Geomys* distribution in relation to *Thomomys* in Manitoba
(Banfield 1974. Deniset 1994)

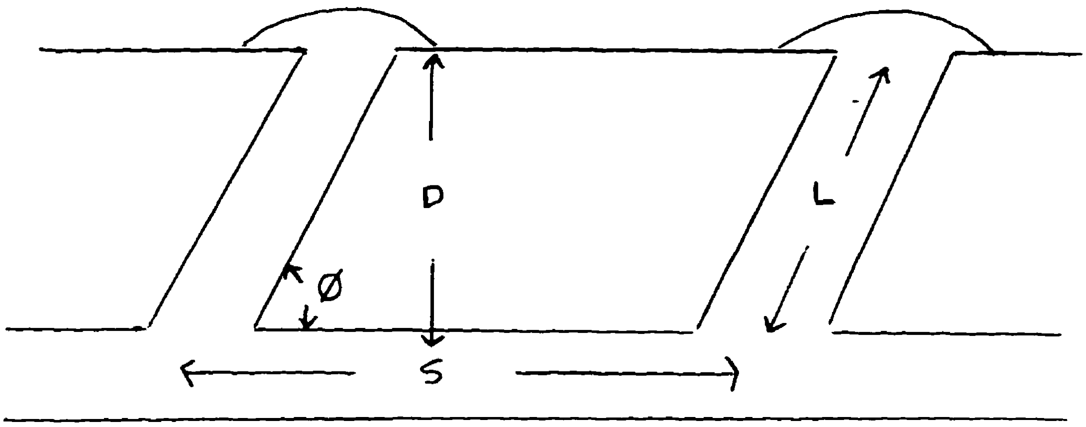


With this well-adapted body type, pocket gophers dig a complex network of shallow tunnels, ranging in depth from 10-40 cm deep (Godfrey 1987). Feeding tunnels constitute over 80% of the total burrow system (Miller 1957, Vleck 1981). Burrow systems are linear and tend to be consistent with a search path to optimize foraging (Tryon 1947, Andersen 1987). They run parallel to the ground surface and are characterized by two types of passages: potholes and laterals (Figure 3). Potholes are short tunnels extending off the main tunnel to the surface whereas laterals are longer and are used to push excavated soil to the surface. Both passages are used in vegetative harvesting at the surface (Vleck 1981). Feeding tunnels in the root zone, range from 30 to 75 m, with an average area encompassed of 110 m^2. This area, considered an individual home range, may vary depending on the food availability in specific localities (Tryon 1947, Godfrey 1987).

Deeper tunnels extending into nesting and food storage chambers are located below the frost line (Godfrey 1987). They range in depth from 45 to 75 cm, providing shelter, protection against predators, food storage and a nesting environment to rear young (Runnells 1988). With a diameter of 20-30 cm, the nest chamber usually has two entrances and consists of a dry mass of shredded grasses. The food chambers are roughly the same diameter and are continually supplied with various roots, stems and shoots (Tryon 1947).

In the process of excavation, excess soil is pushed to the surface, producing crescent-

Figure 3. Diagrammatic sketch of a section of *Thomomys* feeding tunnel.
The two laterals are marked by mounds of soil at their ends on the surface. *D* is depth of main tunnel, *S* the segment length between laterals or between mounds, *L* the lateral length, and ⌀ is the angle of ascent of the lateral (Vleck 1981).



shaped mounds. Case estimates that a single gopher will bring 1130 kg of soil to the surface annually (1983). Besides causing difficulties for forage producers, mound formations contribute beneficially in the regeneration of soils by bringing up sub-surface nutrients and improving soil porosity. The mounds also provide fresh seedbeds for some annuals, weeds and early succession flowering plants, supporting prairie biodiversity (Adam 1994, Deniset 1994).

Accompanying the mounds are two other surface signs that indicate pocket gopher presence. Earth plugs are formed at the end of lateral tunnels, flush with the surface, and are used to seal tunnels that have been excavated to access the surface (Runnells 1988). Soil casts remain on the surface after winter snow melt and are formed as a result of tunnelling activity during the winter months.

Fossorial mammals are neither nocturnal nor crepuscular, tending to be active during both the day and night (Nevo 1979, Gettinger 1984, Proulx 1994). *T. talpoides* is very active, although not always burrowing. During the growing season, approximately 50% of a 24 hour period is spent burrowing, with the remainder used primarily for resting (Andersen and MacMahon 1981). Continuous monitoring of oxygen consumption, in studies by Vleck (1979) and Gettinger (1975), showed similar interspersion of rest and activity periods throughout the day, regardless of photoperiod. In Idaho, seasonal temperature changes seemed to have little effect on the activity level of *T. talpoides*, except during late summer where levels drop for a period of ≤13 days (Kuck 1969, Cox and Hunt 1992).

Studies on seasonal activity patterns of *Thomomys*, in the central and southern areas of the United States, have been based primarily on observations of surface mounds and plugged surface-access tunnels (Miller 1946, Laycock 1956, Bandoli 1981, Gettinger 1984). These findings may not adequately reflect total activity as excavated soil can often be deposited in abandoned tunnels (Cox and Hunt 1992). In 1981, Andersen and MacMahon, along with further studies by Gettinger (1984), used radio-telemetry techniques to monitor subsurface activity. Results indicated relatively high levels of activity in areas where surface signs were not evident. Factors found to influence burrowing and foraging activities included environmental conditions, reproductive physiology and behaviour: *T. talpoides* tunnelled 4.8 times faster in soft, moist soils than in harder packed soils; burrowing rates decreased during winter months, when soils were frozen (Wight 1918, Criddle 1930, Andersen and MacMahon 1981); decreased tunnelling was observed by females in early summer, corresponding to the period of birth and rearing (Criddle 1930); and greater tunnelling was postulated to reflect declining food availability and the dispersal of young during late summer and autumn (Moore and Reid 1951).

2.1.3 Food

Northern pocket gophers are generalist herbivores (Williams and Cameron 1986), feeding on a variety of plant foods, ranging from dandelions to sweet peas (Adams 1994). Since burrowing requires 360 to 3400 times more energy than terrestrial travel, few food items are unused (Vleck 1979, Williams and Cameron 1986). In spite of this generalist diet, there are exhibited preferences, which are ultimately determined by resource availability. In studies by Ward and Keith (1962), pocket gopher food habits were examined in an area with vegetative cover 50% grass, 42% forbs, and 8% shrubs. The stomach contents of the inhabiting pocket gophers (*T. talpoides)* comprised 6% grasses, 93% forbs and 1% shrubs. This is evident in Manitoba, as high forb areas such as alfalfa fields support high numbers of gophers. The alfalfa plants are plentiful, high in nutrient value and retain large amounts of moisture, compared to native forbs.

As discussed, *Thomomys* stores food in underground, sealed caches. In a mixed-grass environment, cache contents range from succulent alfalfa roots and shoots, to stem and leaf materials obtained from other grasses and shrubs. Contents within these storage areas may not necessarily be indicative of the plants preferred by pocket gophers, but rather those less desirable (Aldous 1945, 1951; Turner et al. 1973). Pawlina et al. (1993)

noticed that pocket gophers fed mainly on alfalfa leaves and shoots, leaving the roots for storage. During adverse conditions, succulent root growth (high in water) was preferred (Stuebe and Andersen 1985).

In Manitoba, suitable habitat for the northern pocket gopher extends over a variety of vegetative regimes. From ditches and roadsides to fescue prairie and manicured lawns, *T.talpoides* illustrates supreme adaptability to both man-made and natural environments.

2.1.4 Reproduction

The northern pocket gopher is noted as a solitary, territorial, and secretive animal (Case 1983). The breeding season, extending from late April and early May, is one exception to this behaviour. Parturition occurs between mid-May and mid-June (Cox and Hunt 1992), following a gestation of approximately 19 days (Tryon 1947, Griffith 1978). In one Manitoba study, females had litters of three to eight young, with an average of 4.8 (Deniset 1994). Upon reaching 6 to 8 weeks of age , juvenile pocket gophers are forced out of the maternal burrow, travelling up to one kilometre before digging a new system (Andersen 1978). At this time, the gophers are extremely susceptible to predation by owls (*Bubo virginianus*), hawks (*Accipiter gentilis, Buteo jamaicensis*), weasels (*Mustela frenata and erminea*), badgers (*Taxidea taxus*), coyotes (*Canis latrans*) and foxes (*Vulpes vulpes*) . Within the confines of the burrow, gophers are relatively safe from predators, with the exception of the badger and weasel.

The young attain adult size at approximately 100 days. In fossorial herbivores, this developmental rate is subject to the constraints of burrowing energetics and competition for suitable habitat (Fleming 1977, Griffiths 1978). As suggested by Griffiths (1978), this rapid growth rate may be the result of selection for competitive ability, rather than for increased reproductive capacity or reduced susceptibility to predation.

Studies on plural occupancy within the gopher burrow system have provided valuable information about breeding and dispersal. Hansen and Miller (1959) found that adult males and females tolerate each other during the mating period and may even share the same burrow system during the period of pregnancy and rearing. Wight (1930) cites the fact that the tolerance of plural occupancy of males was greater than that of females due to the tendency for males to enter different burrows in search of receptive females. Griffith (1978) found evidence that during the breeding season, females tolerate the presence of other gophers at all stages, and would even enter other systems. Overall, the system of solitary territories seems to be considerably relaxed during the breeding season.

2.2 Management Systems

In Manitoba, agricultural losses associated with pocket gopher damage were estimated to be at least $15 million annually (Bonnefoy 1985). Comparable losses are estimated in Alberta, Saskatchewan (Case 1983) and Nebraska (by the plains pocket gopher) (Nietfeld and Roy 1990.) Over the years, several control methods have been tested, with varying results. The majority of economic loss in Manitoba is due to yield reduction and loss of forage quality on alfalfa and tame hay fields (Deniset 1994). Mudondwa (1993) states that besides crop consumption and harvest reductions, the life of the hay stand may also be reduced due to the cumulative effects of gopher activities. In addition to these losses, farm machinery is marred by the soil mounds as machines are plugged and swathing knives are dulled, resulting in increased labour requirements, lost time and repair costs.

Over the years, several control methods have been used and tested around the continent to help reduce crop losses. Managing pocket gopher damage in the field is typically more difficult than for situations around human habitation. Many methods have not proven to be very effective or economical on a large scale. For a method to receive widespread use, it must be effective, inexpensive, legal, safe for use by humans, environmentally benign and socio-politically acceptable (Witmar et al. 1995). Most techniques fall short in one or more of these areas, primarily due to the fossorial nature of the pocket gopher. In essence, the battle against pocket gophers revolves around managing a fossorial way of life.

Table 1: Methods and techniques suggested for pocket gopher control in Manitoba

Management Systems		
Physical	**Chemical**	**Biological**
Trapping	Rodenticides	Resistant plants
Buffers	Repellents	Predator perches
Electric barriers	Attractants	Crop rotations

2.2.1 Physical Management Techniques

2.2.1.1 Trapping

Manitoba forage producers have trapped pocket gophers for decades, and continue to do so today. For many, this method delivers immediate satisfaction, as results are actually *seen* in the trap. The occurrence of trapping non-target species is low, as pocket gophers are subterranean and traps are sized specifically for them. On occasion, ground squirrels may enter burrow systems and fall victim to the trap, however, this is rare. In consultation with farmers across Manitoba, there have been no records of non-target species, other than ground squirrels, ever being caught in a gopher trap. Trapping is a legal and relatively safe technique, having little effect on the surrounding environment.

Trapping, as a means of pocket gopher control, falls short in two areas: effectiveness and economics. A report by Deniset (1994) provides the only documented results of the effectiveness of four commonly used gopher traps in Manitoba:

Table 2: Trap effectiveness on Manitoba alfalfa fields

TRAP TYPE	EFFICIENCY
Black Hole	42.8%
Topniks Wooden Box	46.8%
Easy Set (pair)	35.9%
Macabee (pair)	51.5%
OVERALL AVERAGE	**44.25%**

(Deniset 1994)

The effectiveness of this control method depends not only on the trapping device used, but also trapping techniques. As the percent efficiency data presented in Table 2 may fluctuate with technique, inefficiencies are more obvious in the time and labour involved to successfully control a population. The number of traps needed to catch all rodents, and the return visits necessary in the procedure make this method very slow and costly on large fields (Godfrey 1987). Trapping is more successful on small acreages with low population densities (Deniset 1994).

There are several pocket gopher traps available on the market today (Table 3). The preferences and documented efficiencies associated with these traps further indicate that success is a result of technique *and* design. Deniset's study (1994) indicated that the Macabee, a paired impalement trap, was most successful on Manitoba alfalfa fields; whereas Alberta found that the Sidman (box trap) and Convect traps caught the most gophers (PFRA 1996). Management attempts in the United States found the Death-Klutch-1 (similar to the Macabee) as the trap of choice (Patrick 1996, pers. comm.)

Regardless of the device or the technique, success by means of trapping is short-lived. Empty burrows provide a ready made home for newcomers, and the dispersing juvenile pocket gopher is quick to take advantage. To achieve any degree of success, trapping needs to be consistent and continual, which is a difficult task to accomplish for most Manitoba forage producers due to the time requirement.

Table 3: Common Traps Used for Pocket Gopher Control*

TRAP NAME	PRICE (1996) Canadian $	MANUFACTURER/ DISTRIBUTOR
1. Pincher Traps:		
Easy Set	$4.95	EKCO Canada Ltd. Niagara falls, Ont.
Macabee	$8.10	Ace Hardware Yakima, Washington
Quick-set	$13.00	Wilco Distributors Lompoc, California
Zero long-spring	new: $7.50 used: $4.00	Bertram Trap Co. Birtle, MB.
2. Box Traps:		
Blackhole	$15.00	Northstar Seed, Neepawa, MB.
Topniks Wooden Box	$9.49	Topniks Enterprises Ltd. Steinbach, MB.
Sidman	$11.95	Bertram Trap Co. Birtle, MB.
Sure-catch	$8.95	Bertram Trap Co. Birtle MB.

* This list is not inclusive and prices may fluctuate with distributor.

2.2.1.2. Buffer Strips

In silviculture systems, Vollard (1977) suggested that buffer strips left between gopher occupied areas and sites selected to be logged may slow pocket gopher invasion rates. These strips incorporated a natural or near-natural barrier of at least 60 metres surrounding a newly seeded clear-cut area. Similar border control strategies using trapping as a means to control re-invasion, have recently been studied in Alberta (Proulx 1995). Proulx's strategy involves the establishment of a 20m or 40 m wide border zone around alfalfa fields, monitored approximately twice a week for gopher presence at which time invading gophers with traps. Proulx concluded that borders developed at alfalfa stand establishment could easily control gopher invasion, as long as gopher densities were low. This strategy was successful in intercepting, on average, 79% of the invading animals (Proulx 1995).

In Manitoba, there is potential for such a strategy; however, population densities in many areas far exceed the average 13-19 mounds/ha observed in Proulx's study. As suggested, additional research and development is required to find alternative control method to achieve cost-effectiveness in areas of high population densities.

2.2.1.3 Electric Barriers

Electric fences have been used to keep rats (*Rattus rattus*) out of rice paddies and predators away from duck nests (LaGrange et al. 1995), however, they have not been considered a management panacea due to extensive design flaws and electrical malfunctions.

Controlling a fossorial herbivore by electric fencing seems to be an impractical option. Successful exclusion of pocket gophers requires the conduction of electrical current through the ground. Soil characteristics, including salinity, moisture and metal content, must be absolutely ideal. The amount of current required to affect a pocket gopher underground is immense and surpasses all farm safety standards (Crowe, pers. comm. 1996). Randomly transmitting this level of current would produce a dangerous amount of stray voltage in the area (Crowe, pers. comm. 1996).

2.2.2 Chemical Management Techniques

2.2.2.1 Rodenticides

The use of toxic baits, or "rodenticides", in controlling pocket gophers has been relatively successful in Manitoba, however maintaining low population densities have proven more difficult. Limitations with this technique revolve primarily around administration, bait-attractiveness and shelf-life. The most common agents used in the field include strychnine, first and second generation anticoagulants and zinc-phosphide, which has just recently been tested in Manitoba (Bonnefoy et al. 1996). Table 4 provides a summary of the rodenticides tested on Manitoba alfalfa fields.

There is a limited amount of data and literature available on the effectiveness of rodenticides on Canadian alfalfa fields. In the United States, on the other hand, control strategies tested on forest plantations are abundant. Although the food source is different, insight obtained from these studies can be used to postulate the relative effectiveness of rodenticides on gophers in Manitoba.

Anticoagulants- Documented research conducted by Marsh (1985, 1986_a, 1986_b) and Tunberg et al. (1984) concluded that the use of anticoagulants in the control of pocket gophers was both safe and effective. Second generation anticoagulants play an important role in protecting trees and crops in many parts of the world (Marsh 1986_b). Introduction of anticoagulants in the US took place in the 1940's and since this time have evolved as one of the leading control options for field rodents (Marsh 1986_2). One of the newer concepts surrounding the use of anticoagulants is the development of long-lasting baits for single-dose administration (like Maki®) (Tunberg et al. 1984, Godfrey 1987). The behavioural bases behind this strategy are: 1) that pocket gophers are quick to invade unoccupied burrow systems when the previous occupant has been killed, and 2) the invading animal will use the existing food stores. Thus, anticoagulants would prove most effective in an acute (requiring fewer repeat feedings) and long-lasting form (Tunberg et al. 1984). Slow action anticoagulants gave gophers more time to eat excess amounts, leaving none for pocket gophers that may invade the burrow after the original occupant died.

These results provided an optimism for forage producers across the Canadian prairies, however, anticoagulant success rates (Proulx, pers. comm. 1994, Deniset 1994) on alfalfa fields were found to be much lower. Proulx et al. (1994) provided a possible explanation for the relative lack of success in his tests with cholorophacinone (2nd generation anticoagulant) administered to pocket gophers in captivity. In the presence of fresh cut alfalfa, consumption of the bait was inferior to the estimated LD_{50} of 5 mg/kg of cholorophacinone/kg. As well, when poorer quality alfalfa was presented, the gophers ate more of the bait, but still remained alive. It was found that Vitamin K, found in alfalfa, counteracted the pathological changes caused by anticoagulants. Thus, the pocket gopher was consuming a home-made antidote.

Table 4: Rodenticides Tested in Previous Studies (Manitoba)

RODENTICIDE	ACTIVE INGREDIENT*	DOCUMENTED EFFECTIVENESS	COMMENTS
1. ***MAKI®*** ***(Liquid Lightning)***	bromadiolone: A single dose anticoagulant inhibiting the formation of the prothrombin necessary for blood coagulation, thus causing fatal haemorrhages.	■ successful in spring applications	■ antidote is vitamin K found in alfalfa ■ long lasting bait with threat of over-consumption. This may lead to potential secondary poisoning. ■ not registered in Canada. (Deniset 1994)
2. ***QUINTOX®***	cholecalciferol: A slow-acting poison causing a lethal imbalance in calcium levels.	■ more successful in spring applications due to water-resistant qualities	■ consumption of bait in excess of lethal dose is rare. This limits the potential for secondary poisoning. (Deniset 1994)
3. ***GOPHACIDE®***	strychnine: Lethal doses induce asphyxiation caused by paralysis of the respiratory muscles.	■ effective in fall applications	■ secondary poisoning problems. (Deniset 1994) ■ water soluble
4. ***PROZAP***	zinc phosphide: Upon ingestion, toxic phosphine gas is produced with the dilute acids in the stomach.	■ success seen in fall and spring applications	■ inexpensive ■ not stored in animal tissue, thus low risk of secondary poisoning ■ storage problems (moulds), needs to be kept dry. ■ recommended for registration. (Bonnefoy et al. 1996)

Strychnine- In 1989, due to the potential hazard to wildlife, the Canadian government banned strychnine at 5% concentrations for general use as a rodenticide. Today, only products like Gophacide® (.35%) are available on the market and have reported varied results in pocket gopher control. Lewis and O'Brien (1986) found strychnine-laced alfalfa (.5%) to be effective in late spring and summer for the control of the Townsend pocket gopher in forested areas. Contrary to these findings, Tickes (1983) found strychnine (.35%) in a wheat, barley, raisin or milo carrier, to provide control for only 8-13% of pocket gopher populations in alfalfa.

Zinc phosphide- In the US, zinc phosphide is one of the most common rodenticides used, second only to anticoagulants (Marsh 1987). This toxin reacts with the stomach acids to produce phosphine, which is lethal in the blood stream (Tickes et al. 1982). It is an acute rodenticide, stable when kept dry, yet prone to rapid deterioration under damp conditions.

Research on the effectiveness of zinc phosphide (Prozap) was carried out on Manitoba alfalfa fields in 1996. Preliminary results indicated that the product was somewhat successful when administered at 3.0 lbs/acre. These results are undergoing further analysis, at which time more concrete conclusions will be made (Bonnefoy et al. 1996).

Application of the above types of rodenticides, and others, is carried out by a number of different methods. Hand probes can be used, however this is very time-consuming and labourious. The burrow builder machine seems to be the method of choice in Manitoba.

This machine makes an artificial burrow and allows for large areas to be treated in a relatively short period of time (Bonnefoy 1994, pers. comm.). Godfrey (1987) states, however, that these machines are restricted to very specific soil conditions and topography. Dry soil will crumble, and rock obstructions and stumps may limit access to an area. There is even speculation that the artificial burrow may expedite reinvasion by gophers and expansion of the infested area, resulting in a bigger problem (Godfrey 1987).

The fact that the northern pocket gopher prefers alfalfa over most other food stuffs (Case 1983) is perhaps one of the largest obstacles to achieving success with rodenticides. Providing an appetizing bait is the first step in the development of an effective rodenticide. It has been suggested that ideal rodenticides should be in wet form in order to be fully effective (Proulx 1994), however most rodenticides are prone to deterioration under damp conditions. Acquiring bait attractiveness, mastering administration and finding a safe, effective toxin are the keys to potential success with rodenticides.

2.2.2.2 Repellents

Manipulation of interspecific chemical communication between predator and prey has received considerable attention in recent years. Several studies using synthetic components of predator odours have generated avoidance responses in the northern pocket gopher (Sullivan and Crump 1986). Results of field trials in the Okanagan Valley, BC, over a period of 5.5 months, demonstrated that a significant number of pocket gophers avoided synthetic stoat odours administered in areas where original gopher populations were removed (Sullivan et al. 1990). To date, the costs for applying synthetic odours as a method of control are not available

In the prairies, the rapid re-infestation of chemically controlled gopher populations suggests that only short term control is possible with toxicants and other means of depopulation (Deniset 1994, Proulx 1995). Using stoat odour as a repellent may provide an alternative method to the continued use of toxicants and trapping, after initial removal. Sullivan et al. (1988) also suggest that a buffer strip of at least 25 m may be added to an area treated with predator odours to intercept any attempts at recolonization.

The use of naphthalene as a repellent was investigated in Saskatchewan in 1995. Although the study demonstrated no significant difference in gopher populations between control and treatment plots regardless of application rate, application methodology rather than the repellent was considered to be the major drawback (Prince Albert ADD, Board 1995). Mechanical burrow builders used to administer the naphthalene did not uniformly distribute the product into the soil. This study was preliminary and did not consider the costs and environmental effects associated with naphthalene. Sullivan et al. (1990) also supports this need for suitable release devices in the achievement of successful management with repellents.

2.2.2.3 Fumigants

Soil moisture, porosity and fossorial activity are the limiting factors in treating pocket gophers with burrow fumigants. Dry soil negatively affects the rate of diffusion and increases the amount of air-filled pore space; subsequently, gas loss into the surrounding pore spaces results in ineffectiveness (McClean 1981, Moline and Demarais 1987).

Phosphine gas, released in the presence of moisture, is highly toxic to humans and non-target wildlife inhabiting the burrows. The efficacy of aluminum phosphide on the control of the yellow-faced pocket gopher in Texas was estimated at 61.5-85.7% (Moline and Demarais 1987). An alternative approach suggested by Plesse (1984) is the use of a carbon monoxide gas cartridge. The exhaust simply removes the good air from the burrow, with no hazardous residues remaining. It is considered humane and no permit is required by the user. At this time, there are no documented studies on the effectiveness of this control method.

Anhydrous ammonia has been tried, off and on, as a control method for pocket gophers across agro-Manitoba for several years (Bonnefoy 1996, pers.comm.). Effectiveness has been unacceptable as levels insufficient to kill gophers have actually killed the alfalfa crop above the treated burrow. Since this product is commonly used by many annual crop producers as a fertilizer, it would be wise to investigate its effectiveness as a control.

2.2.2.4 Attractants

There are no commercial attractants formulated specifically for pocket gophers. The ultimate objective of this suggested control tactic is to achieve a higher percentage of mortality with the use of baits or traps, thus creating better rodent control.

Marsh (1988) reviewed a number of attractants for use as bait additives in controlling commensal rodent species like *Rattus norvegicus, R.rattus* and *Mus domesticus*. Sugar oils, semi-natural or synthetic flavours, commercial rodent lures, salt, MSG, and pheromones were all discussed in relation to their relative acceptance and palatability. Specific to the northern pocket gopher, Proulx (1995) has documented results of the effectiveness of tomato paste, peanut butter, urine, spearmint oil, catnip and maple/almond extracts in attracting gophers to traps. The ingredients tested did not make a difference in trapping success, and it was suggested that the selection of scents was not discriminant enough (Proulx 1995). Once more, further research is required to determine the potential role of attractants in controlling gopher populations.

2.2.3 Biological Management Techniques

2.2.3.1 Raptor Perches

The rapid acceptance of perches by raptors, indicated in a study by Hall et al. (1981), suggested that perches may prove useful as a management tool for control of pocket gophers. Today, there is little actual evidence to support this contention. Howard et al. (1985) were not able to demonstrate a favourable cost/benefit ratio of rodent control by means of installing temporary raptor perches; however, the perches did provide a tool to improve the welfare of many raptor species. Although the study was not successful statistically, raptor perches may assist in the delay of rapid infestations of rodent populations to immature crops.

2.2.3.2 Resistant Crops and Rotational Benefits

Consistent with changing environmental attitudes (specifically towards the use of chemical controls) and the thrust towards organic and sustainable agriculture, is the introduction of resistant crop species and the realities of rotational cropping benefits. Management options for pocket gophers have concentrated primarily on controlling the *symptoms* (gophers, mounds) rather than the actual *problem cause* (single tap-rooted alfalfa varieties, monoculture, decreased predation). These control methods are usually short-lived and limited in success as the preceding literature review has documented.

Resistant Crops- As stated by Marsh (1991)

> *"...the term "resistant" must be interpreted relatively loosely because, as stated previously, a pest species severely pressed for food may feed upon plants which it normally would not touch and which may be detrimental to its health, especially if consumed over a long period. Resistance per se is often dependent on whether or not other more preferred alternate foods are available."*

With this point in mind, and the supreme adaptability of the northern pocket gopher, damage-resistant cultivars should be seriously considered as a means to conquer the large population densities observed throughout the alfalfa fields in Manitoba.

This option may prove to be a difficult task for many reasons. Planting less-susceptible crops, like alfalfa cultivars with creeping roots (Melton et al. 1988) could initially have significant economic ramifications leading to economic hardship for producers. In the long run, however, changing crop phenology may be a sound approach to avoiding pocket gopher infestations (Marsh 1991).

Unlike the successful genetic manipulation of forest trees, this approach would be more difficult for agricultural crops like alfalfa. Since alfalfa is used as a forage crop for domestic animals, the substituted cultivar must exhibit similar feed values and disease-resistant qualities seen in the current tap-rooted alfalfa varieties. Research is required to determine the possibilities of such a cultivar.

In Saskatchewan and Alberta, Cicer milkvetch (*Astragalus cicer* L.), a legume used for pasture and hay is considered impalatable to the northern pocket gopher. Preliminary research has been initiated in these provinces and the results look promising, as the cultivar has similar nutritional feed values as alfalfa (at this stage, there are problems with germination). Cicer milkvetch could be used in a buffer around an established alfalfa field, or as an alternative to alfalfa. As mentioned, research is on-going with no final conclusions to date (Saskatchewan Agriculture and Food 1996).

Rotational Benefits- According to Entz et al. (1995), the two most common reasons for forage stand termination in Manitoba are reduced yields and damage by pocket gophers. An alternative to managing pocket gopher populations could include the management of alfalfa stands to maximize rotational benefits.

Two factors that discourage forage producers from cycling forages more often include difficulties in establishment and terminating perennial forage stands (Entz et al. 1995). Therefore, producers seem to keep alfalfa stands for as long as possible, averaging 6.5 years in Manitoba. Research indicates that this duration far exceeds the necessary life required for maximum N accumulation and weed suppression (Entz et al. 1995). Decreasing alfalfa stand duration may not only reduce the possibilities of large gopher infestations, but also increase yields in the proceeding crop and decrease infestations of certain weed varieties (Entz et al. 1995).

The difficulty with this approach to management revolves around convincing the forage producers that this option is a viable one. To encourage producers to increase forage cycling as a means of pocket gopher control and other benefits, forage stand establishment and termination systems must be more reliable and economical (Entz et al. 1995). A movement away from stands left too long, towards more sustainable practices, could prove to be a valuable control tool for the northern pocket gopher.

2.2.4 Other Management Techniques

Throughout the course of this research, there have been several other management strategies suggested. For the sake of brevity, these techniques will simply be listed, as there is little documented research on their relative efficiency.

Table 5: Suggested management techniques with limited documentation

Physical	Chemical	Others
burrow flooding *	sterilants	gas ignition ("underground blasting")
barrier fencing	various other rodenticides	suction
sound deterrents		maintaining pocket gopher predator habitat

*Burrow flooding is done on native hay for a period of 4-6 weeks in Manitoba. Benefits include increased yields, weed suppression and pocket gopher control. Tame hays like alfalfa cannot tolerate intense flooding for longer than one week, however this short duration may provide some gopher control (Harris, pers. comm. 1997).

2.3 Costs and Losses Associated with Pocket Gopher Damage

There have been no studies on the losses and extra costs resulting from pocket gopher damage on alfalfa fields in Manitoba. The impacts of pocket gopher activity are seen in alfalfa yield reductions, increased machine wear, decreased quality of harvest, and increased labour efforts, all of which contribute to the total economic loss. Forage producers can only speculate on these costs, as most cannot be accurately or easily estimated. The only information offering suggestions on overall economic loss caused by pocket gophers in Manitoba was compiled by the St. Claude Pocket Gopher Study Committee (SPGSC). The group of forage producers compiled financial records to determine the extra costs and added losses they experienced over time. Research conducted by Entz et al. (1995) found that gopher-related damages were so extreme for forage producers that it was the second most common reason given for premature cultivation in Manitoba and eastern Saskatchewan.

Yield reduction attributed to the presence of pocket gophers has been documented in other localities. In Minnesota, plant biomasses directly over plains pocket gopher burrows are reduced by one-third (Reichman and Smith 1985). The plains pocket gopher has been recorded to cause alfalfa yield losses ranging from 17 to 46 percent on dry land alfalfa and hay meadows in southern Nebraska (Foster and Stubbendieck 1980, Luce et al. 1981, Hegarty 1984, Case 1989). Alsager (1977) noted that the northern pocket gopher caused rangeland yields to decrease 16% in southern Alberta. The economics of controlling pocket gophers have been modelled by Case and Timm (1984) in California, however more data base improvements need to be made (Case 1989).

2.4 Summary

Success in reducing the number of northern pocket gophers in a field seems to be short-lived, as population numbers are quick to rebound after initial control treatments. With the exception of Proulx's border control strategy, there have been no inquiries into alternative long-term gopher management techniques in Canada. For this reason, the study addressed the effectiveness of buffer strips on the control of pocket gopher re-invasion.

This literature review has documented a variety of control methods, all with varying degrees of success. There is information on the effectiveness of most of these techniques, however determining the economic practicality of such methods has never been discussed in Manitoba. In order to make more informed management decisions, especially in choosing a specific control technique, forage producers must be aware of the costs of both gopher-related damages, and the management techniques chosen.

Chapter 3

METHODS

3.1 Study Site

The study was conducted during the summers of 1994, 1995 and 1996, in the rural municipality of Ste. Anne, Manitoba. The majority of this southeastern portion of Manitoba consists of a sandy lacustrine soil material of various thickness, overlying a till layer. Most of this soil type is imperfectly to poorly drained (Eilers, pers.comm. 1996). Although it reaches the northeastern limit of its range in the area, *Thomomys* is locally abundant, often centring its activity in alfalfa (*Medicago sativa)* and mixed-grass fields.

Site design and preparation were carried out during the 1994 summer field season. The study site was located on a 32 hectare (80 acre) field, 1.6 km east of Giroux, Manitoba (23-7-7 EPM) (Figure 4). A 484 m x 258 m (1585 ft x 845 ft) section of alfalfa/mixed-grass was professionally surveyed into 18 x 30.48 m^2 (100 ft^2) plots, each surrounded by a 7.32 m (24 ft.) buffer zone to allow for adequate controls and replications. Mound distribution was patchy, indicating possible selection by the gophers when choosing a burrow site. The plots were randomly selected throughout the site chosen and provided a reasonable area to collect data effectively. The plots were numbered chronologically, in a north/south direction and were surrounded by 73 identical plots used for control purposes (Figure 5). This overall grid design (suggested by Jack Dubois, Assoc.Curator of Mammals, Manitoba Museum of Man and Nature) allowed for as much consistency as possible in external variables, including soil type, border type (roads, other fields, etc.), vegetation type, and climatic conditions. As well, the study could be regulated through cooperation with a sole landowner, as opposed to several.

The forage stand in the study field was approximately three years old and exhibited a relatively high density of mounds compared to that observed at other sites. During the summer prior to selection, an estimated 1200 pocket gophers were removed from the 80 acre field (encompassing the study area) by means of trapping (VanderKroon, pers. comm. 1994). Alfalfa stand densities were estimated for each plot and recorded to aid in the discussion of results.

3.2 *Objective 1*: Determining Yield Losses

Successful and accurate assessment of pocket gopher damage to forage yields depended on the ability to perform several functions effectively. These are: (*I*) maintaining a gopher-free environment in all managed plots, (*ii*) obtaining an accurate measure of gopher density in control plots, *(iii)* obtaining an accurate measure of alfalfa productivity (Alsager 1977), and (*iv*) maintaining similar environmental conditions on all study plots. The methodologies previously described address the above functions and are suggested in Alsagers (1977) "Damage Assessment Tool" for pocket gophers.

In order to compare yield losses due to pocket gopher damage, the eighteen buffered plots were *managed* by means of trapping. The purpose of eliminating the rodents was to

Figure 4: Study area within the range of *T. talpoides*

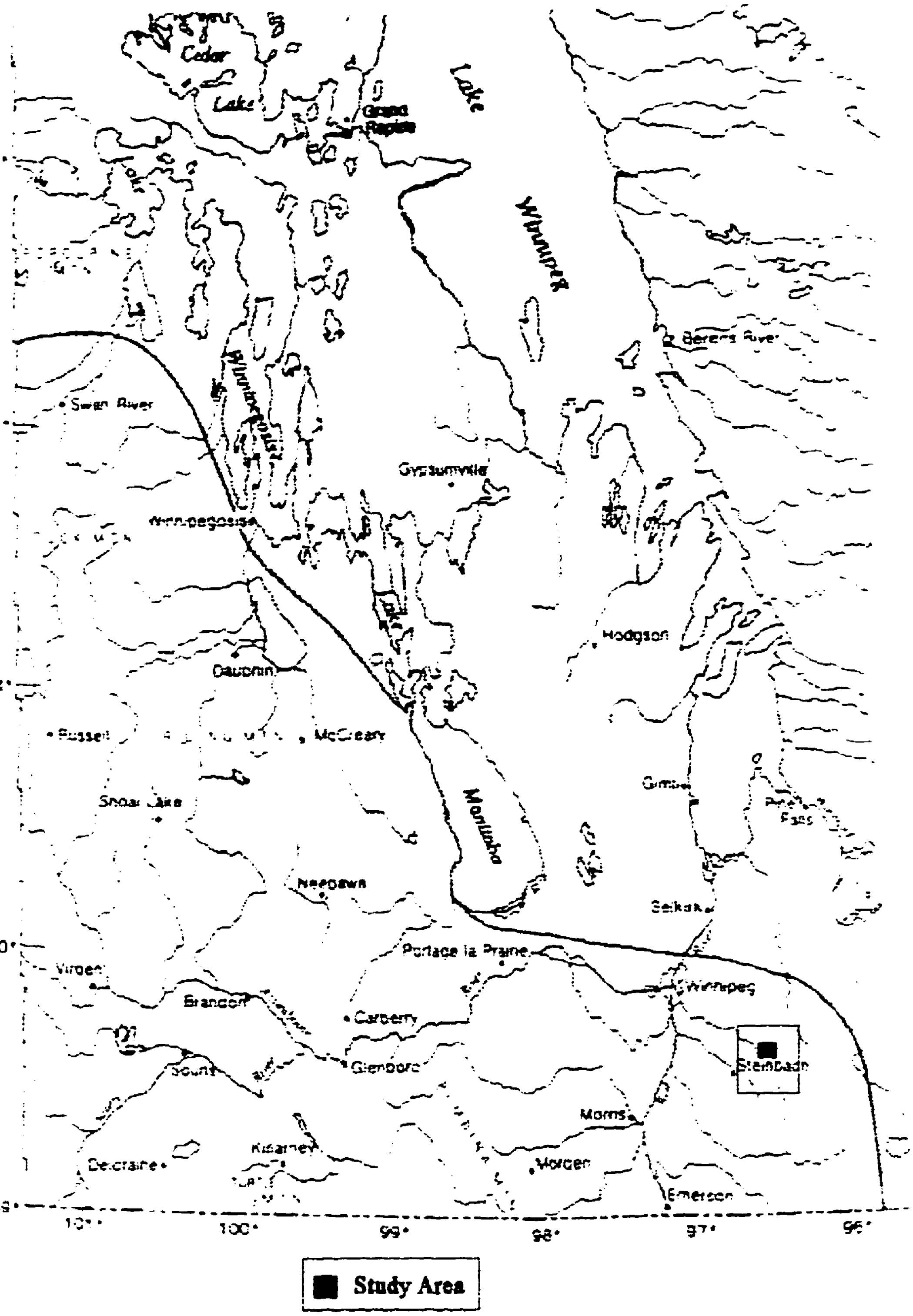
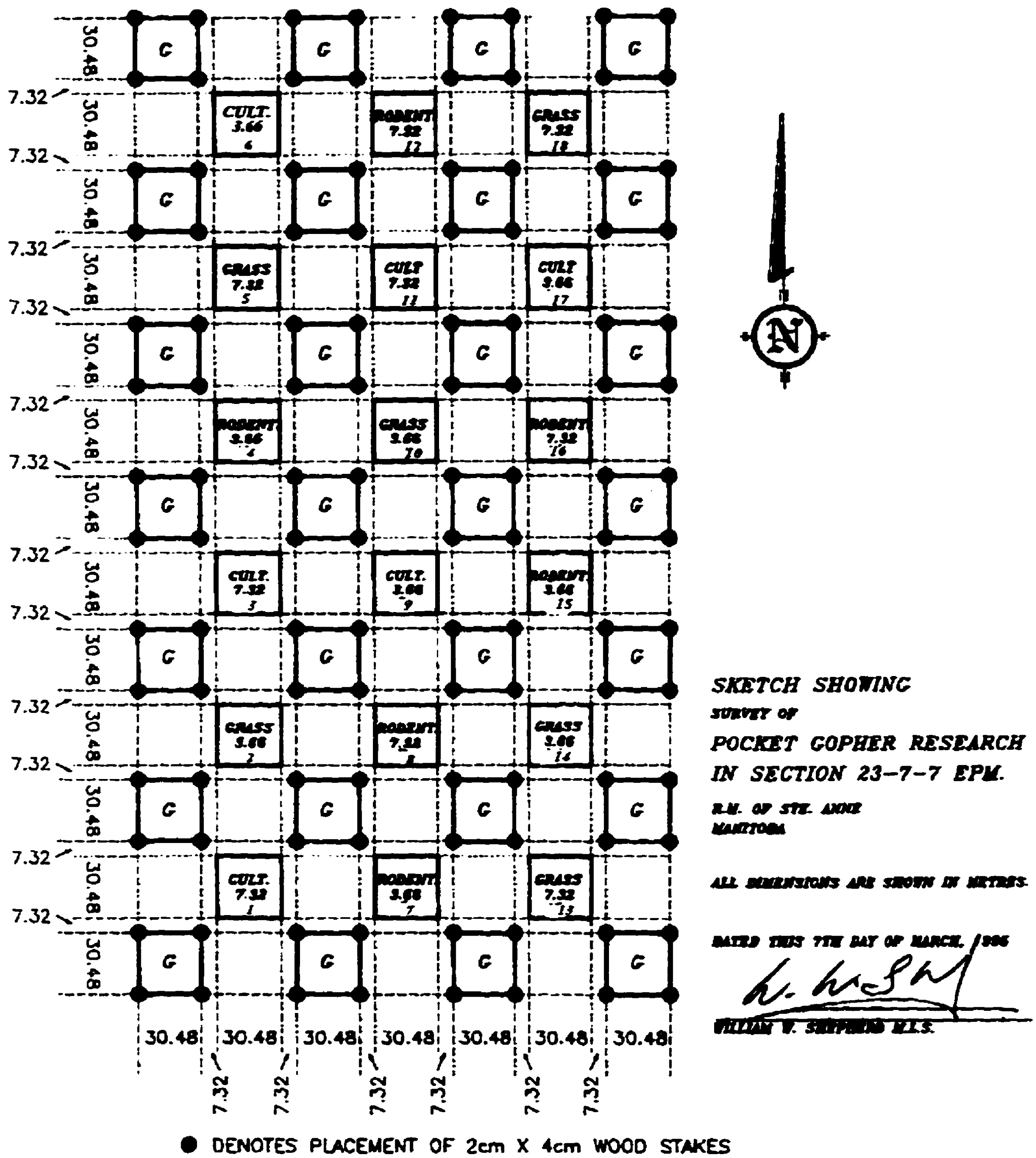


Figure 5: Field design



provide a gopher-free environment, allowing for a simple comparison with plots that were not managed (i.e., had gophers present). Using the presence of fresh mounds as indicators, *Macabee*, *Black Hole*, *Wooden Box* and *Easy-Set* traps were set during the first two weeks of May (1995). Traps were positioned in the underground tunnel systems and covered with soil. Small openings were left at the trap site, with the belief that pocket gophers would be attracted to the damaged burrow. Traps were then marked and secured with bamboo stakes (Deniset 1994). After initial populations were successfully removed, the plots were monitored for fresh mound activity, at which time immigrating gophers were immediately trapped out. Plots surrounding the managed areas were not disturbed. This methodology was carried out from May-August during the 1995 and 1996 field seasons.

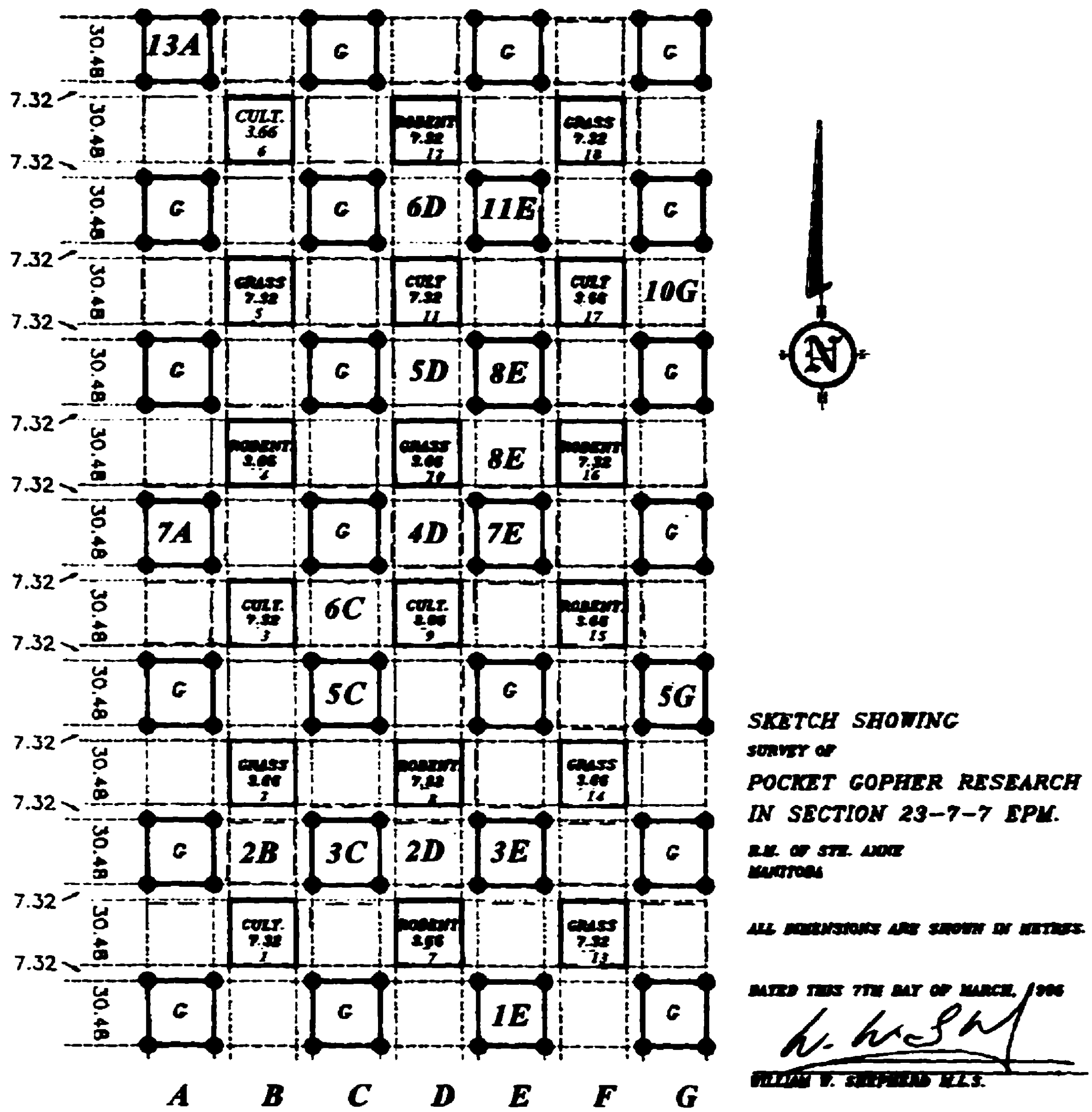
Yield measurements were performed at time of harvest: June 13, 1995 (Harvest 1), July 17, 1995 (Harvest 2) and July 1, 1996 (Harvest 3). To obtain a significant representation of the individual plot yield, four sites were randomly selected within each managed plot. At each of these sites, 1.2 m of swath was collected and weighed, totalling 4.8 m in each plot (Entz 1995, pers. comm.). During Harvest 1, yields from the 18 gopher-managed plots were measured and correlated to samples taken from 18 randomly selected *untreated* plots (Figure 6). Similar methodologies were used for Harvests 2 and 3, with 13 and 17 gopher-managed and non-managed plots sampled, respectively (Figures 7,8).

To determine individual plot yields on a dry matter basis, alfalfa sub-samples were collected from the 4.8 m alfalfa swath samples, weighed and placed in drying rooms for 7 days. Weights from the dried sub-samples were recorded and used to convert the individual managed and untreated plot yields to dry matter. Yields collected from managed and untreated plots were compared in all three Harvests. Statistical analysis utilized the SYSTAT® computer package, version 5.0. The differences in yield for each Harvest were tested for significance using a paired sample t-test.

Yield measurements occurred on a total of 96 plots (30.42 m^2 each) over a period of 2 growing seasons. The methodology used was practical as it employed a minimum of people time, yet provided a reasonable degree of sensitivity and accuracy. The advantage of using swath for measurements, as opposed to numerous individual clippings prior to harvest, is that it resulted in yield measurements which incorporated other gopher-associated losses, specifically with the lifting of machine blades to avoid heavily mounded areas.

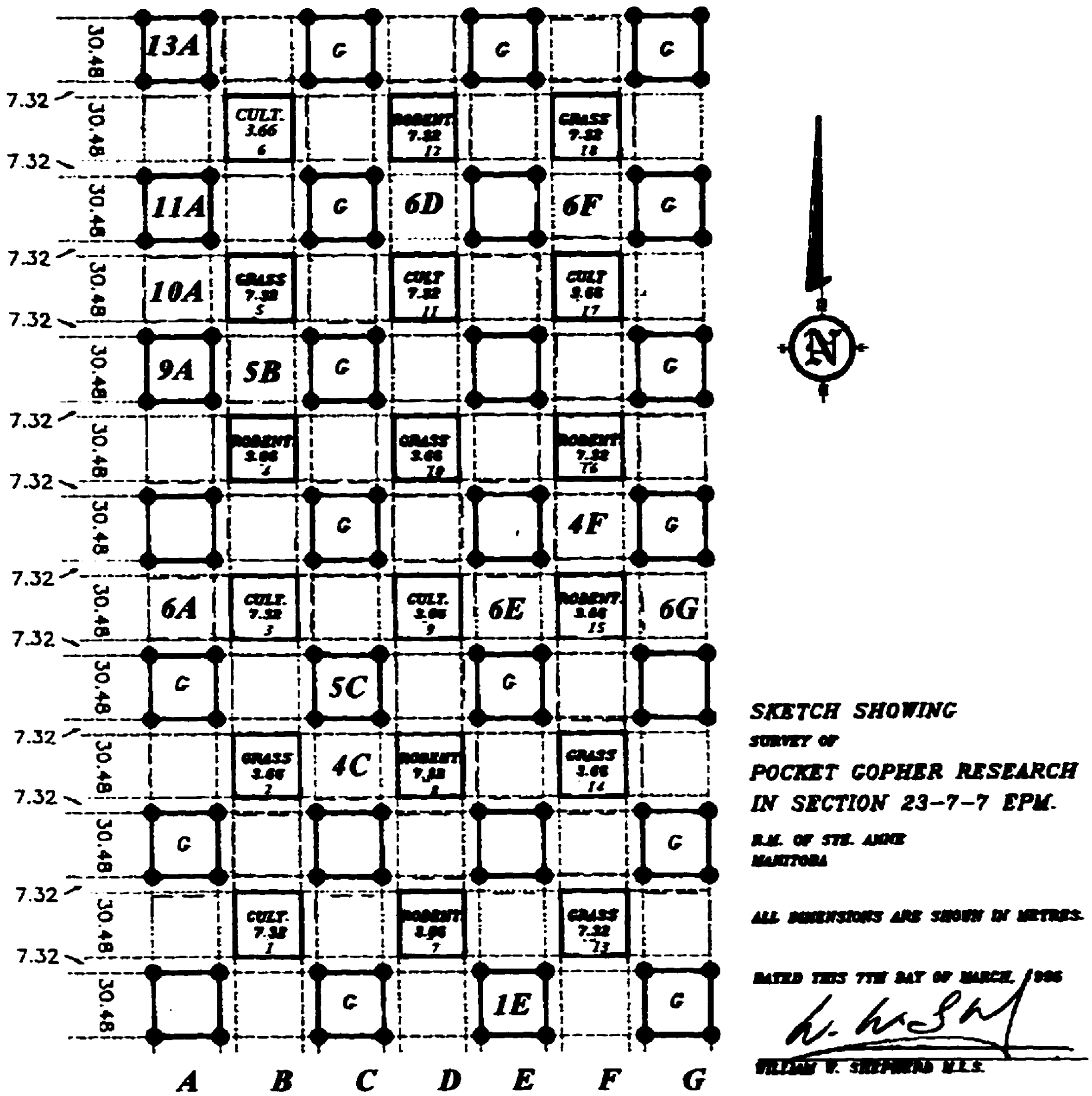
Maintaining similar environmental conditions on all study plots was achieved by collecting data from a single study site. The nature of field experimentation is such that the absolute control of external variables is impossible. Several environmental qualifiers will be used in the explanation of data, including alfalfa plot densities, field history and the location of plots within the field.

Figure 6: Harvest 1 : Sampled untreated control plots



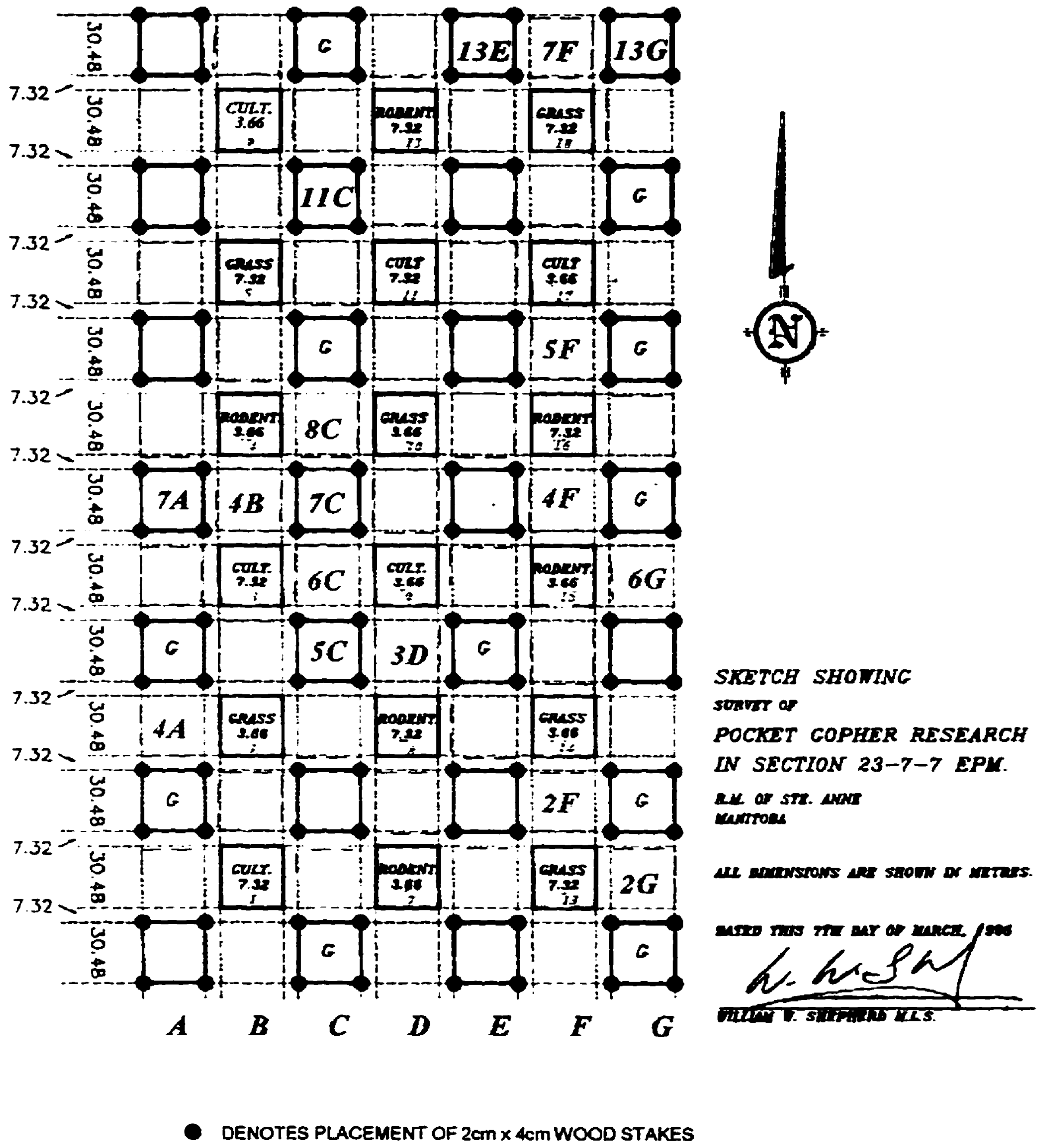
● DENOTES PLACEMENT OF 2cm x 4cm WOOD STAKES

Figure 7: Harvest 2: Sampled untreated control plots



● DENOTES PLACEMENT OF 2cm x 4cm WOOD STAKES

Figure 8: Harvest 3: Sampled untreated control plots



Census counts- Census sign counts were done in an attempt to correlate the measured alfalfa yield to the number of gophers present at time of harvest. The purpose behind establishing such a relationship is to provide forage producers with a management tool to accurately determine gopher population levels (or at least an index to them) and subsequently apply this number index to a pre-determined yield loss.

The development of an accurate census method was one of the objectives of a parallel study, using the same study site. Indexes of gopher populations on the untreated plots were done throughout the 1995 and 1996 field seasons. This involved the use of a *sign* count, which included gopher mounds, earth plugs and open holes. After harvest and yield sample collection, fresh mounds, earth plugs and holes on all untreated sample plots were levelled by simply stepping on the excavated soil until relatively flush with the surface. Older gopher sign was easily distinguishable from fresh sign and remained undisturbed on the untreated plots. The census methodology used focused on counting recent activity sign, disregarding old gopher sign. The plots were left for two days, after which time fresh sign was systematically counted on each plot and recorded. If precipitation occurred during the two-day period, the levelling and sign count had to be repeated as the rain made it difficult to differentiate new mounds and plugs from old ones. The total number of mounds, earth plugs and open holes obtained from these census counts were used in determining a relationship between the amount of yield loss and the level of gopher activity in each Harvest.

In the parallel study, the numbers from the census counts were run through a variety of statistical tests in an attempt to establish an accurate mathematical relationship between the number of mounds in an area and the number of gophers present (Dubois, M. pers. comm. 1996). At the time of this practicum write-up, these results were very preliminary, and thus it was decided that sign numbers as opposed to a gopher population index, would be used in our discussion of yield loss. This census count methodology is consistent with past studies where procurement of data on gopher presence and activity was largely obtained through a method of frequency counts of mound building (Criddle, 1930; Laycock, 1957; Miller and Bond, 1960).

3.3 *Objective 2* : Effectiveness of a Buffer Zone

The study investigated the effectiveness of three buffer zone systems for use in a management strategy for pocket gophers. It is hypothesized that a buffer strip will slow the re-invasion rate of migrating pocket gophers into fields where initial populations have been removed.

Each buffer zone type was replicated 3 times in 2 widths, positioned around one of the eighteen managed plots randomly selected with a width of either 3.66 m (12 ft.) or 7.32 m (24 ft.) (Figure 5). The widths in this buffer control strategy were chosen to allow for ease in cultivation, as most cultivators are approximately 3.66m (12ft.) wide. They also provided a practical starting point for further study, as this buffer technique has never been used before. The 18 buffer replicates included:

3 x 3.66m **grassed**	3 x 3.66m **cultivated**	3 x 3.66m **rodenticide**
3 x 7.32m **grassed**	3 x 7.32m **cultivated**	3 x 7.32m **rodenticide**

Grassed buffer zones- Of the eighteen surveyed plots, 6 were randomly selected for the development of grassed buffer zones. In July 1994, the six buffered areas were treated with Round-up®. Using a mould-board plough, three of the zones were cultivated to a width of 3.66m and the remaining three to a width of 7.32m. In the spring of 1995, the zones were re-cultivated and prepared for seeding. Due to lack of rain in late May and early June, 1995, grass was seeded in mid-June. Alfalfa found throughout the field season within the grassed zone was spot-treated with a herbicide, using a pressurized hand applicator.

Cultivated buffer zones- Six randomly selected managed plots were surrounded with a cultivated buffer. Once again, these buffers were treated with Round-up® in the fall of 1994, and cultivated to a width of 3.66m or 7.32m. The following spring, the zones were re-cultivated and left bare. Any excess alfalfa growth within the buffer was spot-treated with Round-up®.

*Rodenticide buffer zones-*The six plots randomly selected for the testing of a rodenticide buffer zone were treated with Gophacide® in the fall of 1994. Research by Deniset (1994) found Gophacide® to be both effective during the fall months and economical.

Gophacide® was applied using "The Gofer," an artificial burrow-making machine pulled behind a tractor, at a speed of approximately 6 mph. The product was dispensed at a rate of 0.68 kg (1.50 lbs) per acre in the artificial burrow, in rows 3 metres apart (manufacturer's recommended rate) (Deniset 1994). The 3.66 m buffers were treated with one row of rodenticide, and the 7.32 m buffers received two. On June 8, 1995, the buffers were re-treated with Quintox®, a rodenticide found to be more effective in spring conditions due to its water resistant qualities. (Deniset 1994). Application was identical to that of the Gophacide®, although the product was dispensed at a recommended rate of 1.36 kg(3.00 lb)/acre.

Monitoring the zones took place from July 12 to August 20, 1995, where plots were checked twice a week for breach of the buffer. Sign (mounds, earth plugs and open holes) formation was used to determine if gophers had entered the plot. If the buffer was breached, sign numbers were recorded, levelled, and the animals were immediately trapped out. An analysis of variance, using the SYSTAT® computer program, tested the relationship between treatment (grass, cultivated or rodenticide), width, and a combination of both, in the determination of buffer zone effectiveness.

3.4 *Objective 3*: Providing Management Strategies for Forage Producers in Manitoba

With the results from the yield study, the buffer zone testing and other literature on control methods, suggested strategies for a management plan were developed to assist

Manitoba forage producers in pocket gopher control.

- The results of the yield study allowed for estimation of average alfalfa yield losses, due to pocket gopher activity, over the duration of an alfalfa stand (approximately 6 years in Manitoba). Comparing the average yield of an alfalfa field void of gophers with that of a populated one was done with the use of Manitoba average alfalfa yield graphs (Entz 1997, pers. comm.). Calculating yield losses over time, as opposed to a per harvest basis, took into account the dynamics of an alfalfa stand, and the assumption that pocket gopher populations reached a saturation point in alfalfa fields (Scenario One).

- Costs of administering rodenticide as a control technique and those associated with field cultivation as a control technique were applied to the graphs. At this point, the producer will have an estimation of the costs of "no control"(Scenario One), applying a control (Scenario Two), and re-establishing the stand (Scenario Three).

- Other costs associated with pocket gopher activity were discussed at this stage in the report. In the absence of hard data, machine damage costs, increased labour, soil/water erosion and alfalfa quality losses can only be estimated. These estimations were collected from the St. Claude Pocket Gopher Organization. As well as having the most accurate records of machine damage and quality losses due to pocket gophers, this group of forage producers reside in one of the Manitoba regions most highly populated by pocket gophers. Their commitment to dealing with pocket gophers provided vital information for the study. Although their data was not collected from the yield study site, it provided an estimation of economic loss in the specified areas.

- The purpose of this strategy was to aid forage producers in making more informed pocket gopher management decisions. The three scenarios, along with a discussion of other potential losses, will provide farmers with vital information that can be applied to individual alfalfa stands. The strategies were formulated using the average gopher sign/m^2 in untreated plots over three harvests and the resulting average alfalfa yield loss over the same period.

Chapter 4

RESULTS

Field data collection commenced in late June, 1994. This season concentrated solely on field set-up, experimental design and preliminary trapping. Pretreatment trapping took place in May, 1995, with 63 gophers removed from the 18 managed plots, averaging 3.5 gophers per plot.

4.1 *Objective 1: Yield Study*

A summary of the effect of pocket gophers on yield results is shown in Table 6.

Table 6: Summary of yield results

	Total area sampled (m^2)	Average yield in managed plots (kg/m^2)	Average yield in control plots (kg/m^2)	Decrease in yield (%)	Total sign count ($sign/m^2$)
Harvest 1 (18 plots)	549 m^2	.18	.13	**27.8**	.07
Harvest 2 (13 plots)	396 m^2	.11	.09	**18.2**	.36
Harvest 3 (17 plots)	518 m^2	.11	.09	**18.2**	.05
Total	**1463 m^2**			**22.9**	

Harvest 1- Yield samples were collected from the 18 managed plots (549m^2 total) on June

13-14, 1995. Sample weights ranged from 0.08 kg/m² to 0.36 kg/m², with a mean dry sample weight of 0.18 kg/m². Yield collected from 18 randomly sampled untreated plots (occupied by gophers) ranged from 0.07 kg/m² to 0.23 kg/m², with a mean dry sample weight of 0.13 kg/m².

Comparative t-testing determined that the difference between alfalfa weights in the managed vs. untreated plots (27.8%) was significant ($p < 0.02$) based on the sample size used.

Census counts indicated the presence of 40 sign indicators on the 18 untreated plots, averaging 0.07 sign/m².

Harvest 2- Sampling took place July 18-20, 1995. Dry alfalfa samples from managed plots in Harvest 2 weighed less than those in Harvest 1, ranging in weight from 0.07kg/m² to 0.21kg/m². Untreated plots yielded dry alfalfa sample weights ranging from 0.03 kg/m² to 0.22 kg/m².

In comparison to the dry alfalfa weights on managed plots, untreated plot samples in Harvest 2 indicated a decrease in yield of 18.2% (Table 6). The total sign count for the 13 untreated plots was significantly higher than Harvest 1 levels at 143, yielding a density of 0.36 sign/m².

Due to the large number of gopher invaders on 5 of the 18 managed plots, the sample size used was reduced to 396m² (13 plots), lowering the likelihood of significance ($p = 0.18$).

Harvest 3- This harvest was completed on July 1, 1996, resulting in yields per unit area that were identical to those in Harvest 2, even though the total area sampled (518m²) was greater. Yield differentials averaged 18.2%, with a p-value equal to 0.09. Individual managed plot yield samples ranged from 0.04 kg/m² to 0.32 kg/m²; untreated plot samples exhibited a lower range of variability from 0.05 kg/m² to 0.17 kg/m².

During this period of pre-dispersal of young of the year gophers, census counts on the untreated plots indicated the presence of 25 sign indicators for all plots, yielding the lowest density of 0.05 sign/m².

4.2 *Objective 2: Buffer Effectiveness*

The grass, cultivated and rodenticide buffers became operative at different times during the 1995 season, as grass required time to germinate and the rodenticide required specific conditions for effective application. Thus, simultaneous monitoring of all the buffered plots commenced in late July, 1995, with a total monitoring period of 41 days. Sign counts within the buffered plots are shown in Table 7.

Figure 9: Harvest 1,2 and 3 Yield Comparisons

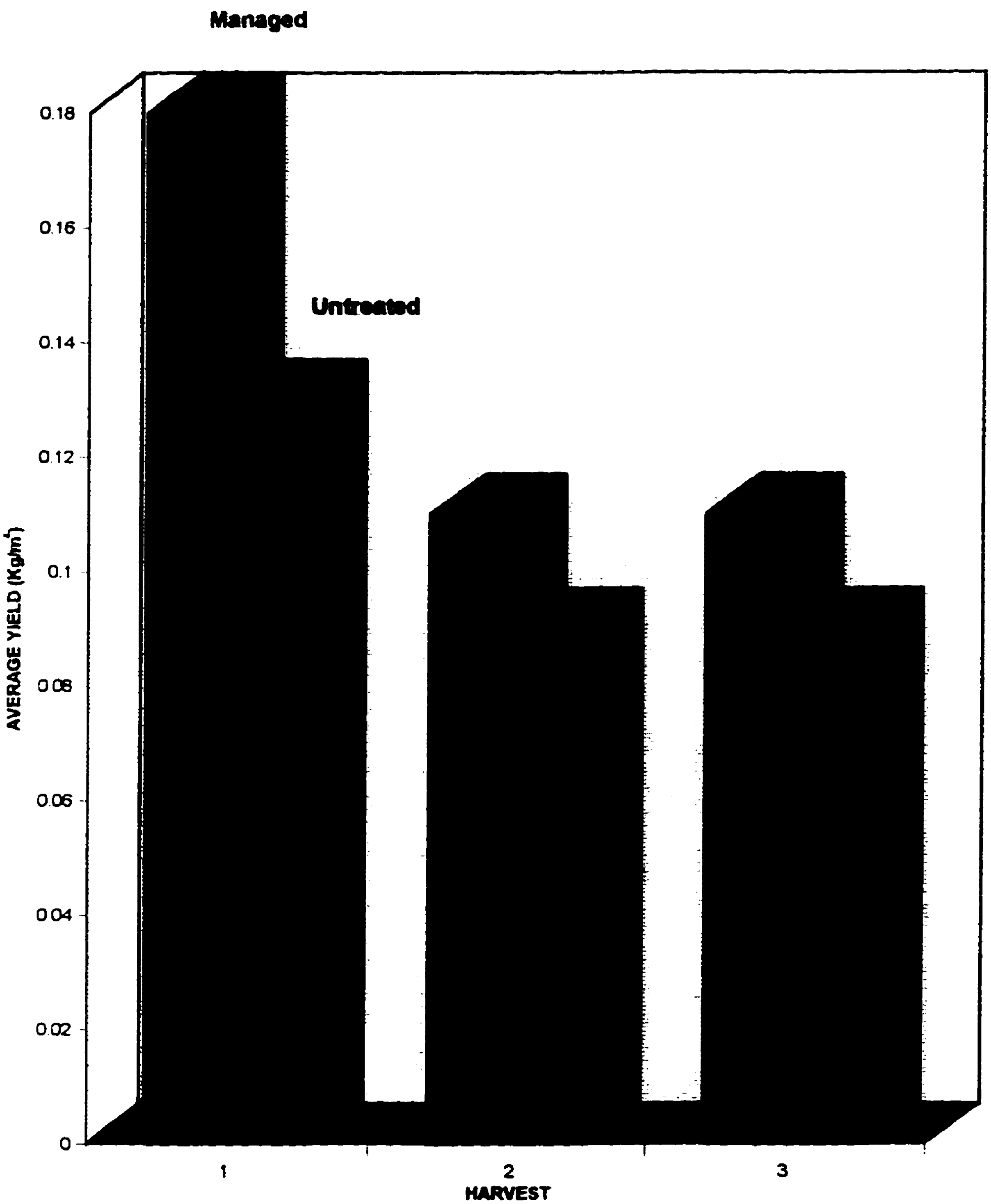


Table 7: Breach of Buffer

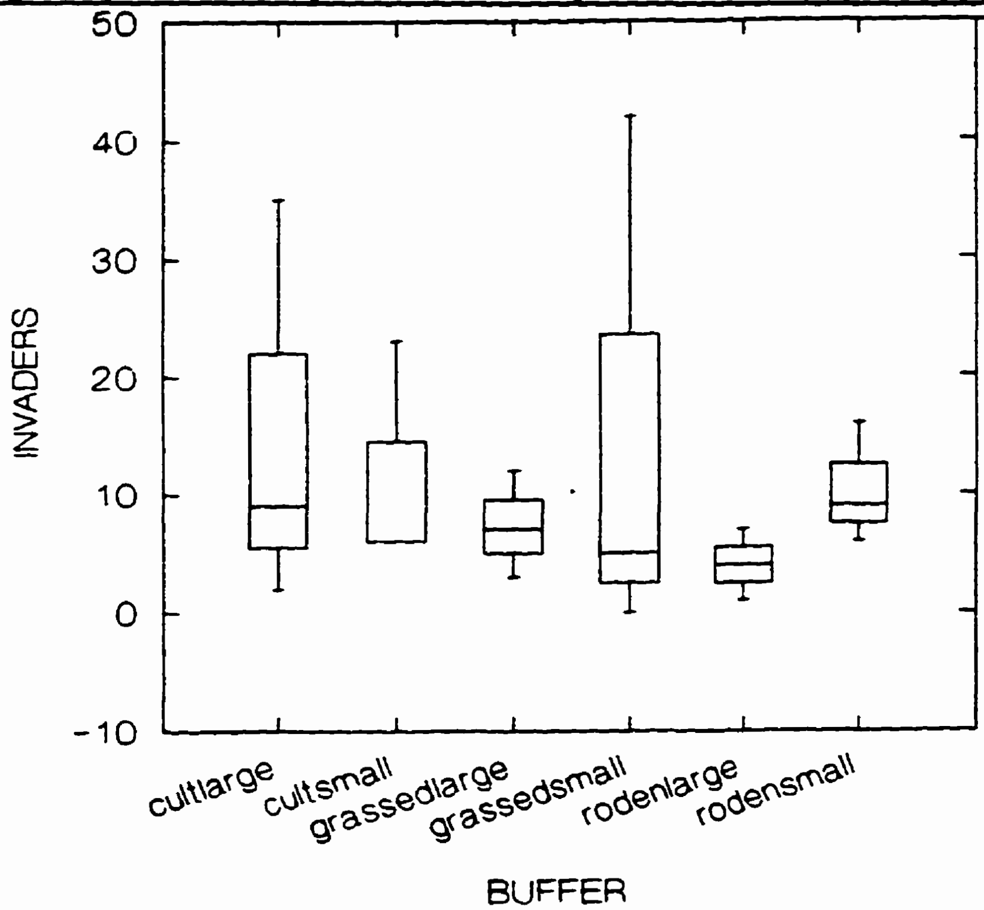
Buffer Type	*Buffer Width*	*# of breaches (sign) within managed plots*
Cultivated	**3.66 m**	**11**
Cultivated	**7.32 m**	**36**
Grassed	**3.66 m**	**30**
Grassed	**7.32 m**	**9**
Rodenticide	**3.66 m**	**22**
Rodenticide	**7.32 m**	**5**

An analysis of variance compared the effectiveness of the buffers in relation to one another. This technique compared all the pairs of treatments and widths in order to check for significance using multiple comparisons. P-values indicated that there was no significant difference between the buffer types, widths, or interactions of both. This was due to the relatively small sample size of each treatment (3). This indicates that under comparable conditions, the buffers will perform at similar levels of efficiency.

Type: p= 0.833
Type x Width: p= 0.754
Width: p= 0.339

The squared multiplier (R= 0.192) indicated that the ANOVA model accounted for 19.2% of the variability in the number of invading gophers. These quantitative conclusions are in agreement with the qualitative conclusions drawn from the following density plot.

Figure 10: Dallal Density Plot: Buffer comparisons



The differences between the medians (indicated by the lines within the graph boxes) are almost the same for 3.66 m and 7.32 m buffer widths, as well as for the different treatment types. This suggests that there is no interaction or significant difference between buffer type and width.

The data indicates that the rodenticide 7.32m buffers seem to be most effective in deterring pocket gophers from an area. The effect of the size of zone differs by zone type. Rodenticide and grassed 7.32m zones showed more promising results than the 7.32m cultivated zones. The effect of the individual treatments differs by type as well, with rodenticide being most effective followed by grass and cultivated buffers respectively.

4.3 Objective 3: Providing Management Strategies for Forage Producers in Manitoba

The losses indicated in Objective 1 relate to yield alone, and do not consider the effects of machine damage, labour and forage quality losses. These results, as well as the buffer findings will be carried over to the Objective 3 discussion and used in the development of a management strategy.

Chapter 5

DISCUSSION AND OBSERVATIONS

The focus of this chapter is to discuss the results of the yield and buffer studies in view of other findings and personal observation. Based on this discussion, a strategy will be devised to serve as a management tool for forage producers in Manitoba (Objective 3). This strategy will ultimately encompass all predicted gopher-related losses and suggestions for effective and economical control options in Manitoba.

5.1 *Objective one: The Impact of the Northern Pocket Gopher on Alfalfa Yield in Manitoba*

The resulting yield losses in the three harvests may have occurred for a number of reasons. In this study, the combined effects of crop consumption by gophers, mound smothering, and decreased quality of harvest are considered to be the largest contributors to alfalfa yield loss. The following discussion will consider these reasons, as well as the methodology used, in an attempt to explain the total average yield loss (22.9%) and the fluctuating losses between harvests.

Yield losses averaged 22.9% over three harvest periods and were similar to the yield damage caused by plains pocket gophers on the US plains, as reported by Foster and Stubbendieck (1980), Luce et al. (1981), and Hegarty (1984). In these previous studies, pocket gophers reduced yields from 17 to 46 percent. Although the studies showed similar results, there is a considerable size difference between the plains pocket gopher and the northern pocket gopher. The plains pocket gopher weighs almost twice that of a northern pocket gopher and likely requires lower population densities to produce the results mentioned.

Alfalfa supports the proliferation of gophers in Manitoba due to its high nutrient and moisture content. Pocket gophers in Alberta are known to consume their own weight in alfalfa on a daily basis (Proulx pers. comm 1994), suggesting that the losses in harvested alfalfa yield recorded in this study may be partially attributed to crop consumption. However, it is the reduced growth due to smothering by soil mounds excavated by the northern pocket gopher that is likely responsible for the majority of damage seen on Manitoba alfalfa fields. As estimated in Case (1983), pocket gophers each may bring up to 1130 kg of soil to the surface annually. Excess soil not only smothers crops, but also makes it very difficult to harvest the crop, as areas with heavy mound densities are bypassed, or cut at a higher level, to avoid contact between knives and soil. In a landowner opinion survey, Deniset (1994) found that producers considered machine damage due to pocket gopher activities to be greater (43.6%) than crop consumption (18.48%) and reduced harvest (29.38%).

Alfalfa yield losses ranged from 18.2% in Harvests 2 and 3 to 27.8% in Harvest 1. In other studies on pocket gopher damage, obvious causes for similar yield losses were direct consumption and burial of vegetation. In studies by Case (1989) is was suggested that plant vigor is also affected by pocket gopher activity and can influence the competive capabilities of alfalfa. This was made evident by the larger yield decreases seen on irrigated alfalfa as compared to dryland habitats (Case 1989). The fluctuating results in this study may have been affected by a number of variables including:

- Trap effectiveness within managed plots.

- Variable alfalfa stand densities and productivity throughout the study period and between sampled plots.

- Seasonal activity patterns of the northern pocket gopher and the timing of yield sample collection.

As reported by Deniset (1994), trap efficiency on Manitoba alfalfa fields was estimated at 44.25%. Consistent with these findings, maintaining 100% gopher-free status within managed plots proved difficult. Prior to Harvest 1 (June 13, 1995), determining successful trapping techniques and the most effective traps to use, required some experimentation. Once it was established that certain techniques and traps were not as effective as others, they were discarded and replaced with more successful designs and methods. It may be that more pocket gophers successfully entered the managed plots at this time than during the pre-trapping periods in Harvests 2 (July 17, 1995) and 3 (July 1, 1996). The alfalfa yields from the Harvest 1 managed plots may have been higher if control techniques were more successful. Thus, the 27.8% yield loss reported in Harvest 1 may have been somewhat understated.

This variable may have played a smaller role in Harvests 2 and 3. Trapping effectiveness was higher, but the pocket gophers still migrated across the buffer zones and produced mounds before being trapped out. For example, during the trapping period prior to Harvest 2, pocket gophers seemed to be more active than during the other harvests. Five of the managed plots experienced a large infestation of pocket gophers and were subsequently eliminated from the yield trials as it was felt that they did not represent a managed environment. Criddle (1930) found in southwestern Manitoba that the northern pocket gopher went through periods of high and low activity throughout the spring, summer and fall seasons. Peak activity periods occurred in April and late August in Manitoba. Miller and Bond (1960) assessed activity trends in Colorado populations, revealing only one peak in late August. High incidences of surface mounds in this study seemed to coincide with the estimated times of late postnatal care and dispersal of young from the maternal burrow system to independent territories. Overall, any mound produced within the managed plots by an invading gopher decreased yields within the plots, which again suggests the understatement of average yield losses in all Harvests for those managed plots that had had gophers in them for any period of time between sampling.

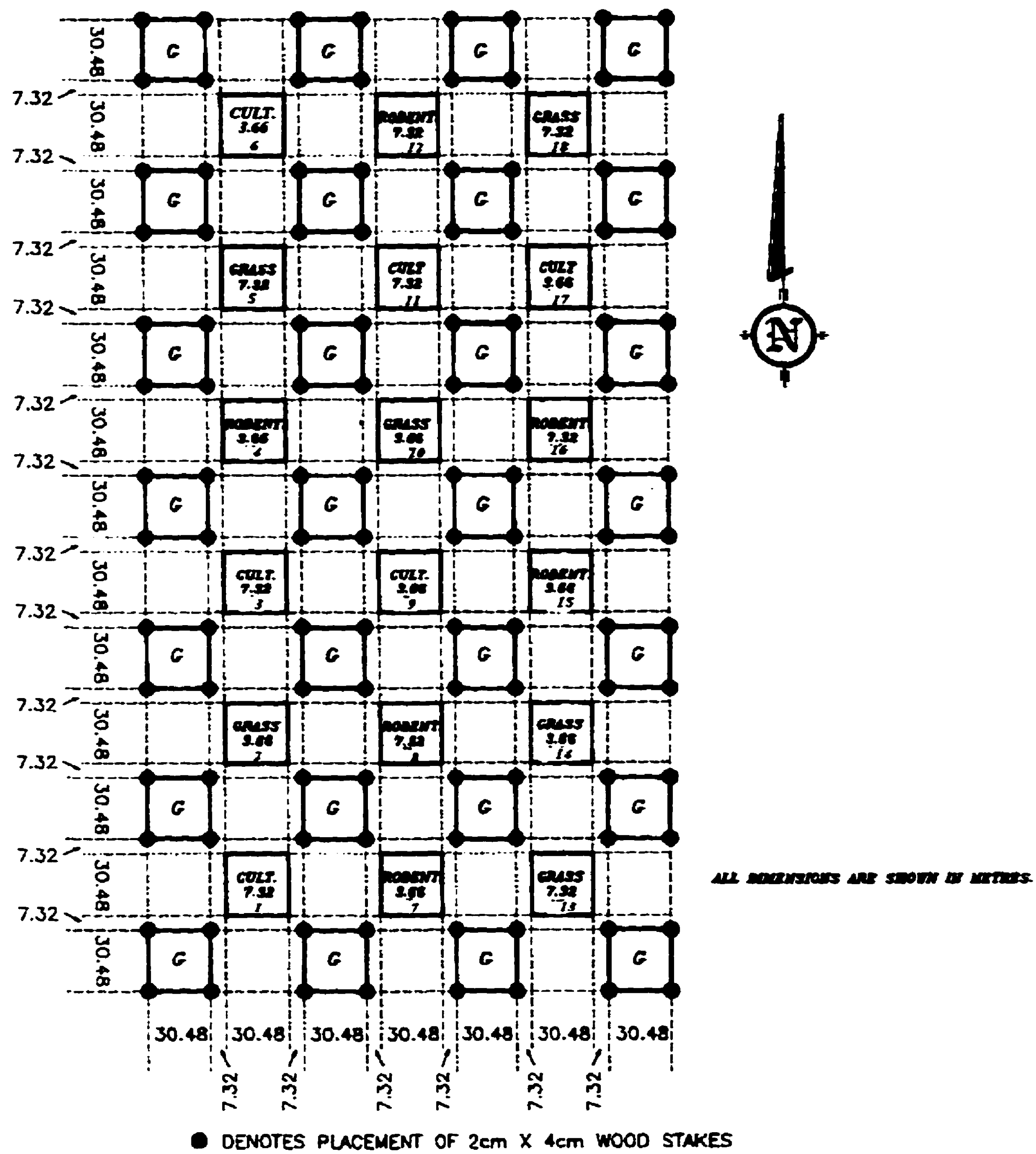
There was a noticeable degree of variability in the managed plot stand densities. In most cases, plots supporting the greatest plant densities exhibited higher gopher activity. This increased activity was made evident by the number of mounds present on the plots at study commencement and the higher labour component required to keep these plots free of gophers during the study. Since all managed plots were used in the yield sampling during Harvest 1, areas of low, medium and high stand densities were all represented. This was not the case in Harvests 2 and 3, as several of the higher density managed plots were not used in the analysis due to gopher re-invasion. As can be seen in Figure 7, approximately one-half of the randomly selected control plots in Harvest 2 were concentrated around high alfalfa density areas (Figure 11), whereas the managed plots representing these areas were not sampled. Eliminating yield measurements from plots that supported high alfalfa densities caused the range of difference in yields between untreated and managed sites to decrease. Incorporation of these higher density managed plots could account for the larger range between managed and untreated plot yields (.18 kg/m² vs. .13kg/m² respectively) in Harvest 1, and thus higher average yield decreases.

The results of objective 1 determined that the yield losses associated with gopher consumption and damage averaged 22.9% over a total area of 1463m² in three harvest periods, rejecting the null hypothesis that alfalfa yield is decreased due to the activities of the northern pocket gopher in fields where they occur compared to fields where they do not. These losses were likely understated due to the methodology and study field used and fall below some studies stated previously. Performing this study on a new alfalfa stand may have reduced the effects of some variables. *Minimum* losses of 22.9% will provide information for forage producers in pocket gopher management decision-making.

5.1.1. Relating yield loss to sign density

The resulting numbers show no clear relationship between gopher sign density and yield

Figure 11: Study site: observed areas of high alfalfa densities



losses in an alfalfa field. For example, Harvest 2 samples (Table 8) were taken during a representing period of high sign density (0.32 sign/m²), however the associated yield losses (18.2%) were identical to those seen during a lower sign density period in Harvest 3 (0.05 sign/m²). This suggests a more complex relationship, one which should consider such variables as pocket gopher foraging strategies, behaviour and the dynamics of an alfalfa stand.

Table 8: The relationship between sign density and yield loss

HARVEST	Sign Density (sign/m²)	Yield Loss (%)
Harvest 1: June 13, 1995	0.07	27.8
Harvest 2: July 17, 1995	0.32	18.2
Harvest 3: July 1, 1996	0.05	18.2

The rate of pocket gopher invasion into a newly established alfalfa field likely depends on it's proximity to other alfalfa stands with gophers. Isolated fields would experience slower rates of migration than fields surrounded by previously established stands. At any rate, the level of initial infestation into an alfalfa field will vary with each site. Being surrounded by older alfalfa stands, the study field showed the first indication of pocket gopher presence occurred almost immediately after the stand was established (VanderKroon 1995, pers. comm.).

For the purposes of further discussion, Table 9 outlines a brief history of the study field.

Table 9: Field history

YEAR	FIELD STATUS
1991 (Year 1)	Stand establishment.
1992 (Year 2)	Pocket gopher presence observed.
1993 (Year 3)	Gopher activity managed by means of trapping. Approximately 1200 gophers removed from the field.
1994 (Year 4)	Study commencement.
1995 (Year 5)	Harvest 1 and 2 yield sampling.
1996 (Year 6)	Harvest 3 yield sampling. Stand cultivated.

Andersen and MacMahon (1981) researched the dynamics of northern pocket gopher populations in Utah. Their findings indicated, with the support of Vleck's (1979) work on fossorial bioenergetics, that population densities were correlated with the below ground density of palatable plant matter. Pocket gophers in forage fields have more spatially concentrated food resources, and thus have smaller territories than other mammals (McNab 1963). Gettinger (1984) points out that territorial boundaries change very little from year to year in adult *Thomomys* and the length of burrows are significantly shorter in more productive habitats (Reichman et al. 1982). Loose, porous soil conditions required for alfalfa growth are also preferred for the tunnelling activities of *Thomomys* (Runnells 1988). These studies suggest that in an alfalfa field, like the one under study, the concentrations of perennial forbs reduce the energy costs incurred to the animal while foraging, allowing pocket gophers to exist at very high densities. Once densities reach the maximum level food supply will permit, the solitary animals space their burrow systems (home ranges) by aggressive exclusion of others.

At some point after the initial influx of pocket gophers into an alfalfa field (Table 9: Year 2), territories are established and the field will eventually reach a point of saturation. The rate at which this point is reached is likely related to the position of the field with respect to other sources of gopher recruits and food supply (as mentioned previously). It is a dynamic equilibrium, balancing mortality due to age, disease and predators with recruitment due to reproduction and immigration, played out against stand history and weather patterns.

Once a field becomes saturated with pocket gophers, it can be speculated that the dispersing young of the year have little effect on alfalfa yield. Due to the lack of unoccupied territories, juvenile gophers must migrate elsewhere to establish new burrow systems. This does not imply that territories remain static in size. Invasion of neighbouring systems that have been vacated occurs rapidly (Ingles 1952, Miller 1964) suggesting that individuals must maintain a certain awareness of each neighbour through surveillance along territorial margins (Wilks 1963). Interspecific aggression restricts juveniles from moving into occupied burrows, as pocket gophers are solitary in nature and aggressively defend their territories.

At study commencement (Year 4), the pocket gopher population in the field was rebounding after the intensive trap-out of 1200 gophers. The large number of vacant burrows likely encouraged the rapid re-invasion of dispersing juveniles and other adults immigrating from marginal areas to more favourable sites. Looking to the results (Table 8, Table 9), Year 5 marked the timing of the first yield sample performed during Harvest 1 (June 13, 1995). This was a "pre-dispersal period," as by most estimates young pocket gophers remain under maternal care until approximately 5 to 6 weeks of age (Criddle 1930, Wight 1930, Miller 1946, Deniset 1994). This may account for the relatively low average sign count (0.07 sign/m^2) over all untreated plots. Harvest 3 (July 1, 1996) also falls into this period of pre-dispersal, showing an average sign count of 0.05 sign/m^2. This reasoning is consistent with the findings of Runnells (1985) who reports that the greater proportion of juveniles (*Thomomys talpoides)* in a Saskatchewan population leave the maternal burrow by the second week of July. Harvests 1 and 3 were very similar in terms of total area sampled and timing of harvest as well, however yield losses were greater in Harvest 1. The differences between average yield losses in the Harvests (27.8% and 18.2%) may suggest that damages in yield plateau after the stand reaches a specific gopher density (saturation point). Comparative yield losses on a younger alfalfa stand may initially be greater (Harvest 1, 27.8%) and then gradually plateau (Harvests 2 and 3, 18.2%) as the stand ages. This observation may also imply that after gopher removal in Year 3, the population took two years to grow to a point of saturation.

Assuming field saturation is further supported by the results of the Harvest 2 yield trials. Samples were taken after juvenile dispersal (July 17, 1995) and showed a higher sign density (0.32 sign/m²). From this, the percent average yield decrease was expected to be greater than that of Harvests 1 and 3; however, the resulting loss was identical to Harvest 3 (18.2%). This may suggest that the juveniles left the study site in search of unoccupied territory, and the higher sign density was due to increased activity of the resident adults.

Prior to this dispersal, neonates are believed to ingest solid food at age 17 days in the maternal burrow and by 37 days are weaned and feeding independently (Andersen 1978). This initial consumption all takes place in the maternal burrow, suggesting that the young use the existing burrow system to forage, producing mounds and other sign only when pushing up soil from the shorter lateral feeding tunnels. There is likely no major burrow construction at this time. This was observed in the small, concentrated mounds seen during the Harvest 2 census count. For example, 15 of the 25 sign counts taken in plot 5B (Appendix B) were small and concentrated in a 4 m² area of the plot, suggesting a lower impact on average yield. By 60 days, mutual intolerance necessitates separation (Andersen 1978, Runnells 1988, Deniset 1994), and the juveniles disperse. Since there was no observed increase in yield loss during Harvest 2, the field may have been at saturation point, forcing the young to establish territories outside the study site. In the process of dispersal, mound formation may have increased initially (accounting for the larger sign density), however not to a large enough extent to affect the yield.

In conclusion, the following suggestions have been made with respect to the relationship between gopher sign density and the resulting average alfalfa yield losses:

- Sign densities in Harvests 1 and 3 are indicative of a pre-dispersal period for pocket gophers.

- Sign densities in Harvest 2 suggest samples were taken during a post-dispersal period.

- The rate at which a field becomes saturated (reaches its highest density of gophers) depends on its location in relation to other gopher sources, stand density and soil/water conditions.

- Lower yield decreases observed in Harvest 2 (with respect to the high sign count) suggest that the study site may have been saturated with pocket gophers, forcing juveniles to leave the area in search of new territories. Once a field becomes saturated, juvenile dispersal has little effect on alfalfa yield.

- Damage in yield loss plateaus after the stand reaches a specific gopher density (saturation point).

- Intensive trap-outs (or the use of other control methods that remove large portions of the population) allow the rapid re-invasion of pocket gophers into alfalfa fields. Unoccupied burrows provide a ready made home for juvenile pocket gophers.

Accurate linking of pocket gopher densities to particular levels of yield loss can not be done at this time, however possible associations were discussed.

In summary, yield losses in this study were calculated in terms of quantity in the swath alone, and did not included losses due to machine damage, extra labour and forage quality losses. This measured yield loss is the first step in determining overall economic losses, leading to more informed choices of control techniques.

5.2 Objective 2: Buffer Zone Effectiveness

The rationale behind the establishment of a buffer zone around alfalfa fields was to determine the smallest, most effective zone of deterrence required to keep re-invading pocket gophers out of alfalfa stands. Sign (produced by re-invading gophers) counts taken in buffered plots varied with both treatment and width. Although the buffers require further investigation to determine overall effectiveness, the grassed 7.32 m wide and the rodenticide 7.32 m buffers did show some promise. These buffers resulted in only 9 and 5 buffer breaches respectively, over a period of 41 days. Proulx's (1995) border control strategy, incorporating 20 m to 60 m strips of the edge of alfalfa fields monitored and controlled by means of trapping, was successful in intercepting 79% of the invading pocket gophers (*T.talpoides)*. In Alberta, this strategy proved to be more effective than any other control technique studied.

With reference to the two most effective buffers in this study, we will discuss the practicality of a buffer zone in controlling pocket gopher re-invasion.

5.2.1. Establishing a 7.32 m Grassed Buffer Strip

A grassed buffer strip around an alfalfa field is conjectured to function as a barrier, due to the fact that >98% of the gopher's diet is forbs. Grass is seeded in the zone to eliminate the potential for soil erosion while providing no food for the gophers.

The 3 plots within the grassed 7.32 m zone experienced a total of 9 breaches throughout the monitoring period. Randomly positioned around two higher density (5,18) and one (13) lower density plots (Figure 11), this buffer seemed somewhat effective in keeping mound numbers down. With such a small sample size for each treatment (3), the rapid invasion of only one plot in the sample could alter results completely. For this reason, this study did not determine the effectiveness of this buffer zone with any degree of significance.

Points to consider in determining the practicality of a grassed strip in controlling pocket gopher re-invasion include:

(1) loss of harvestable alfalfa due to buffer establishment

Ideally, buffer establishment should commence during the first stand year and be maintained for stand duration, which averages approximately 6 years in Manitoba (Entz et al. 1995). Each spring forage producers should trap out all winter invaders within the field and monitor the buffer and field for the remainder of the season.

For every hectare of alfalfa on a field surrounded by a 7.32 m grassed buffer strip, 0.05 ha will be incorporated in the grassed strip resulting in a somewhat lower harvest value in the buffered areas. The costs of a grassed buffer strip are essentially the costs of grass seed/ha plus labour in establishment. The total costs of control over the life of the stand depend on the number of annual harvests in the 6 year period.

(2) potential problems with germination

In this study, dry weather delayed seed germination, making evident the obstacles affiliated with development. A lack of germination would basically leave a cultivated strip, leading to soil erosion and nutrient losses. As well, additional seed and labour would be required to attempt more successful germination.

5.2.1. Establishing a 7.32 m Rodenticide Buffer Strip

Establishment of a rodenticide buffer strip would prove most effective if developed at the time of seeding (any time prior to initial infestation). This study administered two applications of rodenticide in the selected buffers, one in the fall (*Gophacide*®) prior to monitoring and the second in the following spring (*Quintox*®). The plots surrounded by the 7.32 m rodenticide strips exhibited less mound formations than any other zone. This could suggest that these zones were somewhat more effective in deterring gophers from the plot. With the lower sign count observed in the 3 rodenticide buffered plots, we could postulate that some gophers were killed in their attempts to cross the zone.

Determining the practicality of a 7.32 m rodenticide strip in controlling pocket gopher re-invasion depends on the following:

(1) how many applications are required to keep the zone effective?

(2) what product should be used and when?

The research performed by Deniset (1994) on rodenticide effectiveness provided the basis for the products chosen for the buffer trials. *Gophacide*®, a strychnine-based poison, was found to be effective in fall applications and *Quintox*®, containing cholecalciferol, was more effective in spring applications due to its water-resistant qualities. The costs of a rodenticide strip will ultimately depend on the product used. The rodenticides used in this study represented both a higher-priced (*Quintox*®) and lower- priced (*Gophacide*®) product, allowing for a rational estimation of buffer establishment costs.

Based on manufacturers recommended application rates of 1.68 kg/ha for *Gophacide*® ($7.41/ha) in the fall and 3.36 kg/ha for *Quintox*® ($57.43/ha) (Bonnefoy 1995, pers. comm.) in the spring, the approximate cost of treating a 7.32 m buffer is $0.37/ha/year using *Gophacide*®, or $2.87/ha/year using *Quintox*®. Once more, these costs do not include labour and machine wear.

(3) the alfalfa remains in the buffer, thus there is no loss in yield.

This is beneficial for savings in yield revenue, however alfalfa growth makes it difficult to detect fresh mounding activity within the buffer. Grassed and cultivated strips allow for early mound detection as the vegetation is less dense or absent. Monitoring the buffer throughout the season would likely take more time and be less accurate.

5.2.2. Summary of Buffer Zone Effectiveness

As with any method of pocket gopher control, the goal is to limit the degree of damage and subsequently maintain higher yields in quantity and quality. The amount of alfalfa yield saved by the establishment of a buffer is unknown; however, based on the comparative yield results, it can be suggested that lower sign counts indicate higher alfalfa yields. The amount of crop saved using these methods would obviously lower the costs associated with buffer establishment.

Buffers were researched to determine their effectiveness in slowing the invasion of pocket gophers into fields. Although the sign counts in the 7.32 m grassed and rodenticide buffers were lower than those taken in the other buffered plots, we cannot make any definitive conclusions concerning the overall effectiveness of a buffer strip. The migration rates into these 7.32 m buffered plots were not compared to the rates seen in plots void of a buffer, during the same time of year. Further study is required to verify the effectiveness of buffer strips as a pocket gopher control method.

5.3 Objective 3: A proposed management strategy for the control of northern pocket gophers

Alfalfa is a perennial crop, planted in Manitoba for use as a forage. Average stand duration in the province is 6.5 years (Entz et al. 1995), during which the stand experiences fluctuating densities, peaking at year 2 to 3 (Mooney and Jeffrey 1994) and then gradually declining. Pocket gopher populations follow a similar trend in alfalfa fields: initial infestation, growth to peak capacity (saturation point), and finally population stability. A practical optimal strategy will be based on the dynamics of both the alfalfa stand and the pocket gopher population over a 6 year time interval (approximate average alfalfa stand duration in Manitoba). (Mooney and Jeffrey 1994)

The results of the yield trials determined that the average gopher-related yield loss on the study site was 22.9%, in the presence of 0.16 sign/m^2. With reference to the yield discussion, the field under study was considered to be at or near the point of saturation with pocket gophers. Applying these findings (22.9% average yield loss) to a standard average alfalfa yield curve for Manitoba (void of gopher damage) will allow for the determination of gopher-related losses over time. Once this is established, the costs of various control techniques can be incorporated into the scenario. In the absence of hard evidence, losses due to machine damage, increased labour and lower quality will also be discussed, allowing for a crude estimation of overall loss figures. These regimes can be used as management control guides for forage producers across the province.

5.3.1. Scenario One: Determining gopher-related losses in alfalfa yield revenue

Successfully determining the economic viability of a pocket gopher control technique requires an estimation of the cumulative gopher-related losses over the life of the stand. Using the results of the yield loss study and documented expected yields for alfalfa in Manitoba (Mooney and Jeffrey 1994), Figure 12 was derived.

Based on a two-cut regime with no fertilizer or irrigation, expected alfalfa yields peak in years 2 and 3, gradually declining as they approach year 5. The rate of initial pocket gopher invasion will depend on several factors specific to the field: location in relation to other occupied stands, soil type, and water conditions. In areas of high population densities, pocket gophers will likely migrate into the new stand during the first year of establishment. By the second harvest in year 1, the gopher-related losses may become evident, causing a decrease in total revenues. As the field reaches a point of saturation, observed in year 3 on the study field, losses begin to plateau (reflected in Harvests 2 and 3 yield differentials of 18.2%). For ease in discussion, Figure 12 shows a constant 22.9% gopher-related yield loss beginning at year 1.5 and continuing to stand termination in year 5. In a given forage field, actual alfalfa yield losses will fluctuate with the varying degree of pocket gopher activity and density. As postulated in the yield loss discussion (Objective 1), dispersing juveniles have essentially no on-going effect on the yield in a saturated alfalfa field..

Tables 10 and 11 outline the expected gopher-related yield losses in alfalfa over a 5 year period when no gopher control measures are undertaken. According to these average figures, the expected gopher-related losses are estimated at $361.65/ha ($1741.10-$1379.45) and pertain to yield decreases only. This figure can be considered the lower endpoint on the range of "cost of no control" per hectare, over 5 years on a gopher-infested alfalfa field. If other costs were included (e.i., machine damage, quality losses and labour), then costs and losses would increase.

Table 10: Annual returns/hectare of alfalfa in Manitoba, based on a 5 year cycle

YEAR	HARVEST	Approx. expected yield(tonnes/ha)*	Average price/ha ($)*	Revenue ($)
1	first	2.80	57.50	299.00
	second	2.40		
2	first	3.48	57.50	388.70
	second	3.28		
3	first	3.48	57.50	388.70
	second	3.28		

4	**first**	**3.14**	**57.50**	**349.60**
	second	**2.94**		
5	**first**	**2.84**	**57.50**	**315.10**
	second	**2.64**		
TOTAL:				***1741.10***

*Manitoba expected alfalfa yields and prices based on an economic analysis by Mooney and Jeffrey (1994), Department of Agricultural Economics, University of Manitoba.

Figure 12: Average alfalfa yields vs. gopher damaged yields over a 5 year stand duration

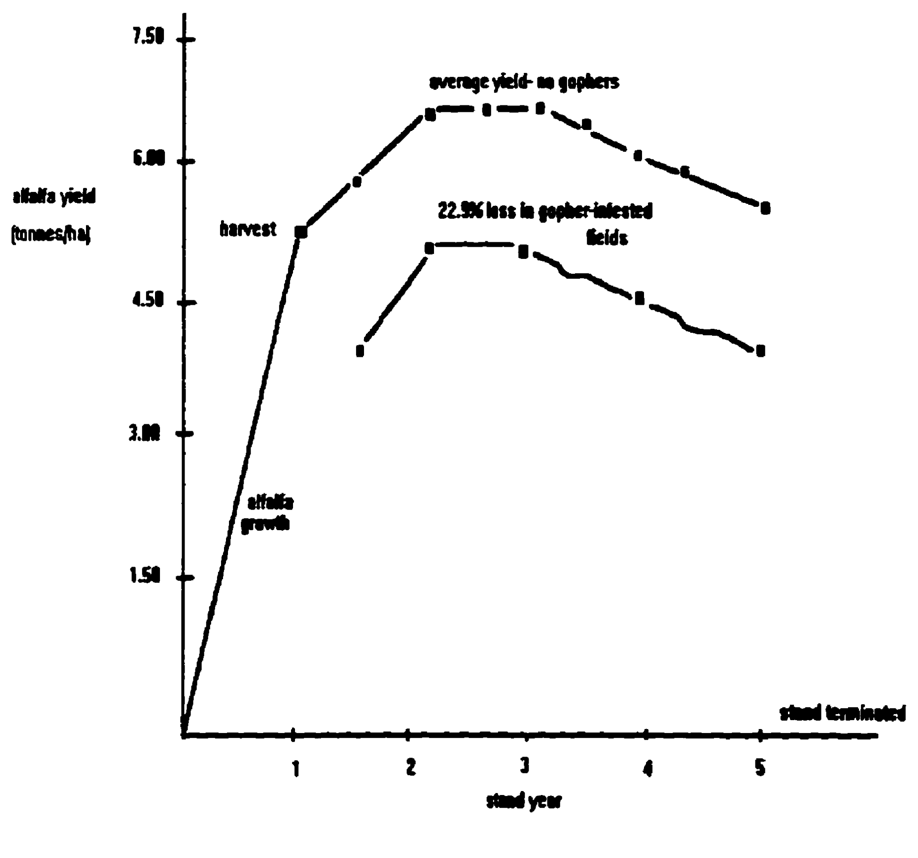


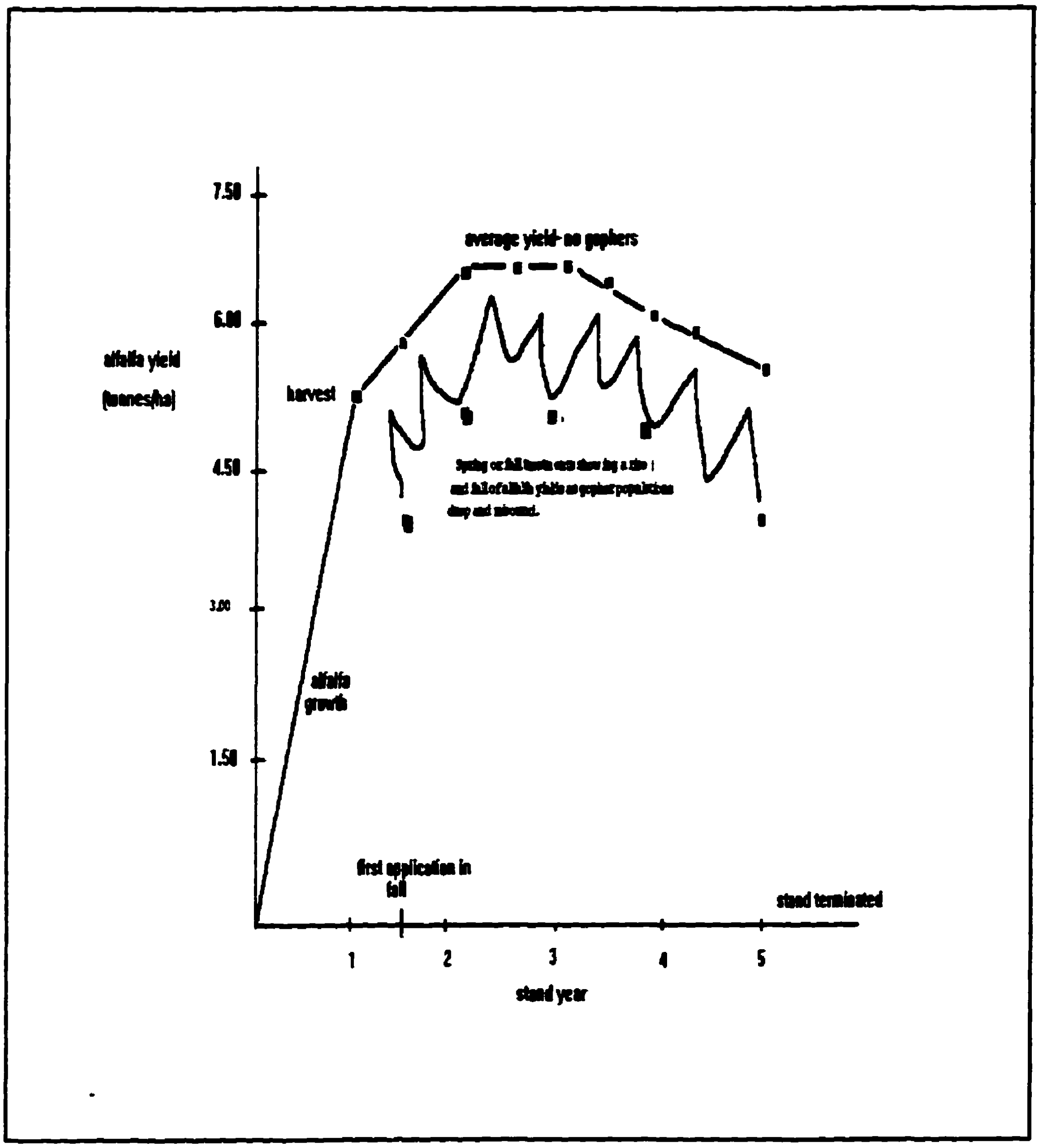
Table 11: Annual returns/hectare of alfalfa on gopher infested fields

YEAR	HARVEST	Approx. average yield(tonnes/ha)	*Average price/ha ($)	Revenue ($)
1	first	2.80	57.50	267.38
	second	1.85		
2	first	2.68	57.50	299.58
	second	2.53		
3	first	2.68	57.50	299.58
	second	2.53		
4	first	2.42	57.50	269.68
	second	2.27		
5	first	2.19	57.50	243.23
	second	2.04		
TOTAL:				*1379.45*

5.3.2. Scenario Two: The costs of administering a rodenticide

Now that the value of cumulative gopher-related yield losses have been estimated, we can determine the practicality of administering a control method. Deniset's (1994) research on the effectiveness of various rodenticides on alfalfa fields will provide the information necessary for this scenario. Deniset (1994) recommended that *Quintox*® was the product of choice for spring applications and *Gophacide*® was most effective in the fall. There were no conclusions made on the timing or frequency of rodenticide treatments in alfalfa fields, however, this scenario will administer one annual treatment of either *Gophacide*® in the fall or *Quintox*® in the spring, at the manufacturer's recommended application rates. Both treatments were effective in lowering pocket gopher numbers immediately after application, although gopher numbers increased post-treatment. This is

Figure 13: The effects of rodenticide treatment on alfalfa yield



illustrated in Figure 13, with the rise in alfalfa yield after treatment followed by a gradual decline as populations build up again. Figure 13 shows the commencement of treatment in year one, after the first harvest, and continuing until stand termination. Depending on personal choice and the degree of infestation in the fields, forage producers may choose different treatment regimes (Appendix E) with respect to timing and frequency of application. With reference to Figure 13, the costs of applying a rodenticide control are estimated as follows:

Table 12: The costs of applying a rodenticide over a 5 year period per hectare

YEAR	HARVEST	*COST OF GOPHACIDE® (FALL) ($)/ha	*COST OF QUINTOX® (SPRING) ($)/ha
1	first		
	second	7.41	
2	first		57.43
	second	7.41	
3	first		57.43
	second	7.41	
4	first		57.43
	second	7.41	
5	first		57.43
	second		
TOTAL:		29.64	229.72

- Refer to Appendix E for prices.

Table 12 provides an estimation of the costs of applying rodenticides to an alfalfa stand. The resulting cost of either $229.72/ha (Quintox®) or $29.64/ha (Gophacide®) over the five year period is less than the overall yield loss of $361.65, however treatment does not eliminate all gophers. Pocket gopher populations also rebound somewhat between treatments, adding an undetermined yield loss. These resulting costs of rodenticide treatment do not include machine rental and labour. These unknown additional costs, however, may be lowered when the savings in yield due to the reduction of gopher-related damages are considered.

5.3.3. Scenario Three: The costs of cultivating the stand

Finally, let us consider cultivating the stand every three years as a method of control. According to Entz et al. (1995), this procedure may benefit not only in destroying pocket gopher populations, but also in providing optimum nitrogen accumulation and enhanced weed suppression. This scenario assumes immediate re-establishment of the stand after termination, with no crop rotation or companion crops. Once more, initial gopher-related losses begin between the first and second harvests in year 1 and continue to year 3, at which point the stand is terminated after the second cut. According to the assumptions in the first scenario, the stand is cultivated at or just prior to the pocket gopher saturation point.

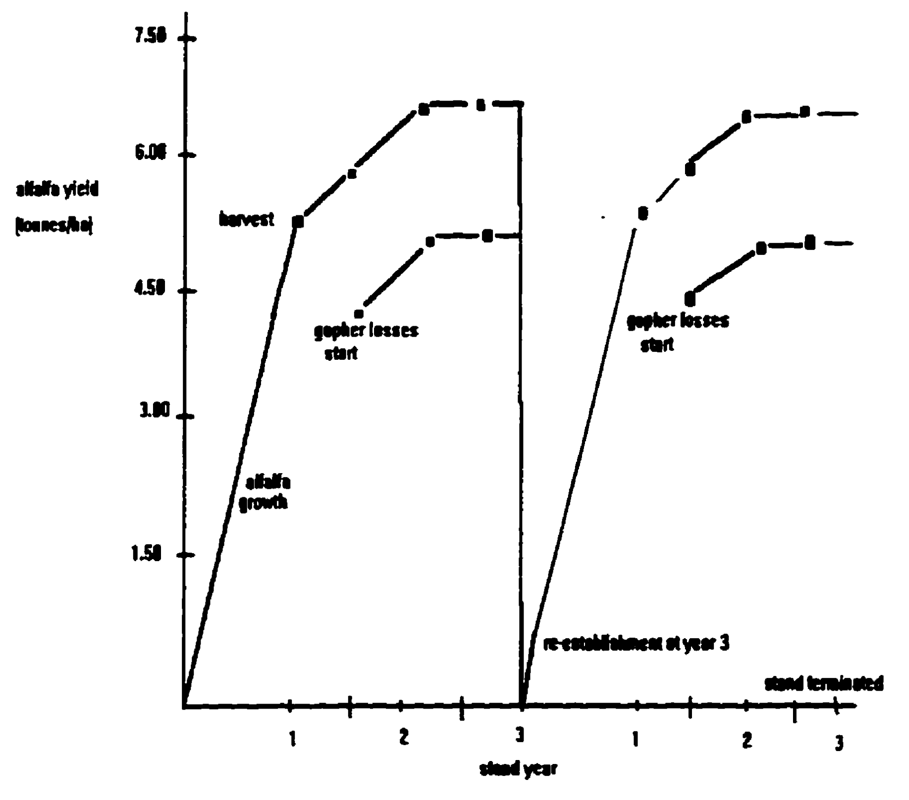
Table 13: Net revenues over five years incorporating re-establishment as a control method

YEAR	HARVEST	Average yield after 22.9% loss (tonnes/ha)	Average price/ha ($)	COST OF RE-ESTABLISHMENT ($/ha)*	Revenue ($)/ha
1	first	2.80	57.50		267.38
	second	1.85			
2	first	2.68	57.50		299.58
	second	2.53			
3	first	2.68	57.50		80.00

	second	**NO HARVEST**		**-74.10**	
1	**first**	**2.80**	**57.50**		**267.38**
	second	**1.85**			
2	**first**	**2.68**	**57.50**		**299.58**
	second	**2.53**			
TOTAL:					***1213.92***

***The costs associated with re-establishing the stand are estimated and include: labour, herbicide treatment and seed (Bruneau pers. comm. 1996).**

Figure 14: Yield losses occurring in stand re-establishment



The costs associated with re-establishing a stand, $527.18/ha ($1741.10 - $1213.92), exceed those of the other suggested control techniques over the 5 year stand duration. The estimated loss/ha ($74.10) incorporated the costs of herbicide treatment, alfalfa seed, labour and operating costs (Bruneau pers. comm. 1996). Once more, the costs of re-establishing the stand may fluctuate with the producer.

5.3.4. Determining machine damage losses

One of the limitations of this study was acquiring accurate records of machine damage costs incurred by producers on gopher-infested fields. A method to accurately determine the degree of machine damage caused by pocket gopher activity would be to compare the financial records of forage producers in infested areas with those in gopher-free localities. Farm financial records contain personal information that forage producers do not readily make public, and financial records are not always accurately recorded, thus, this methodology may prove difficult.

The Ste. Claude Pocket Gopher Control Association (Manitoba), through consultation with its alfalfa producing members, was able to provide an estimation of the extra (over and above typical machine costs) costs put into machinery used on gopher-infested fields. These figures are not based on hard data, but do provide insight for discussion and further study as 43.6% of forage producers consider machine damage to be the greatest loss associated with pocket gopher activity in Manitoba (Deniset 1994).

Bruneau (1996) estimates $12.35/hectare as the cost of machine damage due to pocket gophers annually. Conditioners and swathers endure the most damage. Knives on the swathers dull far more quickly due to mound formations and have to be replaced twice as often at a cost of $200.00 per set, plus labour.

5.3.5. Summary

Based on the yield losses recorded on the study site and the pocket gopher sign densities responsible for these losses, the three previous scenarios outline the cumulative costs associated with leaving the stand untreated, applying a rodenticide, and re-establishing the stand every 3 years, over a period of 5 years.

Table 14: The costs of management options

SCENARIO	COST/HA ($/ha) OVER STAND LIFE (5 YRS.)
1. NO CONTROL	361.65
2. APPLYING A RODENTICIDE ANNUALLY	229.72 (Quintox®) 29.64 (Gophacide®
3. RE-ESTABLISHING THE STAND EVERY 3 YEARS	527.18

As mentioned, these costs did not include machine damage, soil erosion, quality losses, or producer frustration. Determining the degree of yield loss per gopher (or gopher sign) cannot be accurately estimated until a more satisfactory census method is developed.

Specific to the study site, yield losses in the presence of an average gopher sign of 0.16 sign/m^2, were $361.65/ha annually over the life of the stand. This loss figure incorporates the cumulative effects of pocket gopher damage on yield, as well as the dynamics of the alfalfa stand.

Based on Table 14, applying rodenticide treatment to the field proved to be an economically viable option on the study site. Costs may change on fields where gopher sign densities differ from our study site. Re-establishing the stand in year 3, on the other hand, costs forage producers even more than administering "no control," as well as increased soil erosion. This suggests that stand cultivation would not be a wise management choice.

These suggestions, specific to the degree of damage on the study site, should provide farmers with a strategy to choose control options based on individual estimated gopher sign densities

Chapter 6

Summary and Conclusions

Investigating some of the costs associated with pocket gopher activity and the practicality of various control methods has uncovered some interesting conclusions with regard to gopher management strategies and the need for further research.

Objective 1

Objective 1 set out to determine the reduction in alfalfa yield due to pocket gopher activity (consumption and damage), and whether this loss was economically significant. Alfalfa plots managed by means of trapping were sampled during three harvest periods and compared to plots not managed for gophers. The results indicated a 22.9% average yield decrease over the three harvests. This loss, due to pocket gopher consumption and damage, should be considered economically significant. Census counts were performed on the untreated control plots to determine the gopher density responsible for the yield losses. Mounds and earth plugs on the untreated plots were flattened and left for 48 hours. Upon returning to the plots, all fresh sign were counted and recorded. Sign counts over all untreated alfalfa plots averaged 0.16 sign/m^2.

Objective 2

The results of the effectiveness of the buffer zones in slowing the re-invasion rate of pocket gophers into alfalfa fields as tested are inconclusive at this time. Effectiveness was determined by monitoring buffered plots for signs of gopher presence after initial populations were removed. Buffer performance was statistically analysed in relation to one another, resulting in no significant difference between buffer types, widths or interactions of both. This suggested that, under comparable conditions, the buffers would perform at similar levels of efficiency. Of all treatments and widths, the grassed 7.32 m and the rodenticide 7.32 m wide buffers seemed most effective in keeping gopher sign at a minimum. It is unknown, however, if these two buffer types significantly slowed the migration of pocket gophers into the plots, as no control plots were run for comparative purposes.

Objective 3

Developing and promoting the use of a management strategy for the control of northern pocket gophers in forage crops was the primary objective of the project. Yield losses resulting from gopher-related damage on alfalfa fields provided some of the economic information required to develop a strategy to assist farmers in making sound management decisions. Applying these findings (22.9% yield loss) to a standard average alfalfa yield curve allowed for the determination of gopher-related losses over stand duration. Various control techniques and their associated costs can be incorporated into this scenario, assisting producers in making sound management decisions throughout the varying stages of stand development.

Chapter 7

Recommendations

- The suggested strategy should be made active by forage producers to assist in making more informed pocket gopher control decisions

- Consultation with neighbouring producers and the municipality to discuss forage stand establishment schedules and long-term goals may assist in preventing large contiguous sources of gophers, i.e., monocultures of alfalfa forage production. Adjacency of favourable habitat inevitably contributes to rapid infestations and high pocket gopher densities, increasing yield losses and making management more difficult and costly. Making the "ideal" habitat less available and thus reducing source populations may be one management tool.

- The yield trials provided the preliminary determination of the effects of pocket gopher activities on alfalfa yield. In order to present a more accurate account of actual yield losses, it would be beneficial to study the progression of an alfalfa field from stand establishment and document the losses over time as the gopher densities increase and stand density/productivity decreases. This would incorporate the cumulative effects of stand dynamics and gopher population dynamics and activity patterns over time.

- As tested, the results of the effectiveness of a buffer strip in slowing the re-invasion rate of pocket gophers into alfalfa fields were inconclusive and require further research on their design and effectiveness.

- The benefits of shorter alfalfa stand durations, and alternative cropping, should be investigated that may have side benefits controlling gopher populations in alfalfa stands.

- Much of the information collected on costs associated with pocket gopher activities has been observational or estimated. These results require support from data generated from further empirical studies. Accurate accounts of losses to machinery, decreased alfalfa quality, and soil/water erosion should be compiled to aid in more accurate determination of the total overall losses associated with pocket gopher damage. This will assist in further management strategies.

- The establishment of an easy, accurate census method for pocket gophers in Manitoba, and the determination of home ranges, would greatly benefit forage producers.

- Premature cultivation of the stand as a means of pocket gopher control should be re-considered by forage producers as it is the most costly control method and it contributes to soil erosion.

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APPENDIX A: HARVEST 1 DATA

JUNE 13-14, 1995
YIELD: MANAGED PLOTS
Total area sampled: 549m² over 18 plots.

Plot Number (each plot 30.42m²)	Wet Alfalfa (kilograms)	Dry Alfalfa (kilograms)	Dry Alfalfa Yield (kg/m²)
1	17.65	5.02	0.17
2	7.65	3.52	0.12
3	23.30	5.77	0.19
4	12.35	4.73	0.16
5	9.45	2.87	0.09
6	15.50	6.24	0.21
7	7.00	2.46	0.08
8	13.50	5.16	0.17
9	15.60	5.90	0.19
10	10.50	4.09	0.13
11	8.20	2.61	0.09
12	11.40	3.50	0.12
13	14.40	4.45	0.15
14	22.60	10.86	0.36
15	8.00	6.30	0.21
16	18.55	8.36	0.27
17	18.55	8.36	0.27
18	30.30	10.09	0.33
Total:		97.71	**0.18 kg/m²**

JUNE 13-14, 1995
YIELD: UNTREATED PLOTS
Total area sampled: 549m² over 18 plots

Plot Number (each plot 30.42m²)	Census Count (sign/plot)	Wet Alfalfa (kilograms)	Dry Alfalfa (kilograms)	Dry Alfalfa Yield (kg/m²)
6C	3	14.85	3.75	0.12
11E	0	18.50	6.97	0.23
2D	0	5.70	2.20	0.07
7E	2	5.70	2.97	0.10
3E	13	5.00	3.14	0.10
2B	1	9.60	3.68	0.12
10G	2	10.60	4.50	0.15
1E	3	8.40	4.33	0.14
8E	0	8.45	3.61	0.12
5D	0	7.80	3.67	0.12
7A	7	11.20	3.72	0.12
4D	4	7.10	3.02	0.09
5G	0	22.00	5.19	0.17
6D	0	13.10	4.30	0.14
3C	0	9.75	2.75	0.09
5B	5	10.30	3.52	0.12
13A	0	16.65	5.01	0.16
5C	0	15.60	3.96	0.13
Total:	**40 in 549m² (.07 sign/m²)**		**70.29**	**0.13 kg/m²**

APPENDIX B: HARVEST 2 DATA

JULY 18-20, 1995
YIELD: MANAGED PLOTS
Total area sampled: 396m² over 13 plots

Plot Number (each plot 30.42 m²)	**Wet Alfalfa (kilograms)**	**Dry Alfalfa (kilograms)**	**Dry Alfalfa Yield (kg/m²)**
1	31.00	4.81	0.16
3	22.00	3.65	0.12
5	13.40	3.09	0.10
6	20.80	5.21	0.17
8	15.90	2.25	0.07
10	4.60	2.34	0.08
11	9.40	3.96	0.13
12	5.40	2.06	0.07
13	12.30	3.19	0.10
14	10.10	6.35	0.21
16	1.80	1.63	0.05
17	3.40	2.88	0.09
18	8.60	4.30	0.14
Total:		**45.72**	**0.11 kg/m²**

JULY 18-20, 1995
YIELD: UNTREATED PLOTS
Total area sampled: 396m² over 13 plots

Plot Number	Census Count (sign/plot)	Wet Alfalfa (kilograms)	Dry Alfalfa (kilograms)	Alfalfa Yield (kg/m²)
4C	21	16.50	2.21	0.07
5C	23	22.20	6.80	0.22
6A	14	14.20	2.76	0.09
5B	25	9.10	0.82	0.03
9A	8	14.00	4.49	0.15
10A	3	13.50	2.21	0.07
11A	1	13.90	2.36	0.08
6D	1	6.00	1.08	0.04
6E	0	4.80	1.09	0.04
1E	13	13.10	2.81	0.09
6F	2	3.60	2.11	0.07
4F	10	2.10	1.41	0.05
6G	22	9.70	5.34	0.18
Total:	**143 in 396m² (.36 sign/m²)**		**35.49**	**0.09 kg/m²**

APPENDIX C: HARVEST 3 DATA

JULY 1, 1996
YIELD: MANAGED PLOTS
Total area sampled: 518m² over 17 plots.

Plot Number (each plot 30.42m²)	Wet Alfalfa (kilograms)	Dry Alfalfa (kilograms)	Alfalfa Yield (kg/m²)
1	7.70	2.96	0.09
3	14.90	5.12	0.17
4	9.00	4.48	0.15
5	11.70	5.38	0.18
6	16.40	9.73	0.32
7	2.80	2.33	0.08
8	2.90	2.55	0.08
9	4.00	3.31	0.11
10	3.20	2.81	0.09
11	1.20	1.13	0.04
12	.50	0.42	0.01
13	4.00	2.80	0.09
14	4.00	2.51	0.08
15	3.10	2.51	0.08
16	1.90	1.79	0.06
17	4.40	3.62	0.12
18	5.50	4.57	0.15
Total:		58.02	0.11 kg/m²

July 1, 1996
YIELD: UNTREATED PLOTS
Total area sampled: 518m² over 17 plots

Plot Number (each plot 30.42m²)	Census Count (sign/plot)	Wet Alfalfa (kilograms)	Dry Alfalfa (kilograms)	Alfalfa Yield (kg/m²)
7A	3	11.90	3.89	0.13
4A	4	6.40	2.34	0.08
4B	1	13.30	3.89	0.13
5C	2	7.20	5.20	0.17
6C	2	4.40	3.69	0.12
7C	7	5.60	4.79	0.16
8C	4	3.40	3.37	0.11
11C	0	7.00	2.52	0.08
3D	0	1.60	0.24	0.01
4F	0	2.00	1.53	0.05
13E	0	2.60	1.87	0.06
2F	0	3.00	1.81	0.06
5F	1	2.60	2.03	0.07
7F	0	3.70	2.90	0.10
2G	1	4.40	1.73	0.06
6G	0	6.20	3.89	0.13
13G	0	2.90	1.31	0.04
Total:	**25 in 518m² (.05 sign/m²)**		**47.00**	**0.09 kg/m²**

APPENDIX D: BREACH OF BUFFER DATA

Grassed Buffer Zones

1) Grassed 3.66m Buffer Zones

Plot #	Sign in Plot
2	29
10	1
14	0
Total:	**30**

2) Grassed 7.32m Buffer Zones

Plot #	Sign in Plot
5	6
13	1
18	2
Total:	**9**

Cultivated Buffer Zones

1) Cultivated 3.66m Buffer Zones

Plot #	Sign in Plot
6	6
9	1
17	4
Total:	**11**

2) Cultivated 7.32m Buffer Zones

Plot #	Sign in Plot
1	30
3	6
11	0
Total:	**36**

Rodenticide Treated Buffer Zones

1) Rodenticide 3.66m Buffer Zones

Plot #	Sign in Plot
4	6
7	11
15	5
Total:	**22**

2) Rodenticide 7.32m Buffer Zones

Plot #	Sign in Plot
8	2
12	1
16	2
Total:	**5**

APPENDIX E: CONTROL OPTIONS

CONTROL OPTION	LABOUR REQUIRED	EFFECTIVENESS AND PRACTICALITY	COSTS ($)
1. TRAPPING	*All trapping requires a very high labour component. Fields must be monitored regularly.*	*Trapping is not recommended on large fields with high gopher densities (Deniset 1994).*	*Recommended purchase of at least 30 traps to effectively treat a forage field, thus individual trap prices are x 30. These are one time costs and do not include the labour component*
Easy Set	HIGH	35.9%*	**148.50****
Macabee	HIGH	51.5%*	**243.00****
Quick-set	HIGH	unknown in Manitoba	**390.00****
Zero long-spring	HIGH	unknown in Manitoba	**225.00** new** **120.00** used**
Blackhole	HIGH	42.8%*	**450.00****
Topniks Wooden Box	HIGH	46.8%*	**284.70****
Sidman	HIGH	Trap of choice in Alberta, unknown in Manitoba	**358.50****
Sure-catch	HIGH	unknown in Manitoba	**268.50****
2. RODENTICIDES	*Moderate level of labour*	*Multiple applications will be required.*	*Costs are per treatment, and do not include machine rental, wear and labour.*
Quintox®		More successful in spring applications due to water-resistant qualities (Deniset 1994). ■Average fields usually require annual treatments	**Dealer must order a minimum of 60 containers and buyer must guarantee purchase of a minimum of 10 pails (Bonnefoy 1995).** **57.43/ha** **23.25/acre** **at manufacturer's recommended rate**

Gophacide®		Effective in fall applications (Deniset 1994). ■ RE-INVASION WILL OCCUR	**7.41/ha** **3.00/acre**
Prozap		Success seen in fall and spring applications (Bonnefoy 1996). ■ RE-INVASION WILL OCCUR	**35.20/ha** **14.25/acre**
4. Cultivating and re-establishing the stand		Obviously, the most effective way to control pocket gophers	**74.10/ha** (Bruneau 1996)
5. Fumigants (Anhydrous ammonia)		Lacking research/ documentation	
6. Repellants (naphthalene)		Still under investigation in Alberta	

* based on the findings of Deniset, 1994
** refer to Table 3 for distributor