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The Influence of Agricultural Land Management on Antecedent Soil Water and Runoff Generation

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE INFLUENCE OF AGRICULTURAL LAND MANAGEMENT ON ANTECEDENT SOIL WATER AND RUNOFF GENERATION. submitted by Alfred Roderick Burk in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN WATER AND LAND RESOURCES.

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With happiness and the wealth of knowledge,

I dedicate this manuscript to my wife and loving family

for their tireless support and encouragement.

Abstract

Antecedent soil water and runoff generation were examined on hayed, mowed, fallow and grazed treatments to determine the impact of land management on soil hydrologic responses during two field seasons. Potential for runoff generation was low on all treatments during summer months as soil water was generally less than half of available water during both seasons on reclaimed and unmined land, being near both field capacity and wilting point five times during the two seasons. Vegetated treatments had low soil water throughout the soil profile while cultivated soils had slightly higher water content with depth. Under simulated rainfall, infiltration rates in hayed and mowed treatments were higher than those of fallow treatments. Cultivated treatments had higher runoff coefficients than hayed and mowed treatments, although there was generally little runoff even with the high rainfall intensity. Poor functional relationships for both initial abstraction and 5-min infiltration rate with degree of saturation were found for all treatments.

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Table of Contents

List of Tables

List of Figures

1. Introduction

1.1 Background

Surface runoff is generated by a variety of surface and near-surface flow processes, which include Hortonian overland flow, saturation excess overland flow, throughflow, partial-area runoff, direct channel interception and surface phenomena such as crust development and frozen conditions (Ponce and Hawkins, 1996). Hortonian overland flow occurs when the rainfall rate exceeds infiltration capacity. Infiltration occurs at a rate that decreases with time. Infiltration capacity defines the maximum possible rates of infiltration with time (Freeze and Cherry, 1979).

Runoff has often been simply expressed as rainfall minus abstractive losses or abstractions. These abstractions include: interception storage, surface storage, infiltration, evaporation and evapotranspiration (Ponce and Hawkins, 1996). For short periods of time, as for example those used in rainfall simulation, the latter two factors can be ignored. For large areas, surface storage occurs in ponds, puddles and other small temporary storage locations (Ponce and Hawkins, 1996), while for small areas it is usually a result of surface features. Soil surface characteristics of importance to infiltration and runoff include roughness, vegetation, micro-topography, crust and stone cover (Morin and Kosovsky, 1995). Vegetation affects infiltration and thus runoff in several ways: the surface cover intercepts rainfall reducing raindrop impacts, which in turn reduces crust formation while roots generate macropores and stabilizes soil aggregates enhancing infiltration (Morin and Kosovsky, 1995). They found that a bare plot generated 25% runoff but a vegetated plot only 9%. Thus land management practices which control vegetative cover and manipulate the soil surface play a key role in infiltration and runoff.

When accumulated runoff is plotted against accumulated rainfall, runoff starts after some rainfall has collected and the line of relation curving between these two parameter's curves becomes asymptotic to a line of 45° slope (Rallison, 1980). The term 'initial abstraction' was developed to represent the amount of water 'stored' after rainfall begins but before runoff starts and is an integral part of the SCS Curve Number technique for determining storm runoff. This technique is in essence an infiltration loss model (Ponce and Hawkins, 1996). Initial abstraction represents interception, surface storage and infiltration that occur before runoff begins (Rallison, 1980). Soils with high initial infiltration rates would thus have high initial abstraction. Antecedent soil water affects initial abstraction through its effect on infiltration, although its relationship with initial abstraction has not been quantified in the literature. This effect is recognized in the SCS method through variation of the antecedent moisture index (Ponce, 1989). The dry antecedent moisture condition (AMCI) has the lowest runoff potential, the average antecedent moisture condition has an average runoff potential, while the wet antecedent moisture condition (AMCIII) has the highest runoff potential (Ponce, 1989). Since water is transpired by vegetation and evaporated from bare soil, land management that affects either water use or surface cover is indirectly linked to runoff through changes in antecedent soil water. Reduced infiltration due to increased bulk density, poor transmissive properties of soil, surface sealing and/or reduced vegetative growth increases runoff. Evaporation and transpiration influence surface runoff by reducing antecedent soil water. The importance of land management in affecting runoff is recognized in the SCS curve number technique by alterating curve number based on cover type and hydrologic condition, in conjunction with a hydrologic soil group (Ponce, 1989). Halvorson and Doll (1991) showed that topographic position on undisturbed soils affected total water use.

Tillage of agricultural soils affects erosion in that rough surfaces produce less runoff than bare, flat surfaces. Since retention of water between clods on rough surfaces is high, ponding depth in depressions is also high producing longer detention time and a greater hydraulic gradient (Onstad, 1984; Freebairn et al., 1989; Razavian, 1990). Under these conditions infiltration is favored, resulting in the recharge of soil water. Surface residue under no-till and chemical fallow rotations increased rainfall storage efficiency (Tanaka and Aase, 1987; Jones et al., 1994), although infiltration can be reduced on no-till rotations due to crusting (Jones et al., 1994). Freebairn et al. (1989) concluded that cultivation of a silty loam soil increased runoff generation due to surface sealing and a lack of crop and residue cover. Crop rotations that include a stubble-mulch management regime increase infiltration by preventing surface crusting, decreasing bulk density and increasing surface roughness and depression storage capacity (Jones et al., 1994). Van Vliet and Hall (1991) reported that crop rotations including fallow periods had higher overall runoff volume, runoff proportion and soil loss than rotations which incorporated a perennial grass cover of fescue. Surface sealing of tilled winter wheat plots has resulted in increased runoff due to a lack of macropores and biopores which subsequently limits the amount of water entering the soil profile (Dao, 1993). Studying an alfalfa field on a sandy loam soil, Meek et al. (1989) showed that increases in bulk density due to wheel traffic did not decrease infiltration as might be expected. Rather, a decrease in stand density and the subsequent decay of tap roots provided channels (biopores) for infiltration, even on soils compacted by harvest traffic. Bowyer-Bower (1993) and Dao (1993) determined that steady-state infiltration was dependent upon soil type and condition, antecedent soil water content and rainfall intensity.

Grazing reduces vegetative cover, increases bulk density and increases runoff volume (Naeth et al., 1991). Thurow et al. (1988) found that heavy continuous and high intensity, short duration grazing decreased the infiltration capacity of silty clay soils. Examining three rangeland-soil-vegetation complexes in the Walnut Gulch Experimental Watershed in southeastern Arizona, Tromble et al. (1974) found that vegetation and soil surface condition were key factors in determining infiltration. In plots that were devoid of vegetation or in expanses of bare soil between individual plants, infiltration rates were significantly lower than in vegetated areas. Greater litter accumulation resulted in a higher cumulative infiltration while pre-wetting of the surface soil lowered infiltration. Increases in bulk density by compaction reduced both ASW and infiltration (Tromble et al., 1974).

Infiltration, runoff and soil water content are affected by soil disturbances such as surface coal mining and subsequent reclamation. Disruption of in situ properties is an important consequence of mining and reclamation (Potter et al., 1988). Operations used to replace subsoil and topsoil in reclaimed lands generally cause soil compaction which could reduce infiltration, increase runoff and restrict rooting depth which in turn would increase soil water. Four and 11 years after soil construction, bulk density, pore size distribution and hydraulic properties were substantially different in reclaimed soils relative to an equivalent undisturbed soil (Potter et al. 1988). Silburn and Crow (1984) concluded that, as a result of mining, runoff from reclaimed profiles would be greater than that from natural soils due to a reduction in depth to the least permeable layer in the profile (reduced by about 50% after mining), a reduction in hydraulic conductivity throughout the profile due to the decreased percentage of large pores and the lower saturated hydraulic conductivity of the spoils compared with the natural subsoils. Since normal reclamation practice is to place uniform depths of topsoil and subsoil across the landscape, this technique often changes the topsoil and subsoil depths from the premine conditions (Schroeder, 1995). However, he found that these differences in depth did not affect soil water differently on reclaimed minelands than on undisturbed landscapes in a semi-arid climate.

Jorgensen and Gardner (1987) found that infiltration rates on newly reclaimed minesoils were an order of magnitude lower than those of adjacent, undisturbed soils and that there was a strong temporal variation in these rates. Infiltrated volumes under mined surfaces varied from 13 to 94% of the applied rainfall (using dripping infiltrometers). The authors found that in contrast with newly reclaimed soils, most older ($\geq$ 4 y) minesoils exhibited greater vegetation growth and had higher infiltration rates. Infiltration rate and soil water storage in reclaimed mine soils in Wyoming increased with time after reclamation and the amount of plant root penetration (Schuman et al., 1985). Silburn and Crow (1984) determined that reclaimed profiles in Oklahoma had lower WHC (85% of that of the undisturbed soils). Topsoiled profiles with a 60-cm rooting depth had a WHC 85% that of an undisturbed soil. Plant material and vegetative cover reduced the amount of runoff generated from reclaimed mine soils (Gilley, 1980) by intercepting raindrops and creating a complex, rough surface enhancing infiltration.

1.2 Objectives

The goal of this study is to quantify the role of antecedent soil water in runoff generation, to assess the temporal variation of soil water under varying land management practices and then to determine runoff likelihood based on field measurements of antecedent moisture conditions under these practices. This linkage of antecedent soil water and runoff is unique in the literature. It is well known that highest runoff potential occurs when soils are wet (inferred to mean at moisture contents $\geq$ field capacity) but few studies have assessed the frequency of occurrence of such high moisture contents under varying management practices. There is also a need for improved knowledge of soil characteristics affected by, and the hydrologic consequences of, surface mining and reclamation. Hydrologic models are useful for evaluating alternative reclamation practices, although model users are often frustrated by the lack of reliable data on soil properties of reclaimed soils (Silburn and Crow, 1984). This study will provide some of those much needed data.

The specific objectives for this study are, for both unmined agricultural soils and reclaimed minesoils,:

- To quantify infiltration and surface runoff under a range of antecedent soil water conditions for hayed, mowed and fallow management practices using rainfall simulation.
- To compare the temporal variation in soil water under hayed, mowed and agricultural land management regimes.
- Using the same management regimes, to assess the temporal variability of soil water and relate it to water retention parameters [field capacity (FC) and wilting point (WP)].
- To interpret the frequency of runoff given the previous three objectives.

These objectives will be accomplished using rainfall simulation on both reclaimed and unmined soils using fallow, hayed and grazed management regimes at several field sites. These agricultural land management practices should provide widely varying conditions under which to relate antecedent soil water and runoff. In addition, soil water will be measured over two field seasons to determine the frequency at which given antecedent soil water conditions occur.

1.2.1 General project hypotheses

- Fallow treatments will have the highest soil water, both in terms of accumulated infiltration (event-based) and soil water on a seasonal basis.
- Vegetated treatments will have the highest infiltration rates and the lowest total soil water.

- Mowed treatments will have similar soil water to hayed treatments.
- Soil water will rarely exceed field capacity.
- As antecedent soil water increases, runoff increases.
- Reclaimed soils will have similar infiltration and runoff as undisturbed soils.

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2. General Study Area Information

2.1 Study area

This project was conducted at five field sites situated near Keephills, Alberta (53° 30' N and 114° 27' W) in the County of Parkland, approximately 90 km west of Edmonton. This region is dominated by rolling topography having slopes of 5-25%. Land use is predominantly cattle grazing and alfalfa hay production with less than half of total agricultural land area being used to produce annual cereal or forage crops.

The climate of this region is characterized by 432-508 mm of precipitation annually, 60% of which falls in the growing season from May-August (Lindsay et al., 1968). The mean annual temperature for the area is 3 °C. January is the coldest month with an average temperature of -13.8 °C and July is the warmest month with an average temperature of 15.6 °C (Lindsay et al., 1968). This area has at least 90 frost-free days where the temperature remains above 5.6 °C. Soils within the pre-mine study area are dominated by those of the Luvisolic and Solonetzic soil Orders, with the exception of the reclaimed mine soil which is unclassified. Dominant Luvisolic soils are of the Highvale, Nakamun and Maywood series while Kawood and Dnister are the most common Solonetzic soil series (Lindsay et al., 1968).

2.2 Site selection

Five field sites were selected based on slope position, gradient and aspect. Three sites (1, 2 and 3) were alfalfa/grass hay fields while two (4 and 5) were grazed pastures. Site 1 is located on reclaimed mine land within Pit 03 at the Highvale Mine. Site 2 (NW24-51-4 W5) and Site 3 (SW14-51-4 W5) are unmined alfalfa/grass hay fields established on privately owned land. Two grazed pasture sites, Site 4 (SW30-51-4 W5) and Site 5 (SW7-51-4 W5), were developed on unmined lands in the same area. The greatest distance between any two sites was approximately 12 km, being the distance from the reclaimed site to the nearest off-mine site.

2.3 Management regime preparation

This study was conducted during 1995 and 1996, beginning during the spring of 1995 when the field sites were selected. Slope gradients ranged from 15-25% and aspects were south or southwest for all sites. Treatments were established by the end of June 1995.

At each site, research plots were constructed based on a randomized complete block design, with each management regime being prepared in triplicate across the width of uniform hillslopes, avoiding topographic lows (where soil water is generally higher) and changes in slope aspect or slope gradient. Management regimes were as follows:

a) Forage Regimes at Sites 1, 2 and 3.
- Hayed
- Mowed
- Fallow

b) Pasture Regimes at Sites 4 and 5.
- Grazed (Moderately Heavy)
- Fallow

2.4 Plot design

Research plots, measuring 3 m by 3 m, were constructed at each site in a randomized complete block design using three treatments (hayed, mowed and fallow) in triplicate at forage sites and two treatments (fallow and grazed) in triplicate at pasture sites. Each plot was separated from the next by a 1.5-m wide buffer. A series of three randomized plots constituted a block and a set of three side-by-side blocks was named a range. The three blocks were placed adjacent to each other across the width of the slope to minimize interflow contribution into downslope areas, maintain constant slope gradient and to maintain relatively uniform soil conditions, both hydrologically and physicochemically across the blocks.

A second range of randomized plots, similar to the first range, was placed 1.5 m downslope of the first range. Range 2 was used for a rainfall simulation study which provided data for antecedent conditions and runoff generation (Appendix A). The same experimental design was used at the pasture sites, with plots being constructed across the width of the slope in two ranges (Appendix A).

2.4.1 Forage treatments

Hayed plots were maintained using a Jeri® mower. Standing forage was cut to 4 cm and removed from the plot area using hand rakes to prevent mulch formation or the accumulation of organic material on the soil surface. These treatments were prepared at approximately the same time that the farmer-cooperators conducted their haying operations in the fields surrounding the plots.

Mowed regimes were continually maintained to increase the amount of bare ground by frequent removal of standing biomass two to three times per week. The impacts of cattle trampling were not realized through this design. Mowing using a 5-hp Ariens® lawnmower was controlled such that foliage was maintained at a height no greater than 2-3 cm above the soil surface, with cut vegetation removed. Thus, no litter was allowed to accumulate on mowed surfaces.

Fallow regimes were established using tractor/rototilling equipment once late in spring to break the forage cover. Fallow plots were tilled in mid- to late spring and maintained vegetation-free during the growing season using a broad spectrum glyphosate herbicide (Round-up®) at a product rate of 1 L/100 L water, followed by a late fall cultivation at the end of September.

2.4.2 Pasture treatment

Plots were continuously grazed by cattle already present on the cooperator's land. Grazing intensities were moderately heavy (Site 5) with about 120 cow/calf pairs per 160 acres to heavily grazed (Site 4) with approximately 45 yearling heifers on 20 acres. Fallow plots were tilled late in the spring and maintained weed free thereafter as chemical/fallow treatments using a broad spectrum herbicide (glyphosate). A final fall cultivation was performed near the end of September.

2.5 Specific site characteristics

2.5.1 Site 1

This surface coal-mined site was reclaimed to agricultural land in 1992. It is located approximately 7 km west of the Sundance thermal generating station on the Highvale coal mine in Pit 03. Aspect and slope gradient are south at 12.5% and south at 15.6% for ranges 1 and 2, respectively (Table 2.1). Sandy loam textured subsoil, formerly minespoil, was recontoured and overlain by approximately 27 cm of stockpiled loam topsoil (Table 2.2). Plant species composition in 1993 was dominated by smooth brome (*Bromis inermis*), creeping red fescue (*Festuca rubra*), alfalfa (*Medicago sativa*) and quackgrass (*Agropyron repens*). Other species commonly found in lesser abundance were timothy (*Phleum pratense*) and dandelion (*Taraxacum officinale*).

2.5.2 Site 2

This is a privately owned, five to seven year old, forage field situated on the south exposure of a high hill (slope gradient ranging from 15% on range 1 plots to 22% on range 2 plots) approximately 3.2 km south of the Keephills thermal generating plant (Table 2.1). It has been under the same management (hayed forage) for approximately five years. Its soil has a light colored Ap horizon approximately 17 cm thick and a particularly hard subsurface horizon (at approximately 17-30 cm depth) with some dark coloration. The upper 10 cm of the Ap horizon is clayey and light colored, similar to soil at the 20-30 cm depth (Table 2.2). In some locations the Ap horizon was approximately 10 cm thick, underlain by a reddish-brown horizon which was very hard and dry with increasing depth. Soil series at this site are Dnister (Gray Solodized Solonetz), Kawood (Gray Solonetz) and Nakamun (Solonetzic Gray Luvisol). Vegetation in abundance at this site included alfalfa, smooth brome with minor inclusions of fowl bluegrass (*Poa palustris*), red clover (*Trifolium pratense*), timothy, scentless chamomile (*Matricaria maritima*), alsike clover (*Trifolium hybridum*), and Canada thistle (*Cirsium arvense*).

2.5.3 Site 3

This is a five-year-old alfalfa stand located on a southwest exposure with slope gradient ranging from 12.3% on Range 1 to 18.4% on Range 2 (Table 2.1). Topsoil depth at this site is approximately 12 cm (Table 2.1). Generally, this site has a fine textured profile, nearly uniform in clay content (Table 2.2). It has a gas line running through the southern end of the third replicate which may have affected water retention near the surface, as observation confirmed that there was a greater proportion of clay in the upper solum (top 15 cm). Due to admixing during backfilling of the pipeline, more clay may have been combined with surface soil in the third replicate, altering soil water properties and soil profile characteristics. This site appears to be freely drained having no hard or impermeable horizons within the depth of measurement. Soils at this site belong to the Highvale, Nakamun and Kawood series, part of the soil subgroups Orthic Gray Luvisol, Solonetzic Gray Luvisol and Gray Solodized Solonetz, respectively. Dominant vegetation at this was alfalfa and dandelion (*Taraxacum officinale*). Minor species were quackgrass, wheat (*Triticum aestivum*), wild oats (*Avena fatua*), Canada thistle, wild mustard (*Brassica kaber*), alsike clover and red clover.

2.5.4 Site 4

Located on a west-southwest exposure having a uniform slope gradient of 16-18% and topsoil depth of 4 cm, this pasture is part of an early/late season heavy grazing rotation (Table 2.1) and is approximately 7-10 years old. The site has medium textured soils (Table 2.3) and did not appear to contain any impermeable horizons. A thin organic horizon is apparent at some locations, but is rarely more than 2 cm thick, with topsoil depth averaging 3.6 cm (Table 2.1). Topsoil material was underlain by a light colored Ae horizon. This site is comprised of Highvale and Kawood soil series belonging to the Orthic Gray Luvisol and Gray Solonetz soil subgroups, respectively. Plant species common at this site included smooth brome, Kentucky bluegrass (*Poa pratensis*) and creeping red fescue. Minor species were quackgrass, dandelion, Canada thistle, white clover (*Trifolium repens*) and common yarrow (*Achillia millefolium*).

2.5.5 Site 5

This site (approximately 10 years old) is a south exposed field on a 16-19% slope (Table 2.1). It is unique in that it had horizons of varying silt and clay composition within the profile (Table 2.3). Although topsoil is generally 9 cm in depth, an organic litter layer 3 cm deep occurs above mineral soil, particularly in depressional areas i.e. natural channel to the west end of the plots. In some locations, a clayey layer approximately 10 cm thick is present beneath the organic horizon. This horizon gives way at a depth of approximately 25 cm to sandy layers having very yellow hues with some dark olive green pigmentation. There are no impermeable layers evident at this site. These soils are of the Maywood and Highvale series (Orthic Gray Luvisol). Construction of a small wooden water diversion structure (August 2, 1995) was necessary to divert water around the western end of the plots. Upslope runoff generation was flowing over plots on the west end of the first replicate via a small draw. Plant species composition was dominated by smooth brome, Canada bluegrass and white clover with minor inclusions of quackgrass and dandelion.

Table 2.1. Characteristics and soil classification at experimental sites.

Site	Topsoil Depth* (cm)	Slope (%)** Range 1	Range 2	Aspect
1	27	13	16	S
2	18	16	22	S
3	12	12	18	SW
4	4	16	18	SW
5	9	16	19	S

*Taken as the average of 9 points selected across the width of the slope at each site.
**Measurements taken in each treatment plot in each range.

Table 2.2. Soil textural classification for Sites 1, 2 and 3.

Site 1				
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural Classification*
0-15	25.5	43.2	31.3	L
15-30	31.3	36.9	35.2	CL
30-45	19.8	23.0	57.2	SL
45-60	17.4	16.1	66.5	SL
60-75	18.0	16.5	65.5	SL
75-90	18.5	17.5	64.0	SL
90-105	16.6	15.1	68.2	SL

Site 2				
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural Classification
0-15	37.0	52.5	10.5	SiCL
15-30	45.0	47.0	8.0	SiC
30-45	55.2	42.3	2.5	SiC
45-60	47.3	48.8	3.9	SiC
60-75	45.2	50.4	4.5	SiC
75-90	43.7	52.6	4.1	SiC
90-105	42.4	53.3	4.3	SiC

Site 3				
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural Classification
0-15	29.1	51.4	19.5	SiCL
15-30	44.6	39.2	16.3	C
30-45	51.7	32.7	15.6	C
45-60	50.4	34.7	15.0	C
60-75	44.9	39.3	15.9	C
75-90	44.0	36.3	19.7	C
90-105	44.0	42.5	13.6	SiC

Clay fraction < 2 μm; silt fraction 2-50 μm; sand fraction > 50 μm.

*L - loam; CL = clay loam; SL - sandy loam; SiCL - silty clay loam; SiC - silty clay; C - clay.

Table 2.3. Soil textural classification for Sites 4 and 5.

Site 4

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural Classification
0-15	24.8	52.5	22.7	SiL
15-30	37.8	49.9	12.2	SiCL
30-45	54.3	38.0	7.7	C
45-60	48.7	43.5	7.8	SiC
60-75	44.3	46.0	9.7	SiC
75-90	42.6	47.4	10.0	SiC
90-105	39.4	41.1	19.5	SiCL

Site 5

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural Classification
0-15	24.3	54.7	21.0	SiL
15-30	52.9	38.1	9.0	C
30-45	61.5	30.5	8.0	C
45-60	52.4	35.0	12.7	C
60-75	42.7	40.0	17.3	SiC
75-90	38.5	43.8	17.7	SiCL
90-105	36.8	42.6	20.7	CL

2.6 References

Lindsay, J.D, W. Odynsky, T.W. Peters and W.E. Bowser. 1968. Soil survey of the Buck Lake (NE 83B) and Wabamun Lake ($E\frac{1}{2}$ 83G) Areas. Alberta Soil Survey Report No. 24. Alberta Soil Survey Committee. Edmonton, AB.

3. Infiltration and Runoff as Influenced by Land Disturbance and Management Regime

3.1 Introduction

Rainfall simulation has been used to determine the influence of land disturbance on soil physical properties including: infiltration rate (steady state and 30-min volume) by determining net infiltration as the difference between applied rainfall and runoff (Jorgensen and Gardner, 1987); runoff, infiltration and erosional characteristics of surface mined sites (Gilley et al., 1977; Gilley, 1980); and effect of slope gradient on erosion for reclaimed soils (Hahn et al., 1985).

Rainfall simulation is frequently used for quantifying the rainfall-runoff characteristics of an area and provides researchers control over the timing, rate and location of rainfall allowing observation and measurement of erosional and hydrological processes (McIsaac and Mitchell, 1992). Many different types of equipment have been used in field and laboratory settings to simulate rainfall characteristics, each type designed to produce a given set of reproducible conditions based on specific objectives (Appendix B).

Specific information can be obtained using rainfall simulation to assess infiltration rates as affected by land management, specifically, how land management may alter soil hydrologic responses given initial soil water content, land use, surface roughness and vegetative cover. Measuring detention or absorption of incident rainfall prior to the development of runoff provides information about the hydrologic condition of a soil surface and the potential for runoff production. Apparent loss of water prior to runoff production is grouped into a broad term, initial abstraction (I_a), which includes water in depressional storage, infiltrated water prior to runoff and water detained by vegetation and litter. Based on hydrologic conditions at the small plot scale, infiltration rates, surface storage and soil conditions could be used in subsequent inferences about runoff potential on a watershed scale.

3.2 Objectives

- Determine the infiltration rate and accumulated infiltration for each of three land management practices.
- Examine the relationship between initial abstraction and antecedent soil water expressed as degree of saturation.
- Compare the hydrologic response of reclaimed and unmined lands.

3.3 Materials and methods

3.3.1 Rainfall simulation

This component of the study was completed using a Guelph Rainfall Simulator II (Tossell et al., 1987; Appendix B) and runoff frames. Water for simulation was stored in two 250-L fiberglass reservoirs and one 45-gal oil drum. Attached to the water supply was a 1.5-hp electric pump which supplied water to the simulator at a specified rate, determined by a pressure gauge on the simulator. Rainfall intensity was controlled by adjusting pressure output from the pump such that a pressure of 48 kPa was used to provide uniform rainfall at an intensity of 48-55 mm 30 min^{-1} (greater than a 100 year return period), using a 3/8" GG Full-Jet nozzle. Height above the ground surface and runoff frame was kept constant at 2 m for all trials. The effects of wind gusts during simulation trials were eliminated by using a large triangular wind shield and plots were raked a few days prior to simulation to remove surface irregularities.

Runoff volume was measured and recorded every five minutes to an elapsed time of 30 min from a modified 1-m^2 runoff frame having 15.2-cm deep side walls and a standard lower position spout. Rubber tubing was attached to the spout, directing runoff downslope and into collection containers. Frames were hammered into the ground to within 2.5 cm of the surface. Infiltration volume was determined by subtracting runoff volume from precipitation volume for a given time interval. Infiltration rates were calculated as infiltration volume divided by the time increment and averaged for a given 5-min interval; e.g. 5-min infiltration rate is the average for the first five minutes of simulation. Initial abstraction was recorded as the amount of time elapsed from the start of an infiltration session to the onset of runoff. It was calculated as a depth of water (mm) by multiplying this elapsed time by the simulated rainfall rate.

Simulation runs were conducted twice during 1996 at all five sites, once in late July and then again in late September on an undisturbed portion of the plots. In each of the two sessions, daily simulations were completed for an entire site, ensuring there was no change in site parameters due to overnight rainfall.

3.3.2 Bulk density

Near surface bulk density (0-10 cm) of all plots at forage and pasture sites was measured beside each of two access tube using a CPN MC-1 depth moisture/density gauge. Aluminum access tubes were installed to 1.2 m for use in the measurement of soil water. Depth density every 15 cm, to a maximum depth of 95 cm, was measured using a CPN-501 depth moisture/density probe. Depth density was determined once in October, 1995 and surface density was measured before cultivation, two weeks after cultivation and then again three months following cultivation in 1996. In Range 2, surface density was measured with the same equipment and technique as that used in Range 1.

3.3.3 Determination of runoff coefficients

Runoff coefficients, expressing the proportion of runoff relative to the amount of incident rainfall, were calculated for all treatments for both simulation sessions. An average value of the two sessions was then used to compare among sites and treatments.

3.3.4 Calculations and conversions

Antecedent soil water at the soil surface (0-7.5 cm) and at depth was measured just prior to a simulation run using CPN 503 neutron probe. Surface water readings were taken to a depth of 7.5 cm by placing the source, upper half surrounded by a fibreglass shield, horizontally on the soil surface. In order to express initial water conditions relative to pore space, the antecedent water content was expressed as a degree of saturation using surface bulk density (0-10 cm).

$$Degree\ of\ Saturation = \frac{\theta}{\phi} = \frac{\theta}{1 - \frac{\rho_b}{\rho_p}} \times 100$$

where:
θ = volumetric water content,
ϕ = soil porosity,
ρ_b = surface bulk density (Mg m^{-3}), and
ρ_p = particle density (assume 2.65 Mg m^{-3}).

3.4 Statistical analyses of simulation data

3.4.1 Data compilation

This component of the study involved two basic infiltration parameters (infiltration rate and accumulated infiltration). Raw data in triplicate from the two sampling periods were grouped into one data file. Statistical analyses were performed on rainfall simulation data obtained from the three forage sites (1, 2 and 3) each comprised of three treatments (hayed, mowed and fallow) and the two pasture sites (4 and 5) with two treatments (grazed and fallow).

Other parameters analyzed included I_a and degree of saturation. Both I_a and degree of saturation were used in the GLM ANOVA procedure as they dictated the potential capacity of the soil to absorb and store rainfall. Also, linear regression analysis was conducted on degree of saturation, I_a and 5-min IR. All data were checked for homogeneity of variance using the W-test in SAS (SAS Institute, 1987). The level of significance used for all analyses was $\alpha = 0.05$.

3.4.1.1 Infiltration rate based on treatment; sites treated individually.

The null hypothesis was that the least-squared mean (LSM) infiltration rate (IR) of one treatment was equal to the LSM infiltration rate of another treatment. Therefore: LSM (i) = LSM (j) = LSM (k) where i, j and k are treatments, or assuming least squares means, $IR_{hayed} = IR_{mowed} = IR_{fallow}$.

This differentiation was accomplished by using the GLM statistical function in SAS along with the least-squared mean function. A model was fitted using infiltration rate as the dependent variable. Factors used to separate the IR for each time increment (5, 10,..., 30 minutes) were treatment, time and the treatment x time interaction.

3.4.1.2 Accumulated infiltration by treatment; sites treated individually.

This statistical analysis was completed using the same model and settings as the GLM procedure used for infiltration rate. The null hypothesis was that least-squared means of the accumulated infiltration (AI) for a given time are equal for any two treatments, j and k. The dependent variable was accumulated infiltration and the sources of error were treatment, time and the treatment x time interaction.

3.5 Results

3.5.1 Infiltration at forage sites 1, 2 and 3

3.5.1.1 Infiltration rate

Generally, infiltration rates for the hayed, mowed and fallow treatments decreased with time (Table 3.1). After 30 min, infiltration rates had decreased by 29-47 % compared to the initial 5-min IR on all treatments. There were very few significant differences in IR among treatments at both 5-min and 30-min time periods, except 30-min IR for the hayed and mowed treatments at Site 3 which were higher than those of the same treatments at Sites 1 and 2. Although not generally significantly different, the hayed treatment had the highest IR while the fallow treatment had the lowest IR. Steady-state infiltration, which was generally achieved after approximately 15 min, was similar among treatments, except at Site 3.

3.5.1.2 Accumulated infiltration (AI)

AI was generally significantly highest on hayed treatments and lowest on fallow treatments, except at Site 2 (Table 3.1). Thirty-min AI was lowest for the fallow treatment at two of the three sites. Thirty-min AI of hayed and mowed treatments was similar at Sites 1 and 2 but was significantly higher at Site 3 (Table 3.2). Thirty-min AI was lowest for the fallow treatment at two of the three sites.

3.5.2 Infiltration at pasture sites 4 and 5

3.5.2.1 Infiltration rate

The infiltration rates of the grazed and fallow treatments at Sites 4 and 5 were similar for all time increments (Table 3.3). Steady state infiltration rates were similar at Sites 4 and 5 for both treatments.

3.5.2.2 Accumulated infiltration

Accumulated infiltration at Sites 4 and 5 was not significantly different between the grazed and fallow treatments at any time (Table 3.3). In addition, there were no significant differences for 30-min AI between treatments at either site. However, the fallow treatment at Sites 4 and 5 generally had a higher AI than the grazed treatment.

3.5.3 Variability of surface bulk density

Near surface bulk densities varied depending on the time since cultivation of plots. Generally, surface density increased with time from tillage (Table 3.4). Bulk density at Site 1 for recently tilled plots (two weeks after cultivation) was as much as 6% lower compared with the surface density three months after cultivation.

The near surface density of fallow plots at Sites 1, 2 and 3 was generally lower than that of hayed and mowed plots. In all cases, mowed treatments had the highest surface densities. Three months after cultivation, the fallow treatment at forage sites generally had a significantly lower surface bulk density compared to the hayed and mowed treatments (Table 3.4).

At Sites 4 and 5 three months following cultivation, fallow plots had significantly higher near surface densities than grazed plots: 13% higher at Site 4 and 9% at Site 5. Surface density two weeks after cultivation was 11% lower on Site 4 compared to the density after three months, but only 2% lower under the extreme compaction and poor cultivation at Site 5.

Porosity was significantly higher on the fallow treatment of Sites 2 and 3 compared to Site 1 (Table 3.5). Also, the mowed treatment at all sites (with the exception of Site 1) had the lowest porosity. Grazed treatments at Sites 4 and 5 had significantly higher porosity than did the fallow treatments.

3.5.4 Fallow treatment comparisons

The 5-min IR of fallow treatments was generally higher, though not consistently significant, on off-mine sites than at Site 1 (Table 3.6). Fallow treatments at Sites 4 and 5 generally had a lower but non-significant 30-min IR compared to fallow treatments at forage sites. There were no significant differences in 30-min AI among sites.

Degree of saturation was significantly higher on Site 1 than on Sites 2, 3 and 5, with Site 2 having the lowest value (Table 3.6). Fallow treatments at forage sites 2 and 3 had a lower degree of saturation compared to the fallow treatments at pasture sites 4 and 5. I_a for the fallow treatments ranged from 8.5 to 3.1 mm, and was lowest at Site 1 and highest at Site 4. I_a was generally small for all sites, comprising a maximum 7.7% of total incident precipitation.

3.5.5 Runoff coefficients

Runoff coefficients ranged from 0.18 to 0.54, with 9 of 13 values between 0.43 and 0.49 (Table 3.7). Runoff coefficients were highest on fallow treatments at forage sites, with the exception of Site 2. Treatments which were densely vegetated (hayed and grazed treatments) had the lowest runoff coefficients, while those which had low growing vegetation or bare ground (grazed and fallow treatments) had high coefficients. Runoff coefficients varied little among sites, except for Site 3 where coefficients were lower for all treatments compared to Sites 1 and 2. There was no clear treatment trend at Sites 4 and 5.

3.5.6 Degree of saturation, initial abstraction and 5-min IR

Degree of saturation ranged from 46.4 to 71.8% and was significantly different among treatments at Sites 3 and 5. The fallow treatment had the higher degree of saturation at Site 4 and 5, but was lowest at Sites 2 and 3.

Initial abstraction for Sites 1, 2 and 3 was generally significantly greater for the hayed than fallow treatments, except at Site 2 (Table 3.8). At Sites 4 and 5, no statistical differences in I_a between treatments were found. Maximum Ia was found for the hayed treatment at Site 3, comprising 13.8% of total incident precipitation.

Five-min IR and degree of saturation were not significantly correlated for any of the treatments at Sites 1, 2 and 3 (Table 3.9 and Figure 3.1). There was also a poor correlation between I_a and degree of saturation for all treatments (Table 3.9). The best fit line of both the hayed and mowed treatments had a slight positive slope (Figure 3.2), indicating that there may be an direct relationship between degree of saturation and 5-min IR. This is contrary to the inverse relationship of the fallow treatment where 5-min IR and I_a decrease with increasing degree of saturation (Figure 3.3 and Figure 3.4).

3.6 Discussion

Cultivation reduced infiltration capacity and the total amount of infiltrated water. This decrease in both IR and AI with time under cultivation may have been due to the destruction of established pore spaces reduced the capacity of the Ap horizon to conduct water into the soil profile during simulated precipitation events. Meek et al. (1989) concluded that infiltration in alfalfa fields was dominated by macropore flow through old root channels. Therefore, a lack of actively transmitting conduits could lead to the rapid saturation of a poorly drained surface soil. This was likely the case for the fallow treatment where biopores were likely destroyed (Dao, 1993), and the mowed treatment where vegetation was continually removed and the soil surface compacted, potentially leading to a reduction in root growth and root channel formation. With continued mowing and compaction of the soil surface, root density and bioporosity were likely reduced. Also, compaction on mowed treatments may have led to the sealing of surface openings of biopores which would have been capable of transmitting water.

The greater reduction in AI of fallow treatments over the initial 10 min compared to hayed, mowed and grazed treatments was likely the result of surface sealing as silt and clay sized particles were dislodged by rainfall and entered pore spaces. Collection of silt and clay sized sediment in pore openings would prevent water from infiltrating through established pore spaces resulting in decreased infiltration rates.

As hypothesized, infiltration rates in hayed treatments were generally higher than those in the fallow treatments. Root channels and bio-pores are most numerous in soils with surface vegetation, particularly on perennial forages such as alfalfa (Meek et al., 1989). Interception and stem flow may have increased the amount of water being channeled toward the ground where stems and litter then detained water and prevented it from flowing laterally. Water could then enter through pores at the soil surface or just beneath the litter. Dao (1993) found that soil water was recharged through open root channels, biopores and cracks that were not visible at the soil surface. No method was discussed with respect to this finding.

Since litter cushions the soil and dissipates energy transferred from above ground activity, the lack of such a protective layer would make the mowed plots more prone to compaction by mowing equipment and foot traffic. Naeth et al. (1990) found that the removal of vegetation exposed soils to the compactive effects of grazing animals. This effect could be similar on any soil surface which has had vegetation removed, whether by grazing, mowing, or harvesting.

Although there was very little difference in any infiltration parameter among treatments at Site 2, trends in IR and AI at this site were different from those at the other sites due to the physical properties of the soils on this hillslope. High bulk density at this site may have resulted in poor root penetration, decreased hydraulic conductivity and an overall reduction in vegetative growth.

Bulk density may have been a controlling factor for infiltration. Site 2 had the lowest values for IR and AI and had the highest bulk density on the hayed and mowed treatments. Differences in bulk density could explain the higher IR and AI for fallow treatments at Site 2 (compared with mowed treatment) where the surface density of fallow plots was lower than that for mowed plots and the IR of the fallow plots was greater than that of mowed plots.

The higher bulk density and lower porosity of the fallow treatments compared to the grazed treatments at both Sites 4 and 5 may have been a result of two factors. Compaction by cattle would likely account for most of the increased density. Increases in density at forage sites after cultivation were due to settling, while fallowed pasture plots were subjected to compaction due to both cattle traffic and settling.

Infiltration on fallow treatments at Sites 4 and 5 was likely influenced by cattle. At Site 4, the unexpected overlap of trends in IR where higher IR of the fallow treatment dropped below that of the grazed treatment was likely the result of cattle treading on the soil and increasing random roughness on fallow soils. Also, surface sealing may have reduced infiltration rates as splash detachment dislodged soil particles and filled in surface pore spaces. At Site 5, consistently higher (though insignificant) IR of the fallow treatment compared to the grazed treatment was possibly due to physical characteristics of the soil profile which made it more transmissive, increasing the infiltration capacity of this soil.

Cattle on Sites 4 and 5 were attracted to the fallow plots particularly to the aluminum access tubes used for measuring soil water. As a result, much higher traffic was apparent on these plots where cattle tended to dust themselves. Site 5 also had a water diversion structure constructed at one end to which cattle tended to concentrate their activity. Consequently, the adjacent fallow plots were compacted excessively, so much that cultivation equipment was unable to adequately mix the soil during tillage.

High I_a on fallow treatments at Site 4 likely indicates that there was greater detention of water in depressions which would have led to increased infiltration through ponding. Greater 30-min IR on fallow treatments at Site 5 may partially be explained by the physical effects associated with tillage. Thicker topsoil at Site 5 than Site 4 (8.8 cm versus 3.6 cm, respectively) possibly made fallow treatments at Site 5 more transmissive than the grazed ones at that site. Bauer and Black (1992) reported that increasing the organic carbon (OC) content of a fine textured soil increased the water concentration by weight at both FC and WP in a 1:1 ratio such that a unit increase in OC concentration resulted in an identical increase in water concentration by weight at FC and WP. A decrease in soil bulk density with increasing OC concentration may also have resulted in greater water retention by soils at Site 5. Bauer and Black (1992) also found a decrease in bulk density with increased OC concentration.

The higher IR on grazed plots at Site 4 than Site 5 may be due to a rougher soil surface at Site 4. Although the plots were raked a few days prior to simulation, cattle treading on damp ground created hoof depressions in the soils on Site 4, resulting in some detention of water and significantly higher 5-min IR. This observation is supported by the non-significantly higher I_a for Site 4 (8.5 compared to 6.3 mm for Site 5). This trend was also apparent for 5-min IR of both Sites 4 and 5.

Vegetated surfaces had greater resilience to compaction, particularly in a heavy grazing regime where hoof traffic was intense and frequent (Naeth et al., 1990). Based on observation during simulation, rainfall was initially repelled by the litter surface causing water to flow laterally over the soil surface, reducing the amount of water available for infiltration. This also resulted in a decreased IR as litter on the soil surface was wetted (approximately 15 min), gradually allowing water through the litter layer. At this time, IR of the fallow plots was less than that of the grazed treatment. Site 5 did not have this same trend as there was less litter on the soil surface at this site.

Surface cover intercepted rainfall and detained it allowing more water to infiltrate. Reductions in vegetative cover resulted in increases in runoff coefficients as less water was intercepted and detained on the soil surface. However, fallow treatments at Sites 4 and 5 did not consistently have the highest runoff coefficients among treatments as they did on Sites 1, 2 and 3. These differences may have been due to the water content of litter material and surface roughness.

The infiltration rate used in this study was high, allowing quantification of infiltration and runoff for an extreme event, albeit under artificial conditions. The intensity used was not inordinate; Hawkins (1982) indicated that 75 mm h^{-1} is a popular choice of intensity used in studies. Jorgensen and Gardner (1987) used an intensity of 75 mm h^{-1} for 30 min in their study of the infiltration capacity of disturbed soils while Hahn et al. (1985) used an intensity of 63.5 mm h^{-1} to assess the slope gradient effect on erosion. Given that in this study at most one half of the applied precipitation occurred as runoff, one could conclude that the amount of runoff that could be expected for storms of shorter return periods would be even less. Coupling this conclusion with the fact that the antecedent moisture conditions at the time of the tests were quite wet, one could conclude that, in general, the runoff potential of the study area is low.

However, surmising what runoff might have been under lower rainfall intensities is not easy, based on the reported effects of rainfall intensity on infiltration. For example, it is believed that as rainfall intensity increases, runoff will increase (infiltration rate will decrease) due to surface sealing due to soil particle displacement as a result of raindrop impact (see e.g. Farres, 1978). Another school of thought holds that as intensity increases, so does infiltration rate (Nassif and Wilson, 1975; Hawkins, 1982; Dunne et al., 1991). The latter group of authors suggest that this increase occurs, for soils which do not form seals, due to the tendency for higher rainfall intensities to exceed the saturated hydraulic conductivity of larger portions of the soil surface and thereby to raise the averaged hydraulic conductivity. The second reason they give is that increased rainfall intensity increases runoff and, therefore, flow depth. Then as the sheet flow deepens at one place in response to increasing rainfall intensity or along a hillslope at constant rainfall intensity, it inundates a progressively larger fraction of the microtopography. However, their discussions focus on hillslopes, and thus many of their reasons for the increase in infiltration rate with an increase in rainfall intensity may not hold for the small area (1 m^2) of the rainfall plots used in this study. Murai and Iwasaki (1975) attributed this phenomenon to the spatial variation of runoff properties within their plots. Hence, the smaller the plots, the less pronounced would be the effect of rainfall intensity on infiltration.

Data from Murai and Iwasaki (1975) used by Hawkins (1982) to develop his discussion on the influence of rainfall intensity on infiltration rate cover intensities ranging from 100 to 500 mm h^{-1} and thus cannot be used to evaluate such an influence at intensities of less than 100 mm h^{-1}. The infiltration rate influenced by rainfall intensity as discussed by Hawkins (1982) is the steady-state or final infiltration rate, as he stated that the "early" (quotation marks his) parts of any run must be discarded to omit the inconstant early drawdown portion of the infiltration curve. Nassif and Wilson (1975) reported that for soils of low permeability such as peat and clayey sand there was little effect of intensity on infiltration rate, but for their standard soil (11.1% clay and 35.9% silt), there was a strong correlation between the steady-state infiltration and rainfall intensity, which varied from 78 to 312 mm h^{-1}. Yet it is likely that the initial infiltration rate is most affected by management practices and near-surface conditions. Hawkins (1982), using data for Mancos shale soils in Utah on plots 1.52 m long x 0.30 m wide, showed that the effect of intensity on infiltration rate was largely confined to rainfall intensities under 50 mm h^{-1}, and even then the effect was slight.

3.6.1 Reclaimed land comparison to unmined land

A direct comparison of mined and unmined land can be made only for forage treatments. Sites 1, 2 and 3 had comparable 5-min, 30-min IR and 30-min AI, indicating that infiltration parameters of the reclaimed soil were similar to those of the unmined soils. These results are contrary to those found by Potter et al. (1988) on reclaimed mine lands (4 and 11 years after reclamation) in North Dakota and those in the Eastern United States by Jorgensen and Gardner (1987) who found that infiltration rates in newly reclaimed mine soils were an order of magnitude lower than those on adjacent undisturbed soil.

Site 1 had the highest degree of saturation. Initial abstraction was lowest at Site 1 indicating that the soil had the smallest absorptive capacity, perhaps due to the low surface roughness and the high antecedent soil water. Burwell and Larson (1969) found that tillage-induced random roughness and pore space increased water infiltration into a sandy clay loam soil and that random roughness accounted for most of the variation in infiltration among tillage treatments.

3.7 Conclusions

Hayed and mowed treatments had higher infiltration rates and accumulated infiltration than cultivated soils, as hypothesized. Both reclaimed and unmined soils had similar infiltration parameters. Functional relationships between initial abstraction and 5-min IR with degree of saturation were poor perhaps due to similar antecedent soil water conditions under all treatments. Grazing did not have a major effect on near-surface soil porosity or infiltration under either grazed or fallow treatments.

Runoff under rainfall simulation was low on all treatments (generally <50% of incident precipitation), even under a high rainfall intensity. Similarly, I_a was low (3-9 mm) on fallow, but was slightly higher under hayed and mowed regimes.

Table 3.1. Infiltration rate (IR) and mean accumulated infiltration (AI) at forage sites.

		Time (min)					
		5	10	15	20	25	30
		Site 1					
IR (mm/h)	Hayed	95.0 ab*	84.3 a	71.6 a	56.2 a	52.7 a	52.7 a
	Mowed	97.8 a	68.1 b	54.1 b	50.6 a	50.5 a	51.9 a
	Fallow	82.9 b	56.0 b	52.2 b	50.3 a	49.4 a	50.2 a
		Site 2					
	Hayed	96.7 a	64.8 a	58.1 a	59.0 a	58.5 a	58.0 a
	Mowed	91.2 a	59.7 a	55.5 a	53.9 a	51.7 a	50.5 a
	Fallow	95.1 a	62.7 a	57.1 a	56.7 a	54.9 a	55.0 a
		Site 3					
	Hayed	100.1 a	99.4 a	90.6 a	80.7 a	74.6 a	71.3 a
	Mowed	97.2 a	89.3 a	79.1 ab	73.7 ab	69.5 ab	67.6 a
	Fallow	90.8 a	68.8 b	58.1 b	52.2 b	48.6 b	49.7 a
		Site 1					
AI (mm)	Hayed	7.9 ab	14.9 a	20.9 a	25.6 a	30.0 a	34.4 a
	Mowed	8.1 a	13.8 a	18.3 ab	22.5 ab	26.7 ab	31.0 a
	Fallow	6.9 b	11.6 b	15.9 b	20.2 b	24.3 b	28.4 a
		Site 2					
	Hayed	8.1 a	13.5 a	18.3 a	23.2 a	28.1 a	32.9 a
	Mowed	7.6 a	12.6 a	17.2 a	21.7 a	26.0 a	30.2 a
	Fallow	7.9 a	13.2 a	17.9 a	22.6 a	27.2 a	31.8 a
		Site 3					
	Hayed	8.4 a	16.7 a	24.2 a	31.0 a	37.2 a	43.1 a
	Mowed	8.1 a	15.6 ab	22.1 ab	28.3 ab	34.1 ab	39.7 ab
	Fallow	7.6 a	13.3 b	18.1 b	22.5 b	26.6 b	30.7 b

* Means within a column for a given infiltration parameter at a given site followed by the same letter are not significantly different ($P \leq 0.05$).
n = 6 per cell

Table 3.2. Inter-site comparisons of 30-min accumulated infiltration (mm) by treatment.

Site	Hayed	Mowed	Fallow
1	34.4 b*	31.0 ab	28.4 a
2	32.9 b	30.2 b	31.8 a
3	43.1 a	39.7 a	30.7 a

* Means within a column at a given site followed by the same letter are not significantly different ($P \leq 0.05$).
n = 6 per cell

Table 3.3. Infiltration rate (IR) and mean accumulated infiltration (AI) for Sites 4 and 5.

		Time					
		5	10	15	20	25	30
				Site 4			
IR (mm/h)	Grazed	88.6 a*	68.0 a	55.5 a	50.0 a	48.6 a	49.8 a
	Fallow	97.6 a	67.1 a	53.4 a	47.0 a	43.2 a	43.5 a
				Site 5			
	Grazed	86.7 a	56.5 a	42.7 a	42.5 a	40.9 a	42.9 a
	Fallow	87.7 a	64.6 a	56.2 a	49.2 a	45.2 a	43.7 a
				Site 4			
AI (mm)	Grazed	7.4 a	13.8 a	17.7 a	21.8 a	25.9 a	30.0 a
	Fallow	8.1 a	13.1 a	18.2 a	22.1 a	25.7 a	29.3 a
				Site 5			
	Grazed	7.2 a	12.3 a	15.9 a	19.4 a	22.8 a	26.4 a
	Fallow	7.3 a	12.7 a	17.4 a	21.5 a	25.2 a	28.9 a

* Means within a column for a given infiltration parameter at a given site followed by the same letter are not significantly different ($P \leq 0.05$).
n = 6 per cell

Table 3.4. Surface (0-10 cm) bulk density (Mg m^{-3}) two weeks and three months after tillage operations at all sites.

	Treatment			
	Two weeks	Three months		
Site	Fallow	Hayed	Mowed	Fallow
1	1.10 A*	1.13 a**	1.17 a	1.17 a
2	1.14 A	1.26 b	1.32 a	1.17 c
3	1.09 A	1.21 a	1.22 b	1.13 a
	Fallow	Grazed	Fallow	
4	1.09 B*	1.06 b**	1.22 a	
5	1.26 A	1.17 b	1.29 a	

* Means within this column followed by the same uppercase letter are not significantly different ($P \leq 0.05$).
n = 6 per treatment per site.

** Means within a row for a given site followed by the same lowercase letter are not significantly different ($P \leq 0.05$).
n = 6 per treatment per site.

Table 3.5. Surface (0-10 cm) soil porosity three months after tillage.

Site	Treatment		
	Hayed	Mowed	Fallow
1	0.58 a*	0.55 b	0.55 b
2	0.54 b	0.50 c	0.57 a
3	0.55 b	0.54 b	0.58 a
	Grazed	Fallow	
4	0.60 a*	0.53 b	
5	0.57 a	0.50 b	

* Means within a row for a given site followed by the same letter are not significantly different ($P \leq 0.05$).
n = 6 per treatment per site.

Table 3.6. Inter-site comparison of infiltration parameters for fallow plots.

Site	5-min IR* (mm h^{-1})	30-min IR (mm h^{-1})	30-min AI (mm)	Saturation Percentage**	I_a (mm)
1	82.9 c	50.2 ab	28.4 a	68.8 a	3.1 c
2	95.1 ab	55.0 a	31.8 a	46.4 c	4.3 bc
3	90.8 abc	49.7 ab	30.7 a	54.7 bc	6.7 ab
4	97.6 a	43.5 b	29.3 a	62.9 ab	8.5 a
5	87.7 bc	43.7 b	28.9 a	56.4 bc	6.3 abc

* Means within a column for a given infiltration parameter at a given site followed by the same letter are not significantly different ($P \leq 0.05$).

** Water content converted to degree of saturation for a surface depth of 7.5 cm.

n = 6 for each parameter at each site.

Table 3.7. Mean runoff coefficients over 30 min of rainfall simulation.

Site	Treatment		
	Hayed	Mowed	Fallow
1	0.34 b*	0.45 a	0.48 a
2	0.44 a	0.48 a	0.48 a
3	0.18 b	0.23 b	0.43 a
	Grazed	Fallow	
4	0.45 a*	0.49 a	
5	0.54 a	0.44 a	

* Means within a row for a given site followed by the same letter are not significantly different ($P \leq 0.05$).

Table 3.8 Treatment comparison of degree of saturation (0-10 cm) and initial abstraction.

	Degree of saturation				I_a (mm)		
Treatment	Site 1	Site 2	Site 3	Treatment	Site 1	Site 2	Site 3
Hayed	71.8 a*	53.7 a	63.6 ab	Hayed	9.4 a	5.3 a	15.2 a
Mowed	68.3 a	57.0 a	68.9 a	Mowed	7.7 a	4.6 a	12.6 ab
Fallow	68.8 a	46.4 a	54.7 b	Fallow	3.1 b	4.3 a	6.7 b
	Site 4	Site 5			Site 4	Site 5	
Grazed	55.1 a*	47.0 b		Grazed	5.3 a	6.3 a	
Fallow	62.9 a	56.4 a		Fallow	8.5 a	6.3 a	

* Means within a column for a given site followed by the same letter are not significantly different ($P \leq 0.05$).
n = 6 for each treatment at each site.

Table 3.9 Regression results for infiltration parameters.

Regression Test	Treatment	R^2	Sample size (n)	Significance Level
5-min IR x Degree of saturation	Hayed	0.031	18	0.49
	Mowed	0.004	18	0.79
	Fallow (Sites 1-3)	0.133	18	0.14
	Fallow all Sites	0.002	30	0.80
I_a x Degree of saturation	Hayed	0.037	18	0.45
	Mowed	0.042	18	0.42
	Fallow (Sites 1-3)	0.009	18	0.72
	Fallow all Sites	0.016	30	0.50

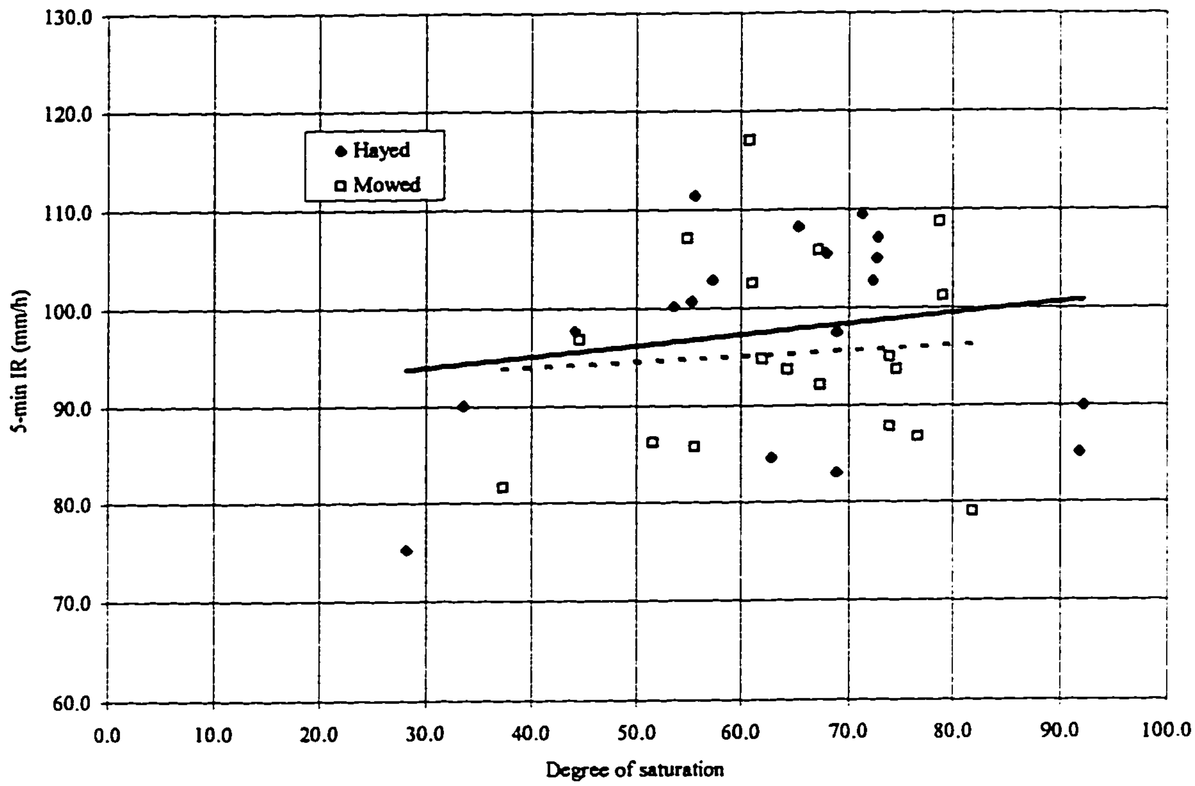

Figure 3.1 The relationship between 5-min IR and degree of saturation at forage Sites 1, 2 and 3.

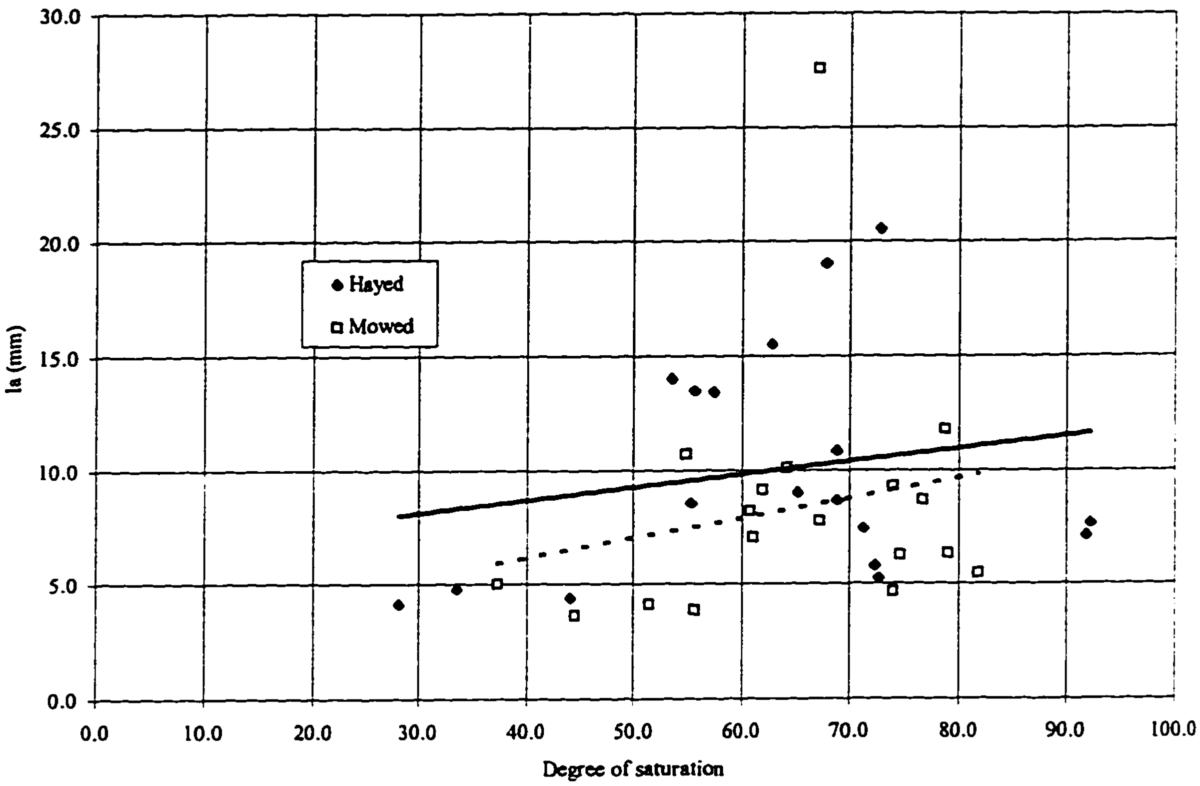

Figure 3.2 The relationship between initial abstraction and degree of saturation at forage Sites 1, 2 and 3.

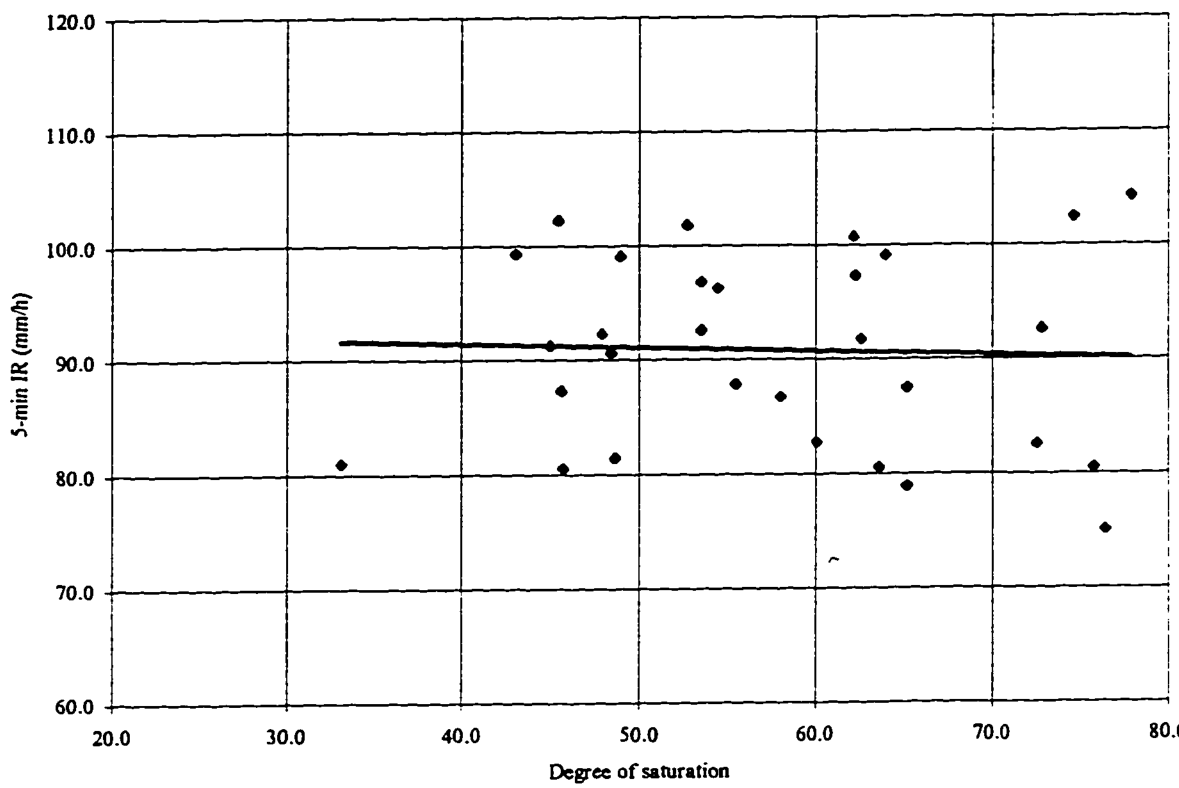

Figure 3.3 The relationship between 5-min IR and degree of saturation for fallow treatments.

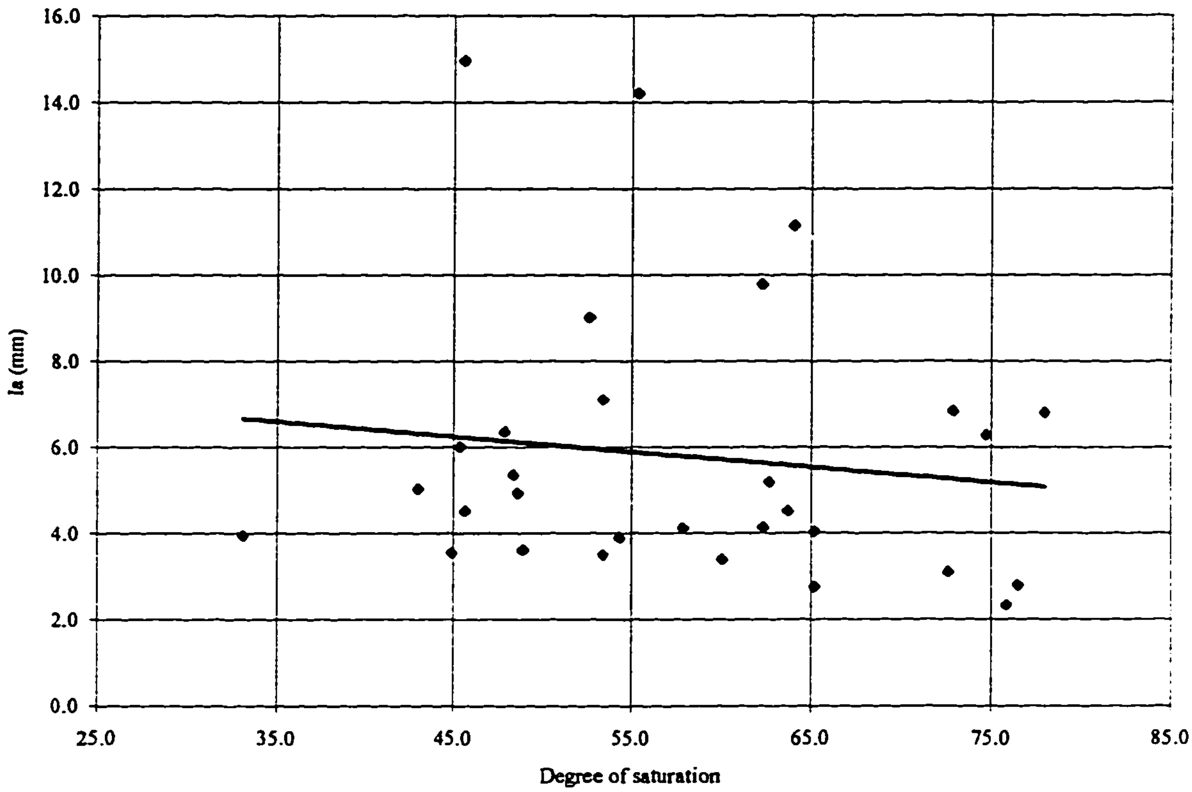

Figure 3.4 The relationship between initial abstraction (I_a) and degree of saturation for fallow treatments.

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4. Antecedent Soil Water of Different Management Treatments

4.1 Introduction

Generally, as soil water increases, air filled porosity and infiltration rate decrease increasing flow across the soil surface (Sharma et al., 1983). Soils with dry antecedent soil water conditions have a higher infiltration capacity than do wet soils. It is generally accepted that less overland flow occurs on dry soils than wet ones, assuming similar soil texture, structure and organic matter content. Therefore, measurement of soil water provides a way of determining the potential for overland flow.

Transpiration of water by vegetation or evaporation of water from bare soils decreases antecedent soil water. Therefore, antecedent soil water is expected to vary as a function of land management, including the type and age of crop, surface cover, water content of litter, tillage practice (Tanaka and Aase, 1987), soil profile characteristics and slope position. Daigger et al. (1970) found that alfalfa had the greatest consumptive water use in the first of three cuts of alfalfa, but that this was also the time of the year when water was used most efficiently. Schroeder (1995) found that available soil water generally increased from upslope to downslope positions with increases in yield of wheat along the same gradient.

4.2 Objectives

- Determine soil water on forage and pasture fields.
- Determine the frequency of differing levels of soil water.
- Compare soil water status in reclaimed and unmined soils.

4.3 Materials and methods

4.3.1 Field procedures

4.3.1.1 Soil water

Two aluminum access tubes were installed to a depth of 1.2 m in each plot in Range 1 on June 20, 1995 using a hydraulic coring machine mounted on the back of a

2850 Kubota tractor. Two access tubes were randomly placed within each 3 by 3 m plot, such that both upslope and downslope positions were represented. These tubes were used to measure the antecedent soil water to a depth of 85 cm using CPN 503 neutron probes. Soil water measurements were taken every 2 weeks in both 1995 and 1996, collecting two 16-s probe counts every 10 cm to a maximum depth of 85 cm, starting 15 cm below the soil surface.

Surface water measurements were also taken at the time of depth measurements using the 503 neutron probe with a surface shield installed around the source (Chanasyk and Naeth, 1988). Two readings were taken beside each access tube, unless there was dew or any liquid water present on vegetation, in which case surface readings were not taken.

As part of fall sampling in 1995, a CPN 501 depth moisture/density probe, which measures soil water and bulk density simultaneously, was used to determine the bulk density and soil water at the depths listed above. These soil water data were incorporated into the 503 water data set.

Measurements in 1995 were taken on June 30, July 12, 26, August 9, 25, September 14, 28 and October 16. During 1996 soil water readings were taken on April 22, May 27, June 10 and 24, July 8 and 23, August 15 and 27 and October 21.

4.3.1.2 Soil sampling

Soil samples for textural analysis were taken during access tube installation. Analysis of these samples provided information for inter-site textural comparisons as well as general site characterization. A complete, uncompacted core of the soil profile was removed during each tube installation and divided into depth increments. To minimize the number of soil samples, one core was taken from the first treatment of each block at each site. Depth increments were: 0-15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-105 and 105-120 cm from the soil surface.

4.3.1.3 Precipitation

To determine the amount of rainfall received at the four off-mine sites, single, standard rain gauges were located adjacent to each site. These gauges were read every two weeks or as needed and cumulative rainfall determined using summed precipitation data from previous readings. Site 1 has a complete meteorological station located approximately 100 m to the northeast and provided detailed meteorological data.

4.3.1.4 Soil bulk density

Bulk density with depth was determined in soil water access tubes using a CPN 501 depth density gauge during late fall 1995 water readings. Surface bulk density (0-10 cm) was measured in spring and fall 1996 using a CPN MC1 surface moisture/density probe while surface density was measured immediately before the 1996 spring tillage operations and then again one week after cultivation.

4.3.1.5 Slope gradient and aspect

Gradient at each site was measured in fall 1996 using a meter-stick apparatus with % and degree calibrations. Twenty-seven slope measurements were taken within each range - three slope measurements per treatment. Aspect was defined by visually describing the direction based on zero declination from geographic north.

4.3.1.6 Topsoil depth

A 30-cm soil sample was obtained from a soil sampler taking a core of 2.0-cm diameter. Surface soil depth was measured to a difference in texture or color, roughly indicating the interface with the next horizon. In cases where an organic horizon preceded the mineral one, topsoil depth was expressed as the summation of the depths of the mineral and organic horizons. Nine measurements were made at each site in a stripwise fashion across the width of the slope - three samples on each end and three in the middle.

4.3.2 Laboratory analyses

4.3.2.1 Determining water holding capacity

To determine soil water characteristic curves for the study soils, 10-20 g of air dried soil from each ground sample (0-15, 15-30, 30-45, 45-60, 60-75, 75-90 and 90-105 cm) was placed in small PVC rings on a ceramic pressure plate. These samples were then saturated for 24 hours, after which they were placed into a steel chamber at constant pressure for 48 hours. Water content was determined at 0.01, 0.033, 0.1, 0.3 and 1.5 MPa pressure. Samples were removed from the chambers and placed into drying tins where they were weighed (wet without PVC retaining ring), oven dried at 105 °C for 24 hours and then weighed dry. Gravimetric water content was converted to volumetric basis by multiplying the gravimetric water content by bulk density determined from 501 depth density readings for the depth increment being considered. Field capacity was assumed to be the water retained at 0.033 MPa with wilting point at 1.5 MPa. The available water holding capacity of the soil was then calculated as the difference between field capacity and wilting point.

4.3.2.2 Particle size analysis

Textural analysis was performed on soil samples taken during access tube installation. Once these samples were air dried and ground, they were separated into sand, silt and clay fractions using the hydrometer method outlined by Gee and Bauder (1986). Using this method, a soil sample of known weight was dispersed through dissolution in distilled water and sodium-hexametaphosphate, followed by mixing. Fine textured soils (silts and clays) required sample weight of 10-20 g while coarse textured materials required larger sample sizes (60-100 g). A 10-g sample of the same soil was weighed and oven dried at 105 °C to determine oven-dry weight.

A calibrated hydrometer was then lowered into the mixed suspension, with solution density readings being taken (g/L) at 30 s and 1 min, followed by rinsing and subsequent readings at 1, 4 and 24 hours.

4.4 Results

4.4.1 Characterizing summer precipitation

Although precipitation in 1995 was similar at Sites 2, 4 and 5, Site 3 had a noticeably lower accumulated precipitation, with a steadily increasing accumulation throughout the summer months while other sites had a marked increase after August 2, 1995 (Figure 4.1). In 1996, there was a greater difference in precipitation among sites than in 1995, although the trend in precipitation at all sites was similar in both years (Figure 4.2).

In 1995 and 1996 there were two dominant periods over which most of the site-averaged summer precipitation was received (Figure 4.3). In 1995, a large proportion of the summer rainfall occurred from July 26 to August 9, accounting for 48% of the measured summer precipitation, while in 1996, 42% of the summer precipitation was received from June 10 to June 23. Note that the summer measurement period in 1996 was longer than in 1995.

4.4.2 Soil water retention and characteristic curves

Soil water retention at field capacity and wilting point varied by site, depending largely on the texture of the soil such that FC and WP to 30 cm were highest at Site 2, FC to 90 cm was highest at Site 2 while WP to 90 cm was highest for Site 5 (Table 4.2). Site 2 also had the highest available water holding capacity (field capacity - wilting point) to both depths. Site 5 had the lowest available water holding capacity. At Site 1, less water was retained in the subsoil (> 30 cm) than the topsoil (0-30 cm): the loam and clay loam textured surface (0-30 cm) material at this site had higher soil water retention than did the sandy loam subsoil (Appendix C). The sandy loam textured subsoil below 30 cm generally exhibited equivalent water retention throughout the full range of pressure.

Water retention for Sites 2 and 3 was similar for different depth intervals. Surface soils to 30 cm at these sites generally held less water throughout the full range of pressures than did soils below 30 cm, though this difference was very small (Appendix A).

Water retention of soils at depths below 30 cm at Sites 4 and 5 was similar, maintaining a very narrow range (Appendix C). At Site 4, water retention at nearly all pressures was similar for all depths, except for soil in the 15-30 cm depth interval which retained the least amount of water.

4.4.3 Effects of management on total soil water (TSW)

Total soil water to 30 cm (TSW30) varied considerably throughout the study period, though there were consistent trends both seasons. There were four notable recharge times during the study: August 9, 1995, April 22, 1996, June 24, 1996 and October 21, 1996 (Figure 4.4). Springmelt recharge was obvious in 1995 but not in 1996. TSW30 was generally low on July 26 and September 28, 1995 and May 27 and August 27 in 1996.

4.4.3.1 Seasonal fluctuations in total soil water to 30 cm (TSW30)

4.4.3.1.1 Site 1

TSW30 was highest for the fallow treatment from August 25, 1995 to June 24, 1996. TSW30 was similar for both the hayed and mowed treatments with the mowed treatment reaching the highest TSW30 in both 1995 and 1996. There was a fifth notable recharge period at Site 1, on July 23, 1996.

The fallow treatment did not have a high TSW30 in fall 1996, although soil water measurements were not taken in September. Spring TSW30 was higher in fallow than in the hayed and mowed treatments. However, there was a small decrease in TSW30 on fallow over winter, whereas TSW30 in both the hayed and mowed treatments increased markedly.

4.4.3.1.2 Site 2

At this site, fallow had the highest TSW30 for the duration of the study after August 25, 1995 (Figure 4.4). Generally, the mowed treatment had the lowest TSW30, but was generally similar to the TSW30 of the hayed treatment. While peak TSW30 occurred on the hayed treatment in 1995, the fallow treatment consistently had the highest TSW30 in 1996.

As a result of over-winter recharge, the hayed treatment had the greatest increase in TSW30 of the three treatments, with TSW30 equaling that of the fallow treatment, which did not increase appreciably in TSW30 over-winter.

4.4.3.1.3 Site 3

At this site TSW30 was very similar among treatments until late June 1996 (Figure 4.4). Fall recharge occurred during both seasons with TSW30 being higher in fall 1996 than in 1995.

There was little difference in TSW30 during spring 1995 and 1996 when the fallow treatment had the lowest TSW30 (Figure 4.4). TSW30 increased in both the hayed and mowed treatments during this period with TSW30 of these two treatments following winter recharge being nearly equivalent. The fallow treatment showed a markedly lower TSW30 than the hayed and mowed treatments in 1996, unlike in 1995 when TSW30 for the mowed and hayed treatments was similar in the first season while the mowed treatment had the highest TSW30 in the second season. In both the 1995 and 1996 seasons, the fallow treatment frequently had the lowest TSW30.

4.4.3.1.4 Site 4

At this site, the fallow treatment maintained the higher TSW30 for most of the study (Figure 4.5). Occasionally, TSW30 of the grazed treatment exceeded that of the fallow treatment: early in the study and on June 24, 1996. TSW30 increased over winter on both treatments in 1995 and 1996, except fallow in 1996. After 3 of the 4 recharge periods (except April 22, 1996) TSW30 for the grazed treatment was similar to or greater than that of the fallow.

4.4.3.1.5 Site 5

TSW30 was generally higher on the fallow treatment although the pattern for the grazed treatment was more dynamic than that of the fallow treatment (Figure 4.5). After recharge, TSW30 was generally higher in the grazed treatment than in the fallow treatment (e.g. April 22, June 24, 1996 and May 1, 1997).

4.4.3.2 Seasonal fluctuations in soil water to 90 cm (TSW90)

Generally, although subdued, trends in TSW90 over time (Figure 4.6 and Figure 4.7) were similar to those for TSW30. Effects of the four recharge periods on TSW90 are clearly evident. The fallow treatment at Site 1 had the highest TSW90 after August 9, 1995, with the other two treatments having similar TSW90.

At Site 2, TSW90 was highest on the fallow treatment for most of the study (Figure 4.6), although there was a more subdued, earlier peak in TSW90 for the fallow treatment than there was for TSW30. Peak TSW90 occurred on the fallow treatment whereas peak TSW30 occurred on the hayed treatment.

At Site 3, TSW90 was similar for all treatments (Figure 4.6) and remained fairly constant over time. At Site 4, TSW90 was generally higher on the fallow treatment than the grazed treatment (Figure 4.7), while at Site 5, it was similar for the two treatments (Figure 4.7).

Both TSW30 and TSW90 were generally higher in spring than in fall. However, the decreases in TSW30 and TSW90 at Site 1 between fall and spring were only evident on fallow plots from which snow melted early in the season. On all other sites, the fallow treatment generally did not show the same magnitude of increase in TSW30 and TSW90 following winter recharge as did the hayed and mowed treatments.

4.4.4 Relationship of TSW30 and TSW90 to field capacity (FC) and wilting point (WP).

During recharge periods, TSW30 increased to near FC (Figure 4.4 and Figure 4.5), especially at Site 1. Minimum TSW30 was near or below WP on four dates, most notably at Site 4. TSW90 at Site 2 was generally closest to WP. Mid-range TSW90 was evident at Sites 3 and 5.

4.4.5 Site comparison of total soil water (TSW)

4.4.5.1 TSW30

TSW30 for both the hayed and mowed treatments was generally lowest at Site 1, except during mid-summer 1996 (Figure 4.8). At Site 3, TSW30 was highest in the spring on the hayed and mowed treatments. No consistent trend in TSW30 for either the hayed or mowed treatments was evident across sites.

At Sites 4 and 5, there was no consistent trend in TSW30 across years for either the grazed or the fallow treatment (Figure 4.9). For the grazed treatment, Site 5 generally had the higher TSW30, while for the fallow treatment generally Site 4 did.

4.4.5.2 TSW90

Generally, TSW90 was highest at Site 3 for all treatments at Sites 1, 2 and 3 (Figure 4.10), most notably for the mowed treatment. TSW90 was generally lowest at Site 1 across all treatments, least so for fallow.

For the entire study, the grazed treatment at Site 5 maintained the higher seasonal TSW90 than it did at Site 4 (Figure 4.11). Trends in TSW90 under fallow were similar at Sites 4 and 5, except in the initial month.

4.4.6 Comparison of reclaimed and unmined lands

Site 1 had similar TSW30 to that of the other sites for the fallow treatment (Figure 4.8). It had the lowest TSW30 under the hayed treatment for most of 1995, but highest in 1996. A somewhat similar pattern was evident for the mowed treatment. Site 1 had the lowest TSW90 of all sites during the two field seasons, particularly in the hayed and mowed plots (Figure 4.10). TSW90 of the fallow treatment at this site was generally similar to that for the fallow at the other two sites.

4.4.7 Frequency of soil water status

Soil water frequency at Sites 1, 2 and 3 varied by depth interval and treatment, though generally, for at least 50% of all measurements, soil water was low, falling into Classes I and II for surface soil water, TSW30 and TSW90 (Table 4.3). To 90 cm, Classes I and II accounted for the greatest proportion of soil water frequencies across all treatments. Frequency for surface soil water of hayed and mowed treatments tended to vary among sites, although the hayed and mowed treatments generally had at least half of their soil water frequencies in Classes I and II. The fallow treatment generally had a greater frequency of surface soil water in Classes I and II compared to the hayed and mowed treatments (Table 4.3). Soils at Sites 1, 2 and 3 were generally dry with most values in the lower range of available soil water (Classes I and II). At greater depth, there was generally a shift in frequency such that classes representing higher soil water had more observations for the fallow treatment than the hayed and mowed treatments.

At Sites 4 and 5, the grazed treatment generally had at least 50% of soil water conditions in Classes I and II compared to the fallow treatment which tended to have a greater soil water frequency in Classes II and III, particularly for TSW30 and TSW90 (Table 4.3). Surface soil water in the grazed treatment was generally more frequent in Classes I and II than in the fallow treatment.

4.4.8 Soil water profiles with depth

4.4.8.1 Sites 1, 2 and 3

Fallow treatments generally had higher soil water at depth than the hayed and mowed treatments (Figure 4.12). Generally, the water content of all treatments decreased with depth and surface water (0-7.5 cm) was often higher compared with all other depths below 20 cm, except at the beginning of the study. Through each season, soil water increased, both at the surface and with depth, generally with a sharp separation between the fallow and the hayed and mowed treatments. The fallow treatment had a higher water content for depths >40 cm than the other two treatments in fall 1995 and in mid-summer 1996.

Soil water with depth of the hayed and mowed treatments tended to be similar at all three sites (Figure 4.12), following the same general decreasing trend during periods of high evapotranspiration. Soils at both Sites 1 and 2 had lower soil water with depth on both the hayed and mowed treatments, though the fallow treatment maintained higher soil water at both sites at most depths.

4.4.8.2 Sites 4 and 5

Soil water below 40 cm at Sites 4 and 5 varied considerably between treatments. Above this depth, soil water was generally highest on the fallow treatment at both sites, with the grazed treatment having greater water below 40 cm (Figure 4.12). Soil water throughout the profile in both the grazed and fallow treatments was higher in 1996 than in 1995.

The fallow treatment at Site 5 had lower soil water below 40 cm than the grazed treatment. Soil water to 90 cm of the grazed treatment at Site 5 was higher compared to the same treatment at Site 4, while soil water under fallow was generally similar at Sites 4 and 5 at all depths.

4.5 Discussion

4.5.1 Total soil water to 30 and 90 cm

Elevated spring TSW30 on hayed and mowed treatments compared to fallow treatments at forage sites may be explained by entrapment of snow between the stems and leaves of dormant vegetation. As snow settled between stems, it was not as easily dislodged by winter winds thereby preventing exposure of the soil surface. Early melting of snow may have occurred on all fallow plots due to a shallow snow cover and low albedo of the soil surface when it became exposed during melt. As small portions of the plot surface became visible, accelerated melting exposed more bare soil surfaces. Subsequent heating of the bare soils may have evaporated soil water which had accumulated during the winter and initial springmelt. This early loss of snow may have led to a reduction in infiltrated meltwater. Had soil water been measured earlier than April 22, 1996, when soil surfaces were completely thawed, this loss of soil water may not have been missed and a higher winter soil water content due to over-winter recharge may have been measured.

Site 5, unlike Site 4, had a very narrow range in soil water content between treatments. Compaction at Site 5 by grazing cattle may have reduced infiltration (Section 3.5.2) such that both the grazed and fallow plots maintained similar water contents through both field seasons.

The higher total soil water of the grazed treatment at Site 5 than Site 4 may have been due to a reduced ground cover at that site. Higher surface cover was observed at Site 4 and there was likely a greater repulsion of water by litter, as was found during rainfall simulation. Thus, at Site 5 more water was able to infiltrate and a greater proportion of precipitation to be stored in the profile. Higher TSW30 of grazed treatments compared to the fallow treatments coincided with spring recharge, the loss of water on fallow treatment in spring (evaporation from bare surfaces) and periods of high rainfall.

The large decrease in TSW30 and TSW90 of all treatments at all sites following the August 1995 recharge was likely due to a period of high evapotranspiration as vegetation was growing rapidly, recovering from harvest which had occurred three weeks prior to the peak TSW30 and TSW90. Three weeks after harvest, the plants would have had a high leaf area and thus a much greater surface capable of transpiring. During 1995, TSW30 and TSW90 followed the precipitation trend for July and August, such that as precipitation increased to August 9, total soil water increased accordingly. After August 9, precipitation decreased as did soil water.

The steady decline in soil water of fallow treatments at Site 3 in 1996 was likely due to evaporation and a large amount of uncontrolled weed growth on these plots after cultivation in mid-June. As there was less weed growth at Site 1, soil water on fallow at that site would have been less affected by transpiration and the controlling process in loss of water from these plots would have been evaporation. High TSW30 of the mowed treatments at both Sites 1 and 3 may be explained by reduced demand on soil water by transpiration from less dense plants with greatly reduced leaf area. The low TSW30 for the hayed treatments at Sites 1 and 3 was likely due to a high demand on soil water.

TSW30 at Sites 4 and 5 was not variable over time likely due to the activity of cattle on the plots. Their activity increased bulk density (Section 3.5.3) and may have reduced infiltration, reducing the accumulation of water in the soil profile through all depths. After two seasons of fallowing and extensive compaction, TSW90 was greatly influenced. TSW90 on grazed treatments at Site 5 was significantly higher than at Site 4 likely due to the higher evapotranspiration of the greener and lusher vegetative growth at Site 4 than 5. Fallowing at each of these two sites tended to equalize their respective soil water regimes, with high TSW30 and TSW90 at both sites.

4.5.2 Site comparison of TSW30 and TSW90

Increases in soil water following haying operations at all forage sites, in both 1995 and 1996, were likely due to the absence of above ground biomass as haying removed 75-85% of the top-growth (observation). Since August was past the prime growing season at these sites, plant growth at this time was slow and less water was evapotranspired. During the recharge period in August 1995, soil water was sharply increasing, coinciding with reduced evapotranspiration and regular additions of water through precipitation. As the first cut was removed near the beginning of August, 1996, only a short growing period remained before winter. As there was very little precipitation until the end of August, TSW30 and TSW90 decreased until the end of the month, at which time reduced evapotranspiration and increased precipitation resulted in increased soil water.

The decrease in soil water following the July 1995 peak was likely due to evapotranspiration, evaporation from bare soils and a lack of precipitation. As mowed and hayed treatments displayed this same increasing and decreasing pattern in August 1995, precipitation during this period was a controlling factor in soil water recharge as evapotranspiration was at a minimum following haying. Also, soil water was recharged significantly over the period from July 12 to August 9, 1995 and May 27 to June 24, 1996 as there was a large proportion of summer rainfall during these time periods - 51% in 1995 and 41% in 1996 over the specified time intervals.

Soil water was higher in pre-mine soils under both hayed and mowed land management than when soils were fallowed or reclaimed. The low TSW90 on reclaimed plots was likely due to lower water retention of the sandy subsoil.

At all sites, a high rate of water use during the growth period in early summer depleted surface water rapidly and allowed very little remaining water to percolate into the subsoil and recharge soil water. However, in the fallow treatments TSW90 continually increased for the duration of the study. Thus, the incorporation of a fallow period as a management regime increases soil water.

Although soil water content below 30 cm was low on all treatments, soil water at these depths was lowest for the vegetated treatments (hayed and mowed). It is likely that root uptake of water in the surface soil resulted in decreased water in the vegetated treatments. Since the fallow treatment was unvegetated, water likely moved deeper into the soil profile.

Higher TSW90 of the hayed and mowed treatments at Sites 2 and 3 than Site 1 may have been due to higher retention of water. As soils at Site 2 and 3 had a high clay content, retention of water was high, but this water became less available to plants under increasingly stressful conditions (dry periods when total soil water approaches wilting point).

Surface sealing and the lack of macropores and biopores to greater depths within the soil profile may have been the most significant factors controlling infiltration, particularly at Site 2. Duley (1939) found that surface sealing was due to changes in the immediate surface and that protected surfaces reached higher steady state infiltration rates than did bare soils. This finding may support the low total soil water found in these soils as rainfall may have also sealed the surface of the soil, given sufficient intensity. Due to the high percent bare ground on vegetated treatments at this site, it is possible that surface biopores in vegetated treatments were also sealed in a similar manner.

4.6 Management implications

The hayed management regime was an appropriate land use for the area, given sufficient time to establish into a stand capable of good production and soil protection. The hayed treatment offers the best land management option as it protects soil on steep slopes, is a perennial, requires less annual inputs (costs associated with growing annuals cereals or oilseeds) and produces good forage yields. Hayed alfalfa reduced soil water greatly below that of the fallow treatment and thus, this treatment is prone to having soil water below wilting point thereby causing plant stress and a potential decrease in yield.

The mowed treatment could be used to accumulate small amounts of soil water. However, since mowing on a large field scale is an impractical and very labour intense treatment, it would be an expensive and damaging practice - damaging to the soil by frequent wheel traffic leading to compaction and detrimental to plant growth as mowing would eventually reduce surface cover and tiller density resulting in an increased potential for soil erosion.

Fallow was a treatment which could be used to increase soil water while also reducing the variation in soil water over time. Fallowing could be a practical management option if it were necessary to increase the porosity of dense or compacted soils. However, this would not be a practical water management treatment to be used on soils of the study area as both soil texture and slope gradient would result in accelerated water erosion at these sites. In addition, two cultivations and two herbicide applications would be recommended to reduce weed growth. However, these operations become expensive to land owners as moderately productive land is not being utilized, thereby reducing potential income from an alternate land use.

Since soil water on compacted fallow plots at Sites 4 and 5 was similar to that of grazed plots, it is likely that fallowing with extensive compaction may lead to similar accumulation of water as a grazed treatment under high intensity grazing and hoof traffic. Also, fallow appeared to be an effective way of homogenizing the soil at pasture sites as there was very little difference in water content of fallow plots at these sites.

Land management to prevent overland flow on the soils in this area would best be designed such that increases in soil water were accomplished while maintaining soil cover. High runoff rates would be expected under conditions where the soil surface is bare and also in cases where a vegetated soil has a low infiltration capacity. Therefore, vegetation management offers the best alternative to cultivation based management for soils in this area as runoff could be expected to be high from soils under fallow management due to lack of surface cover and high soil water (see Chapter 3).

4.7 Conclusions

Soil water varied during each season by depth, treatment and time. The hayed and mowed treatments had similar soil water by depth and also had a greater variation in accumulated soil water than the fallow treatment. Pasture sites were generally wetter than forage sites; this difference was most pronounced on fallow treatments.

Soil water across all treatments was generally most frequently measured in classes representing dry conditions. However, under fallow, the frequency distribution of soil water to greater depths shifted to higher classes (higher soil water), particularly at pasture sites. Total soil water in reclaimed soils was generally similar to that at off-mine sites with full vegetative cover.

Table 4.1 Summer precipitation (mm).

		Precipitation		
Date		Summer*	Total growing season rainfall**	% of total summer rainfall
1995	July 26-Aug 9	101.5	212.0	48
1996	June 10-23	106.0	252.8	42
		Fall		
1995	Sept 1-Oct 31	25.0	212.0	12
1996	Sept 1-Oct 31	82.0	252.8	32

* Summer was taken as the months between June 1 and August 31 of the respective year.
** Growing season was the months from May 1 to October 31 in each respective year.

Table 4.2 Total soil water (mm) at field capacity (FC) and wilting point (WP).

	To 30 cm		To 90 cm	
Site	FC	WP	FC	WP
1	118	56	312	150
2	148	68	502	225
3	124	54	431	199
4	123	61	415	218
5	119	67	404	247

Table 4.3 Soil water frequency at a) Site 1, b) Site 2, c) Site 3, d) Site 4 and e) Site 5.

a) Site 1

		Hayed			Mowed			Fallow		
Class [φ]	SW (mm)	Freq [*]	%	Cumul [**]	Freq	%	Cumul	Freq	%	Cumul
Surface (0-7.5 cm)										
I	17-21	7	41.2	41.2	4	23.5	23.5	5	29.4	29.4
II	22-26	1	5.9	47.1	4	23.5	47.1	5	29.4	58.8
III	27-31	2	11.8	58.8	5	29.4	76.5	4	23.5	82.4
IV	32-38	7	41.2	100.0	4	23.5	100.0	3	17.6	100.0
TSW30										
I	55-70	7	38.9	38.9	5	27.8	27.8	2	11.1	11.1
II	71-85	2	11.1	50.0	2	11.1	38.9	2	11.1	22.2
III	86-102	5	27.8	77.8	5	27.8	66.7	9	50.0	72.2
IV	103-118	4	22.2	100.0	6	33.3	100.0	5	27.8	100.0
TSW90										
I	149-189	4	22.2	22.2	3	16.7	16.7	2	11.1	11.1
II	190-229	6	33.3	55.6	7	38.9	55.6	1	5.6	16.7
III	230-270	7	38.9	94.4	5	27.8	83.3	5	27.8	44.4
IV	271-313	1	5.6	100.0	3	16.7	100.0	10	55.6	100.0

[φ] Denotes soil water class divisions.

Class I	WP $\leq$ SW < (WP + 0.25 WHC)
Class II	(WP + 0.25 WHC) $\leq$ SW < (FC - 0.50 WHC)
Class III	(FC - 0.50 WHC) $\leq$ SW < (FC - 0.25 WHC)
Class IV	(FC - 0.25 WHC) $\leq$ SW < FC

[*] Freq = frequency of occurrence, a number.

[**] Cumul = cumulative percentage frequency of occurrence.

Table 4.3 (Continued) Soil water frequency at a) Site 1, b) Site 2, c) Site 3, d) Site 4 and e) Site 5.

b) Site 2

		Hayed			Mowed			Fallow		
Class [φ]	SW (mm)	Freq[*]	%	Cumul[**]	Freq	%	Cumul	Freq	%	Cumul
Surface (0-7.5 cm)										
I	19-24	8	47.1	47.1	9	52.9	52.9	10	58.8	58.8
II	25-31	4	23.5	70.6	4	23.5	76.5	2	11.8	70.6
III	32-37	3	17.6	88.2	2	11.8	88.2	1	5.9	76.5
IV	38-46	2	11.8	100.0	2	11.8	100.0	4	23.5	100.0
TSW30										
I	68-87	5	27.8	27.8	9	50.0	50.0	3	16.7	16.7
II	88-107	11	61.1	88.9	8	44.4	94.4	9	50.0	66.7
III	108-127	2	11.1	100.0	1	5.6	100.0	6	33.3	100.0
IV	128-148	0	0.0	100.0	0	0.0	100.0	0	0.0	100.0
TSW90										
I	225-293	18	100.0	100.0	18	100.0	100.0	11	61.1	61.1
II	294-362	0	0.0	100.0	0	0.0	100.0	7	38.9	100.0
III	363-431	0	0.0	100.0	0	0.0	100.0	0	0.0	100.0
IV	432-502	0	0.0	100.0	0	0.0	100.0	0	0.0	100.0

[φ] Denotes soil water class divisions.

Class I	WP $\leq$ SW < (WP + 0.25 WHC)
Class II	(WP + 0.25 WHC) $\leq$ SW < (FC - 0.50 WHC)
Class III	(FC - 0.50 WHC) $\leq$ SW < (FC - 0.25 WHC)
Class IV	(FC - 0.25 WHC) $\leq$ SW < FC

[*] Freq = frequency of occurrence, a number.

[**] Cumul = cumulative percentage frequency of occurrence.

Table 4.3 (Continued) Soil water frequency at a) Site 1, b) Site 2, c) Site 3, d) Site 4 and e) Site 5.

c) Site 3

		Hayed			Mowed			Fallow		
Class [φ]	SW (mm)	Freq [*]	%	Cumul [**]	Freq	%	Cumul	Freq	%	Cumul
Surface (0-7.5 cm)										
I	15-19	1	5.9	5.9	1	5.9	5.9	4	23.5	23.5
II	20-25	6	35.3	41.2	5	29.4	35.3	6	35.3	58.8
III	26-31	3	17.6	58.8	4	23.5	58.8	3	17.6	76.5
IV	32-39	7	41.2	100.0	7	41.2	100.0	4	23.5	100.0
TSW30										
I	53-70	2	11.1	11.1	2	11.1	11.1	2	11.1	11.1
II	71-87	7	38.9	50.0	4	22.2	33.3	9	50.0	61.1
III	88-105	5	27.8	77.8	5	27.8	61.1	6	33.3	94.4
IV	106-124	4	22.2	100.0	7	38.9	100.0	1	5.6	100.0
TSW90										
I	198-255	4	22.2	22.2	2	11.1	11.1	1	5.6	5.6
II	256-314	10	55.6	77.8	9	50.0	61.1	11	61.1	66.7
III	315-372	4	22.2	100.0	7	38.9	100.0	6	33.3	100.0
IV	373-431	0	0.0	100.0	0	0.0	100.0	0	0.0	100.0

[φ] Denotes soil water class divisions.

Class I	$WP \leq SW < (WP + 0.25\ WHC)$
Class II	$(WP + 0.25\ WHC) \leq SW < (FC - 0.50\ WHC)$
Class III	$(FC - 0.50\ WHC) \leq SW < (FC - 0.25\ WHC)$
Class IV	$(FC - 0.25\ WHC) \leq SW < FC$

[*] Freq = frequency of occurrence, a number.

[**] Cumul = cumulative percentage frequency of occurrence.

Table 4.3 (Continued) Soil water frequency at a) Site 1, b) Site 2, c) Site 3, d) Site 4 and e) Site 5.

d) Site 4

		Grazed			Fallow		
Class[φ]	SW (mm)	Freq[*]	%	Cumul[**]	Freq	%	Cumul
Surface (0-7.5 cm)							
I	21-24	6	35.3	35.3	7	41.2	41.2
II	25-29	1	5.9	41.2	2	11.8	52.9
III	30-33	4	23.5	64.7	0	0.0	52.9
IV	34-39	6	35.3	100.0	8	47.1	100.0
TSW30							
I	60-75	7	38.9	38.9	3	16.7	16.7
II	76-90	2	11.1	50.0	3	16.7	33.3
III	91-106	7	38.9	88.9	5	27.8	61.1
IV	107-122	2	11.1	100.0	7	38.9	100.0
TSW90							
I	218-266	9	50.0	50.0	3	16.7	16.7
II	267-315	7	38.9	88.9	4	22.2	38.9
III	316-364	2	11.1	100.0	11	61.1	100.0
IV	365-415	0	0.0	100.0	0	0.0	100.0

[φ] Denotes soil water class divisions.

Class I	WP ≤ SW < (WP + 0.25 WHC)
Class II	(WP + 0.25 WHC) ≤ SW < (FC - 0.50 WHC)
Class III	(FC - 0.50 WHC) ≤ SW < (FC - 0.25 WHC)
Class IV	(FC - 0.25 WHC) ≤ SW < FC

[*] Freq = frequency of occurrence, a number.

[**] Cumul = cumulative percentage frequency of occurrence.

Table 4.3 (Continued) Soil water frequency at a) Site 1, b) Site 2, c) Site 3, d) Site 4 and e) Site 5.

e) Site 5

		Grazed			Fallow		
Class[φ]	SW (mm)	Freq[*]	%	Cumul[**]	Freq	%	Cumul
Surface (0-7.5 cm)							
I	19-22	3	17.6	17.6	4	23.5	23.5
II	23-26	8	47.1	64.7	5	29.4	52.9
III	27-31	2	11.8	76.5	4	23.5	76.5
IV	32-37	4	23.5	100.0	4	23.5	100.0
TSW30							
I	67-79	4	22.2	22.2	1	5.6	5.6
II	80-92	6	33.3	55.6	4	22.2	27.8
III	93-104	4	22.2	77.8	10	55.6	83.3
IV	105-119	4	22.2	100.0	3	16.7	100.0
TSW90							
I	247-286	2	11.1	11.1	1	5.6	5.6
II	286-324	8	44.4	55.6	8	44.4	50.0
III	325-363	7	38.9	94.4	8	44.4	94.4
IV	364-404	1	5.6	100.0	1	5.6	100.0

[φ] Denotes soil water class divisions.

Class I	$WP \leq SW < (WP + 0.25\ WHC)$
Class II	$(WP + 0.25\ WHC) \leq SW < (FC - 0.50\ WHC)$
Class III	$(FC - 0.50\ WHC) \leq SW < (FC - 0.25\ WHC)$
Class IV	$(FC - 0.25\ WHC) \leq SW < FC$

[*] Freq = frequency of occurrence, a number.

[**] Cumul = cumulative percentage frequency of occurrence.

Table 4.4 Surface (0-10 cm) porosity (cm cm^{-3}) for all treatments during fall sampling.

Forage			
Site	Hayed	Mowed	Fallow
1	0.58	0.57	0.55
2	0.54	0.50	0.57
3	0.55	0.54	0.58

Pasture		
Site	Grazed	Fallow
4	0.60	0.53
5	0.57	0.51

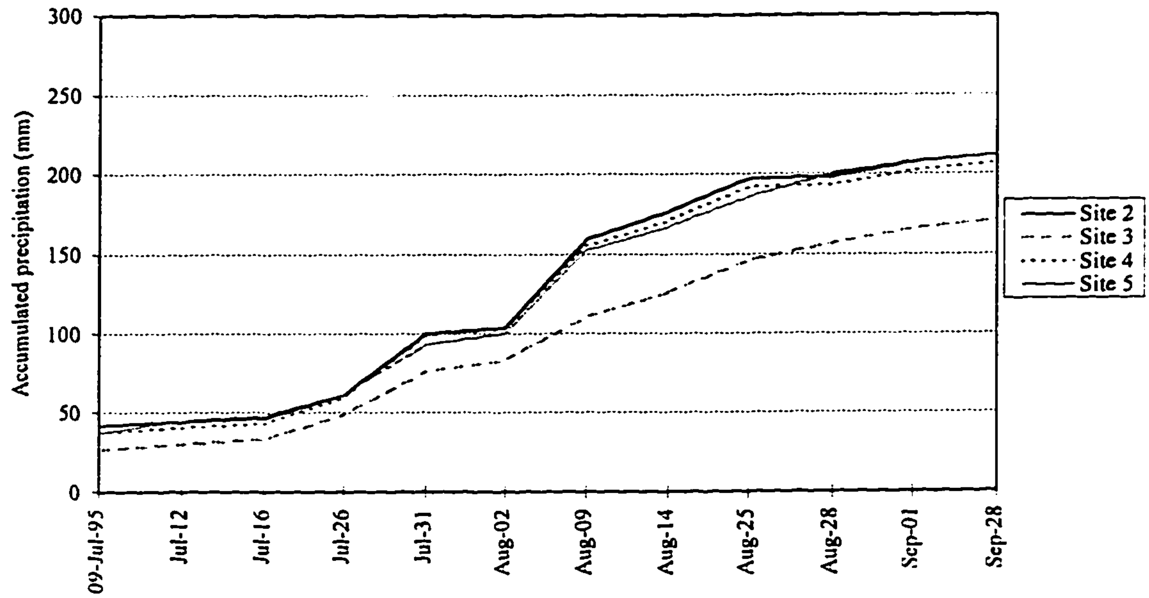


Figure 4.1 Accumulated precipitation for 1995.

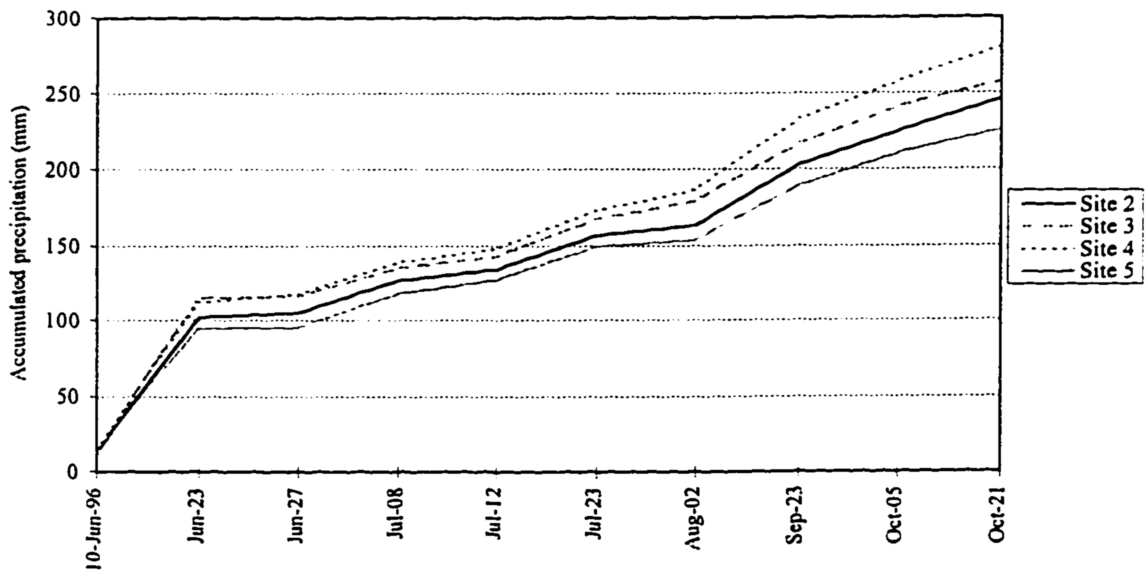


Figure 4.2 Accumulated precipitation for 1996.

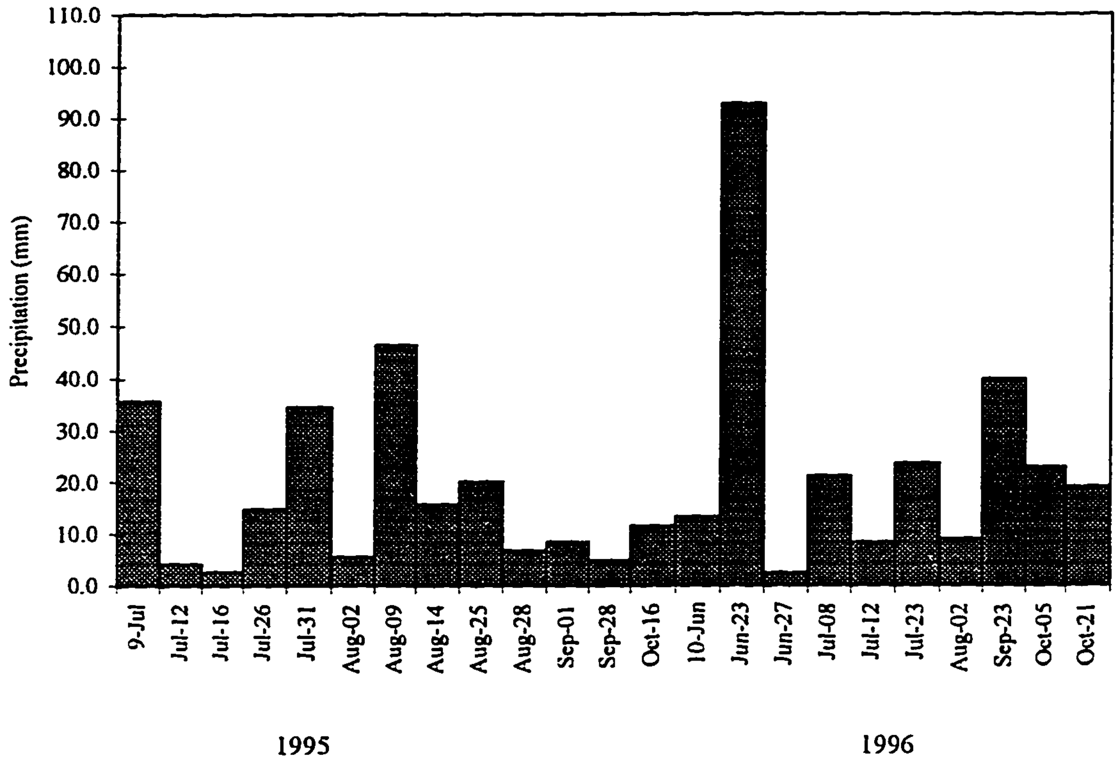


Figure 4.3 Site-averaged annual summer precipitation for elapsed period since previous measurement date.

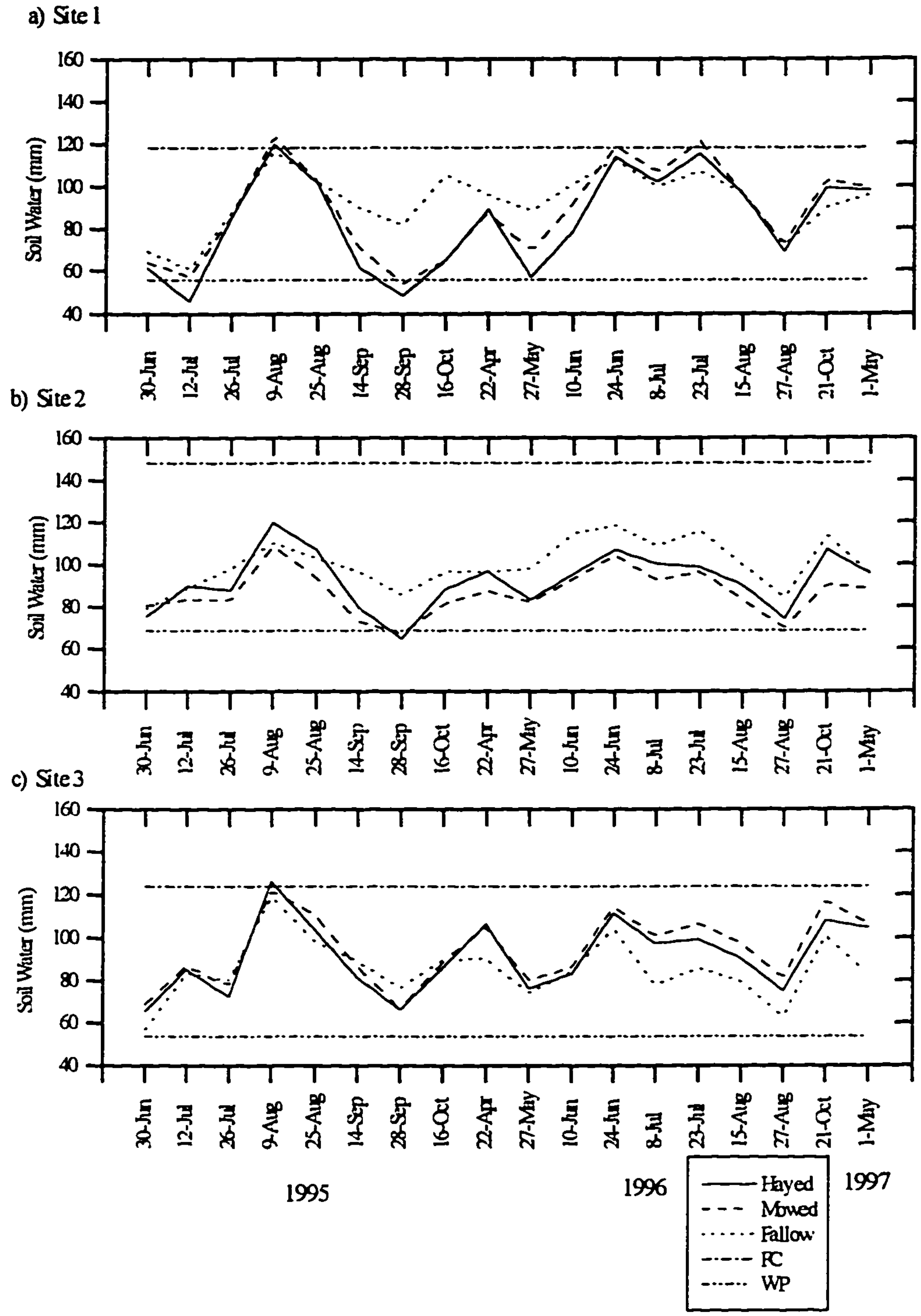


Figure 4.4 Total soil water to 30 cm at a) Site 1, b) Site 2 and c) Site 3.

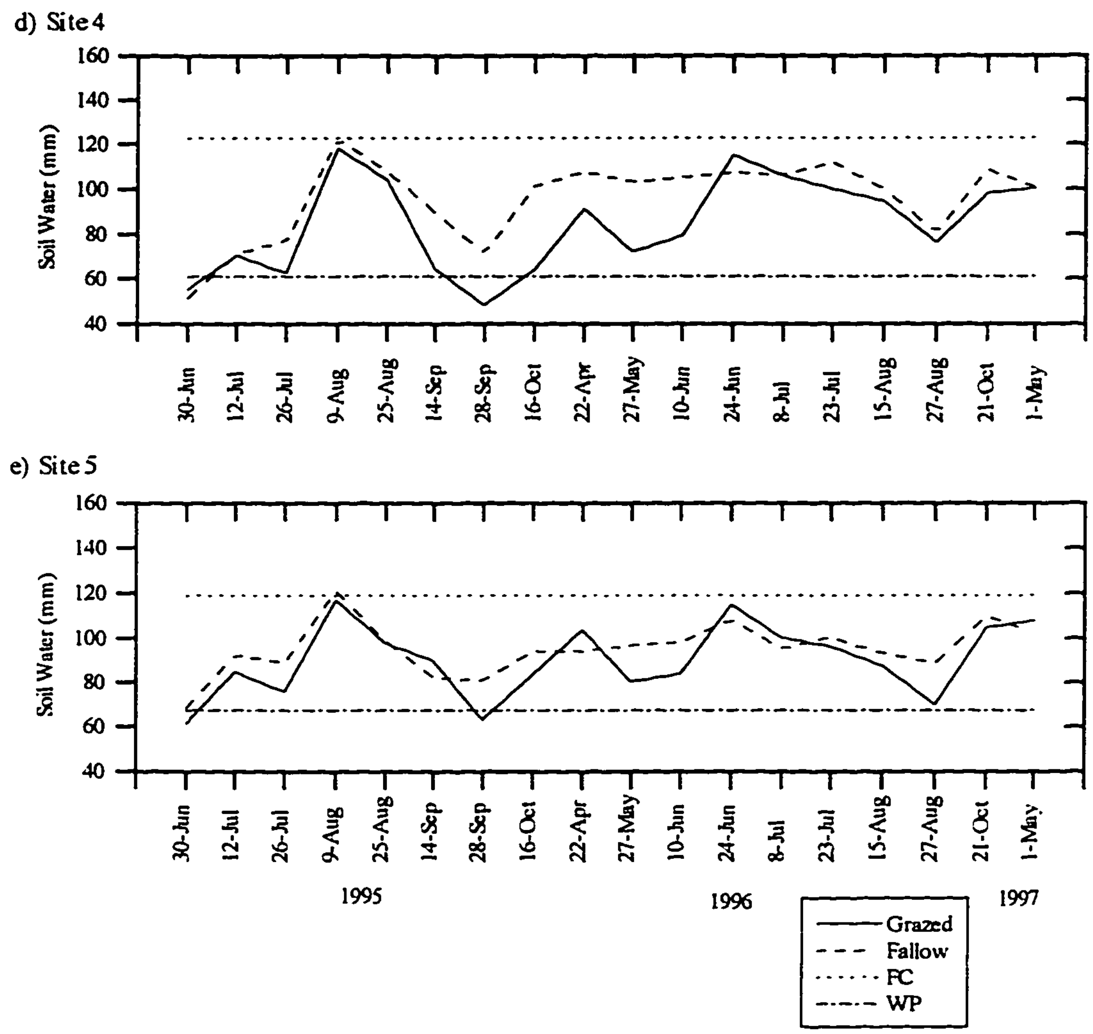


Figure 4.5 Total soil water to 30 cm at a) Site 4 and b) Site 5.

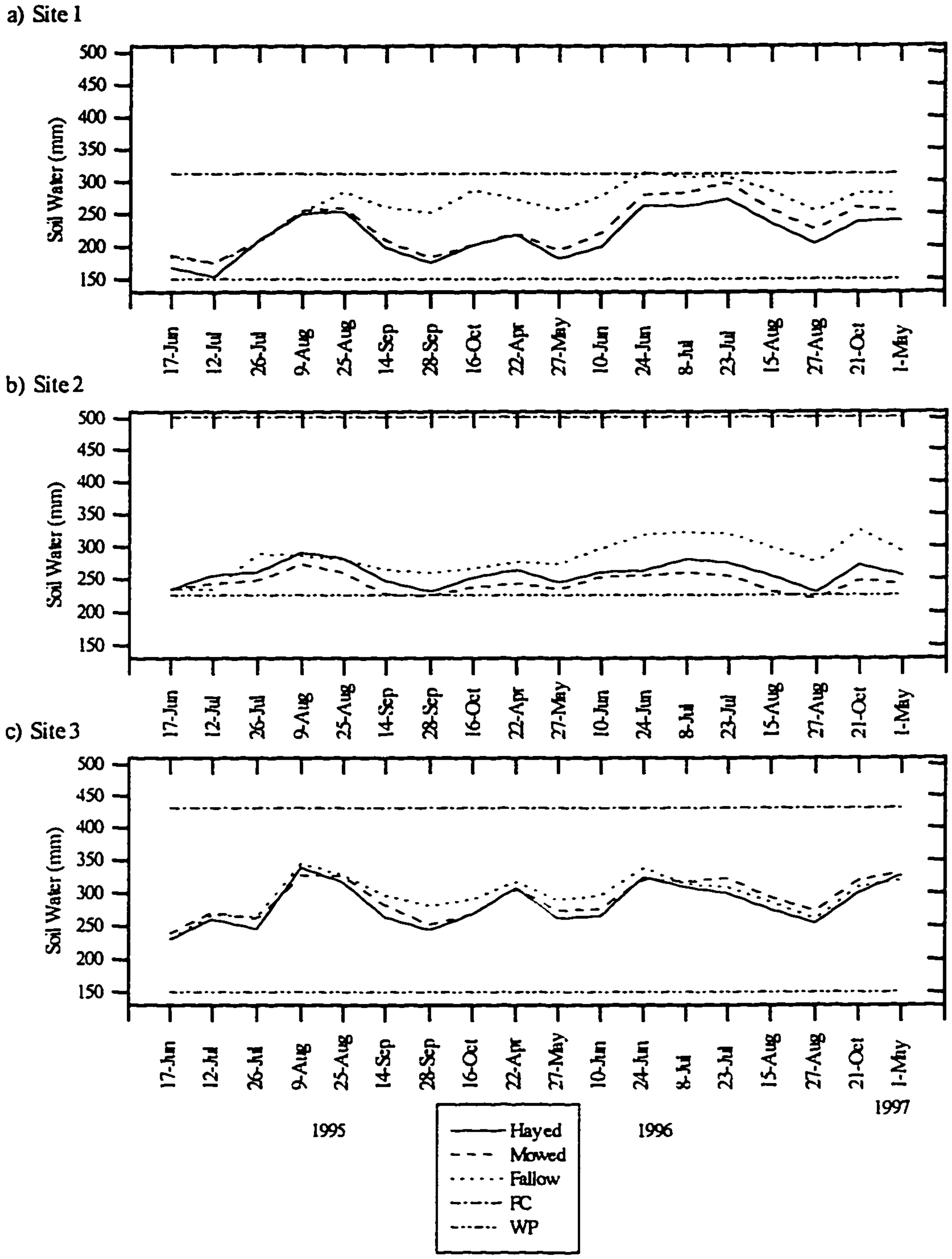


Figure 4.6 Total soil water to 90 cm at a) Site 1, b) Site 2 and c) Site 3.

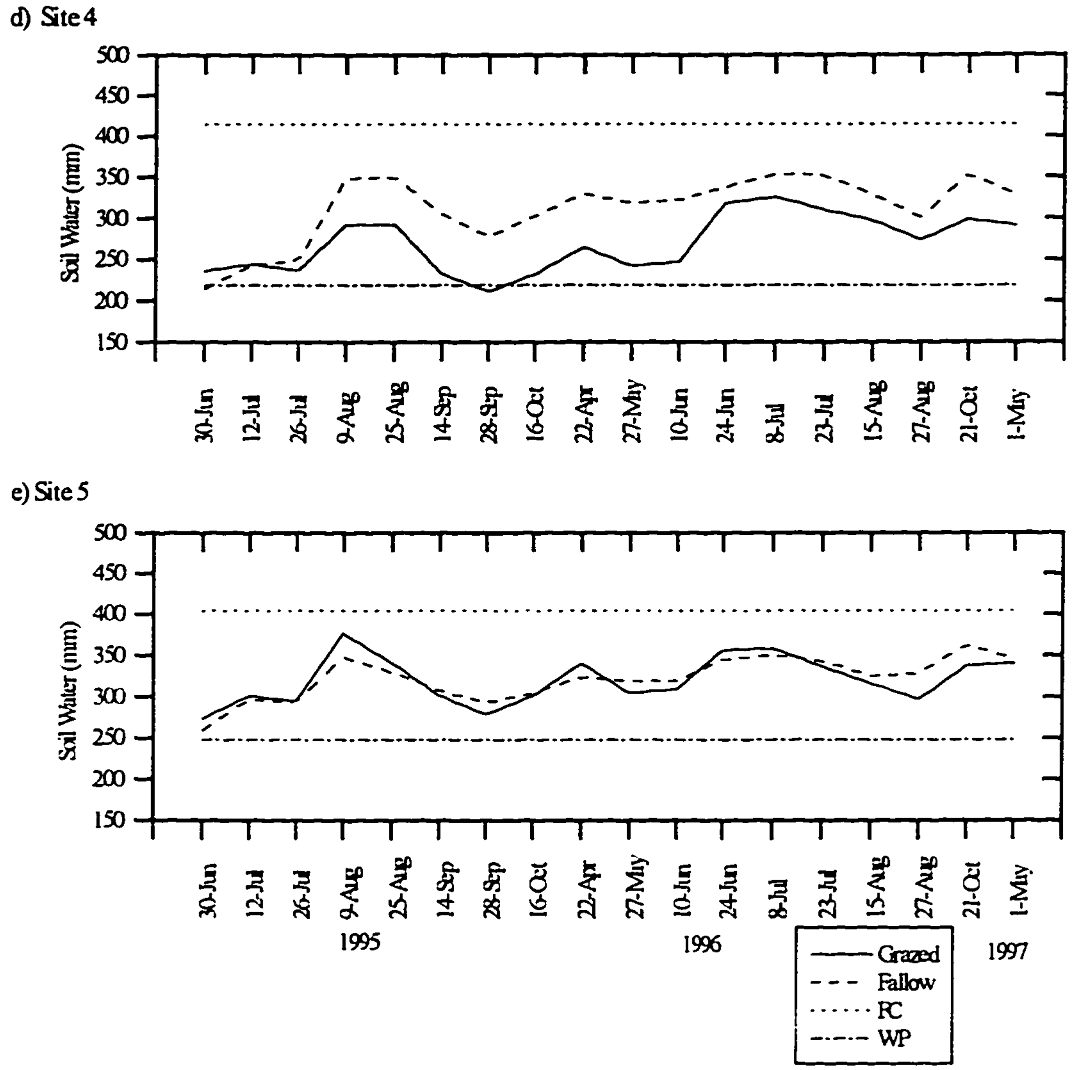


Figure 4.7 Total soil water to 90 cm at a) Site 4 and b) Site 5.

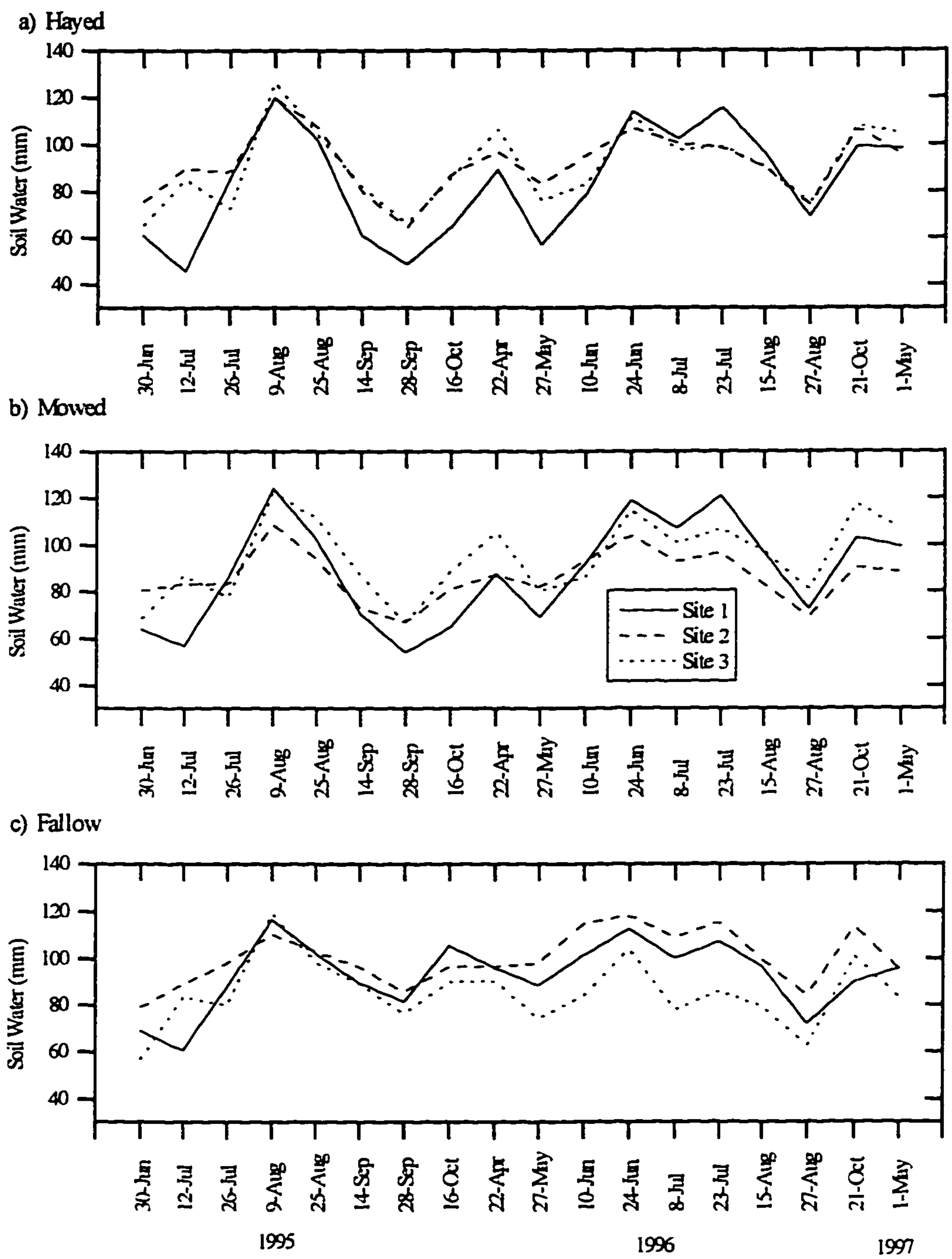


Figure 4.8 Inter-site total soil water to 30 cm for a) Hayed, b) Mowed and c) Fallow treatments.

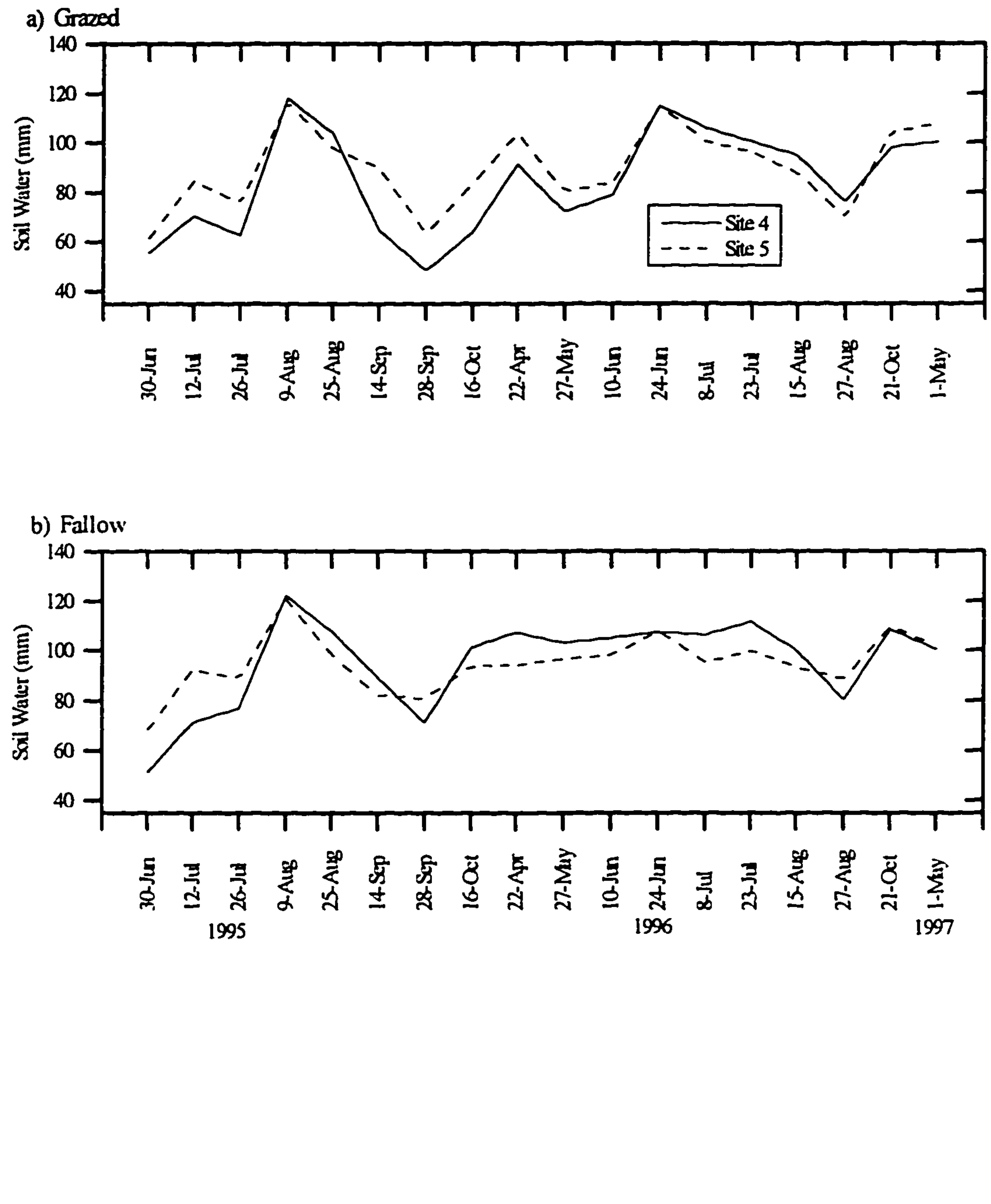


Figure 4.9 Inter-site total soil water to 30 cm for a) Grazed and b) Fallow treatments.

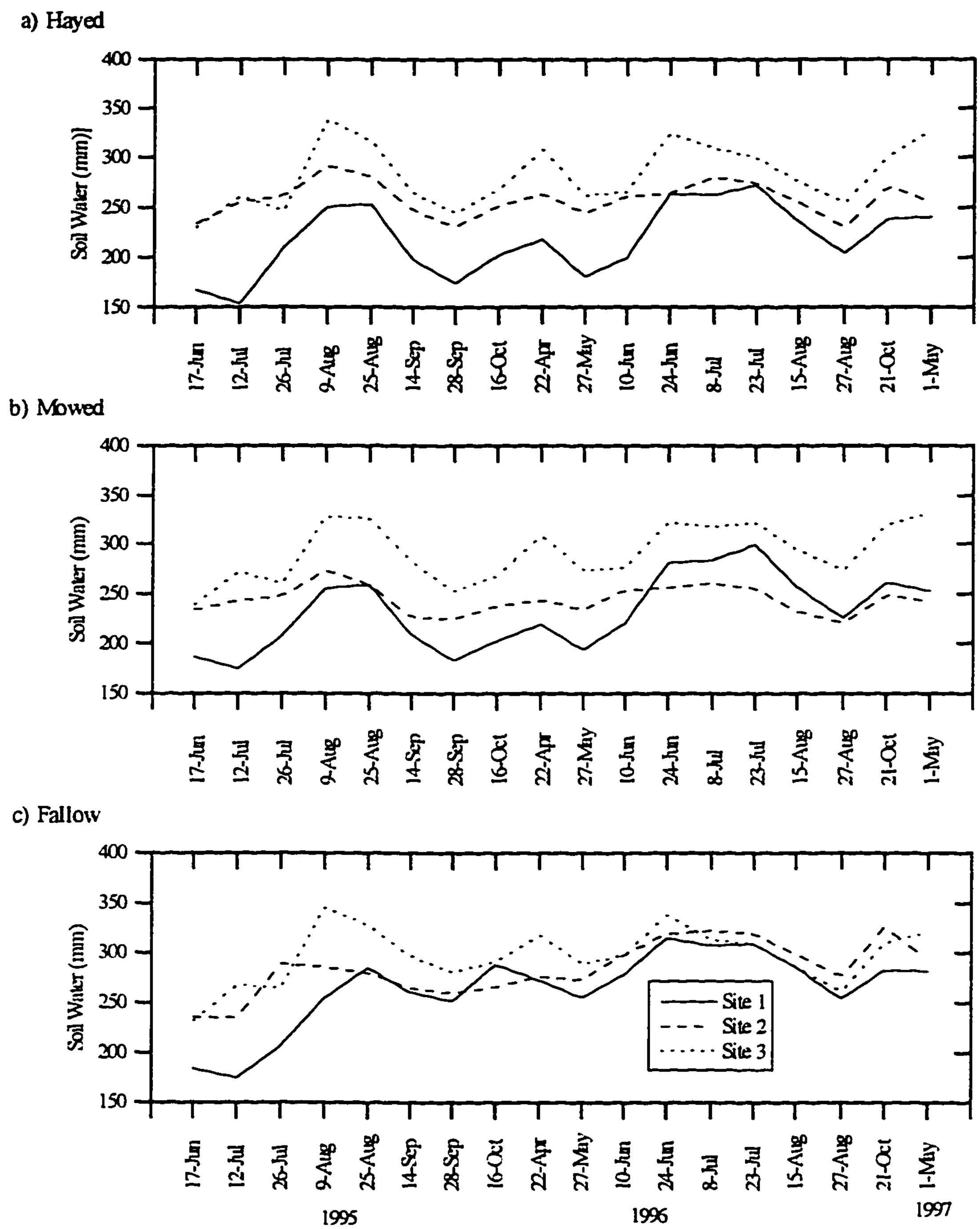


Figure 4.10 Inter-site total soil water to 90 cm for a) Hayed, b) Mowed and c) Fallow treatments.

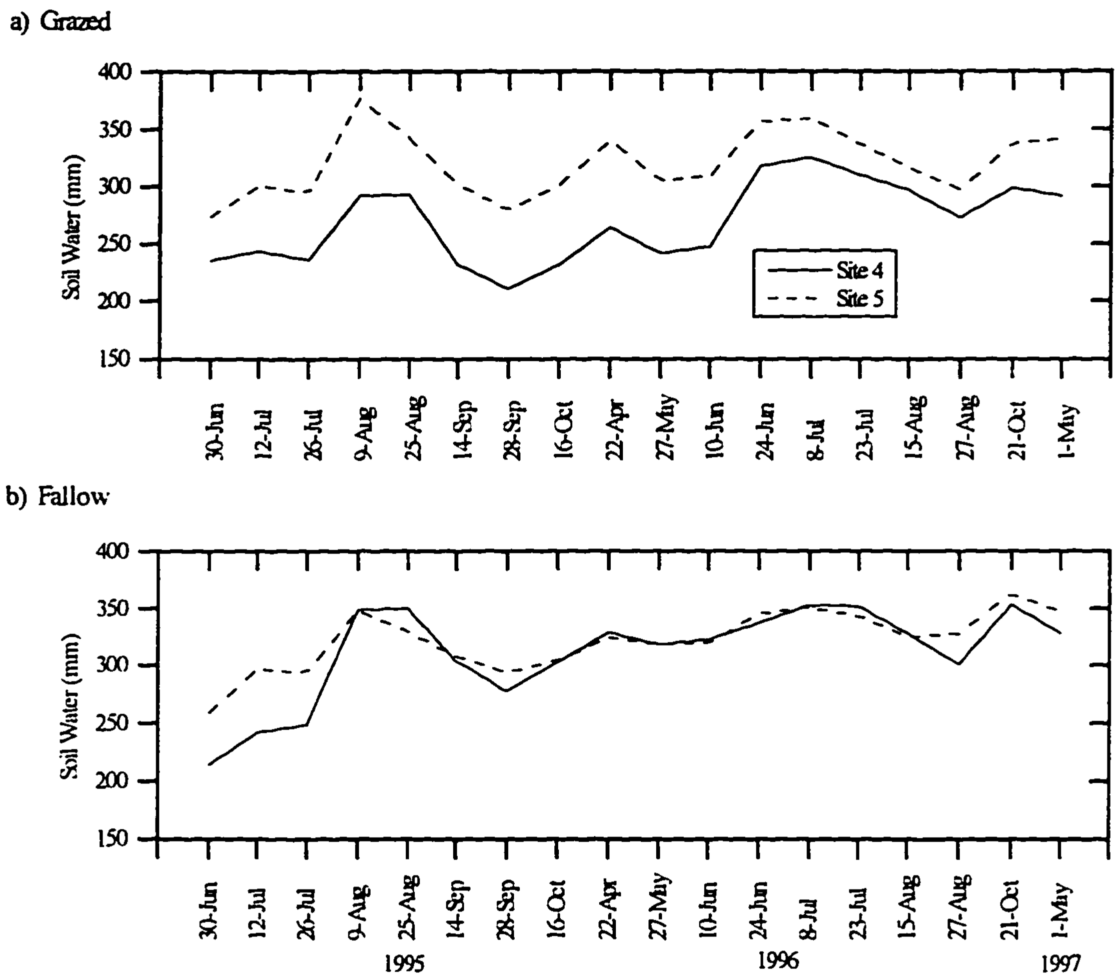


Figure 4.11 Inter-site total soil water to 90 cm for a) Grazed and b) Fallow treatments.

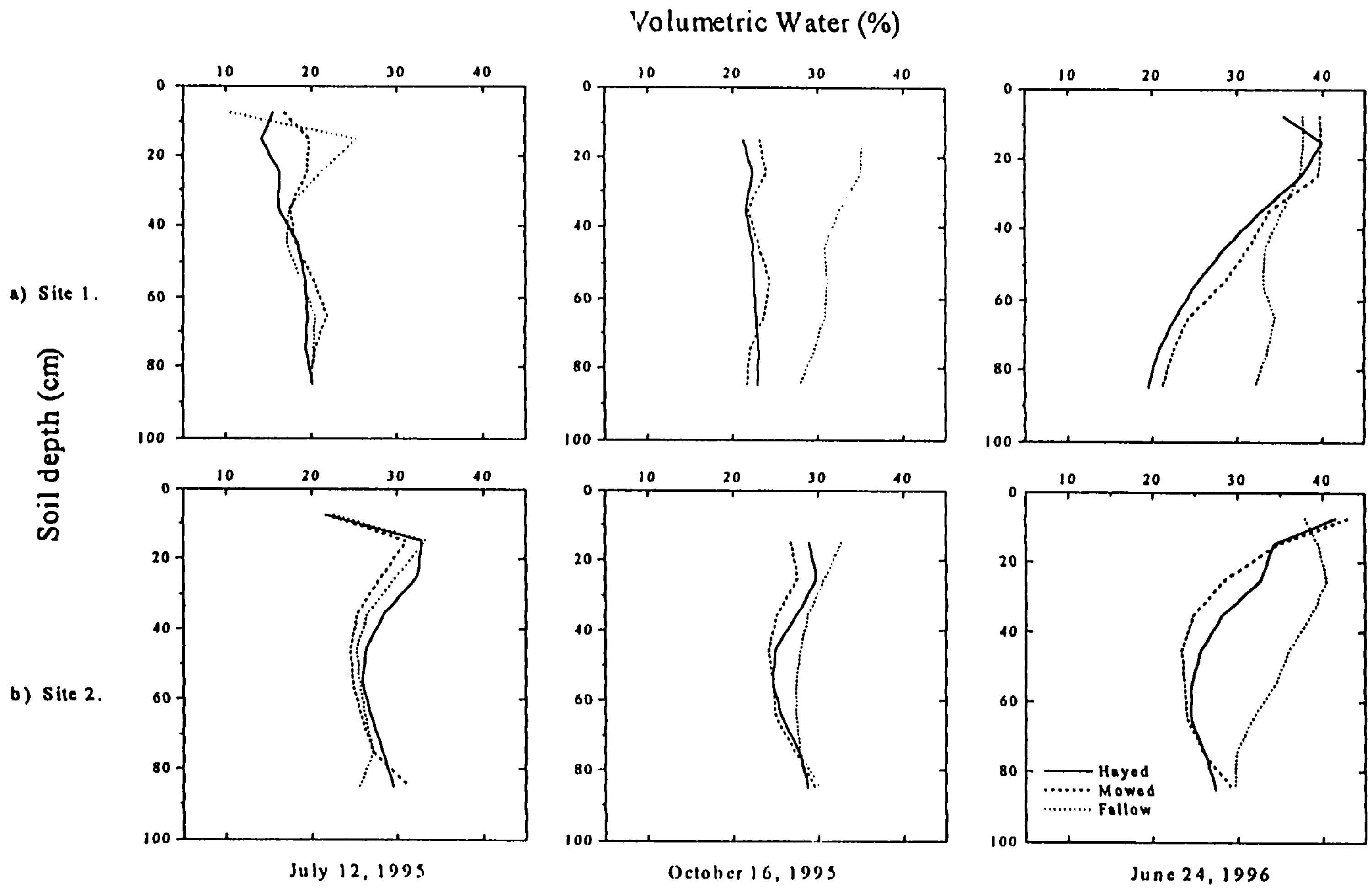
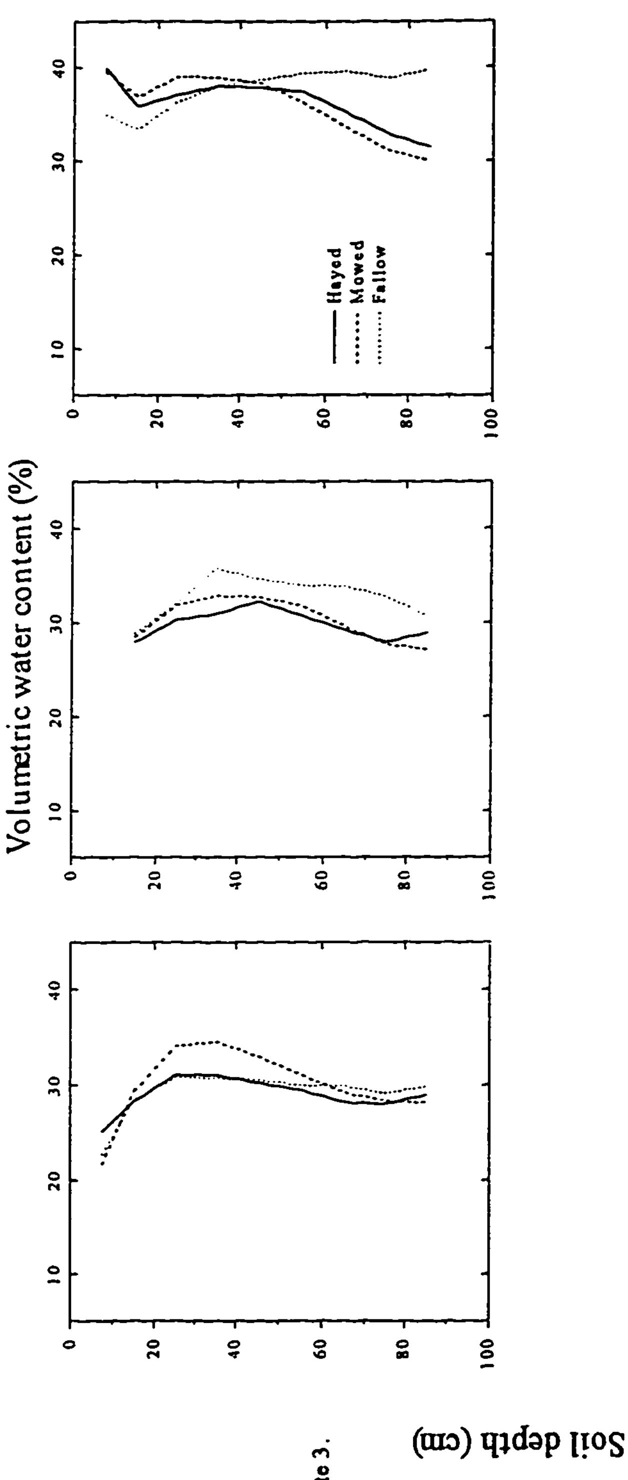


Figure 4.12 Soil water with depth for a) Site 1, b) Site 2, c) Site 3, d) Site 4 and e) Site 5


Volumetric water content (%)
Soil depth (cm)
Hayed
Mowed
Fallow
10
20
30
40
0
20
40
60
80
100

c) Site 3.

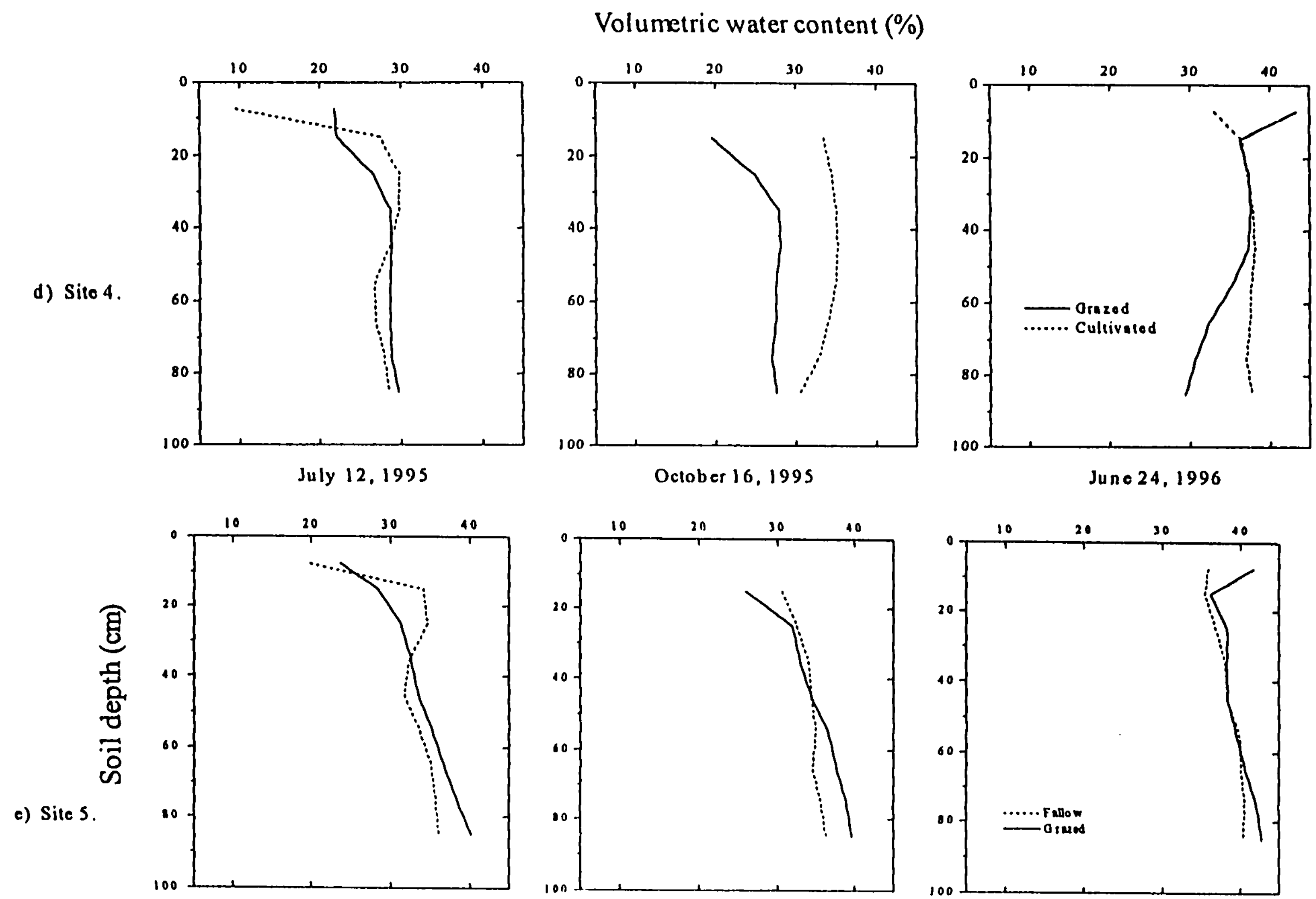


Figure 4.12 (Continued) Soil water with depth for d) Site 4 and e) Site 5.

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5. Synthesis

5.1 Introduction

Land management is a dynamic component of any agricultural production system. Management practices in a given area will change depending on the economic prospectus of primary production and sale of such goods in both national and international markets. Potential changes in land use associated with reclaimed land will be realized when current land owners receive reclamation approval and sell the reclaimed lands to private owners. At this time, it is conceivable that management strategies, production goals and land stewardship of those who buy this land will differ from the previous owners. This study examined how a change in land management could potentially lead to changes in the hydrologic characteristics of an area, providing results which could potentially be extrapolated to a watershed scale.

5.2 Runoff Production

Soil water was highly variable, ranging from wilting point to field capacity. The greatest potential for runoff occurs when soil water is high. At these times, though infrequent, infiltration capacity of the soil is low. When soil water is low (near or below wilting point), the potential for runoff would be very low as the infiltration capacity is high. The high frequency of soil water conditions in Classes I and II (low soil water) indicated that the rainfall runoff potential was low given the relative dryness of the soils at these sites. These dry conditions were frequent during each season. There were relatively few instances during the study when soil water was near field capacity.

Given the low antecedent soil water and high simulated rainfall intensity with relatively long duration, runoff is unlikely in this area given similar precipitation events and degree of saturations (50 to 70%). In cases where runoff was produced from plots, coefficients were generally <50%. However, should high intensity, long duration precipitation events occur when soil water is near FC, runoff potential would be much higher as would be runoff coefficients. Runoff would also have been lower had rainfall simulation been performed when antecedent soil water was low.

Runoff relationships might be based not only on surface management but also on degree of saturation and initial abstraction. Expressing antecedent soil water as a degree of saturation may provide a method of standardizing runoff potential with respect to the water retention parameters of a specific soil.

On a watershed scale, assumption of homogeneity is generally unrealistic, since runoff potential becomes a function of the heterogeneous nature of soils, vegetation and hillslope characteristics and the hydrologic conditions of the soil, air and general landscape. Runoff potential could then be based on a functional relationship between specific factors such as soil water class, degree of saturation or initial abstraction, hydrologic groups and cover classes.

5.3 Future research

a) Additional research could be conducted into infiltration at different antecedent water contents to adequately describe the variable nature of infiltration processes based on antecedent soil water.

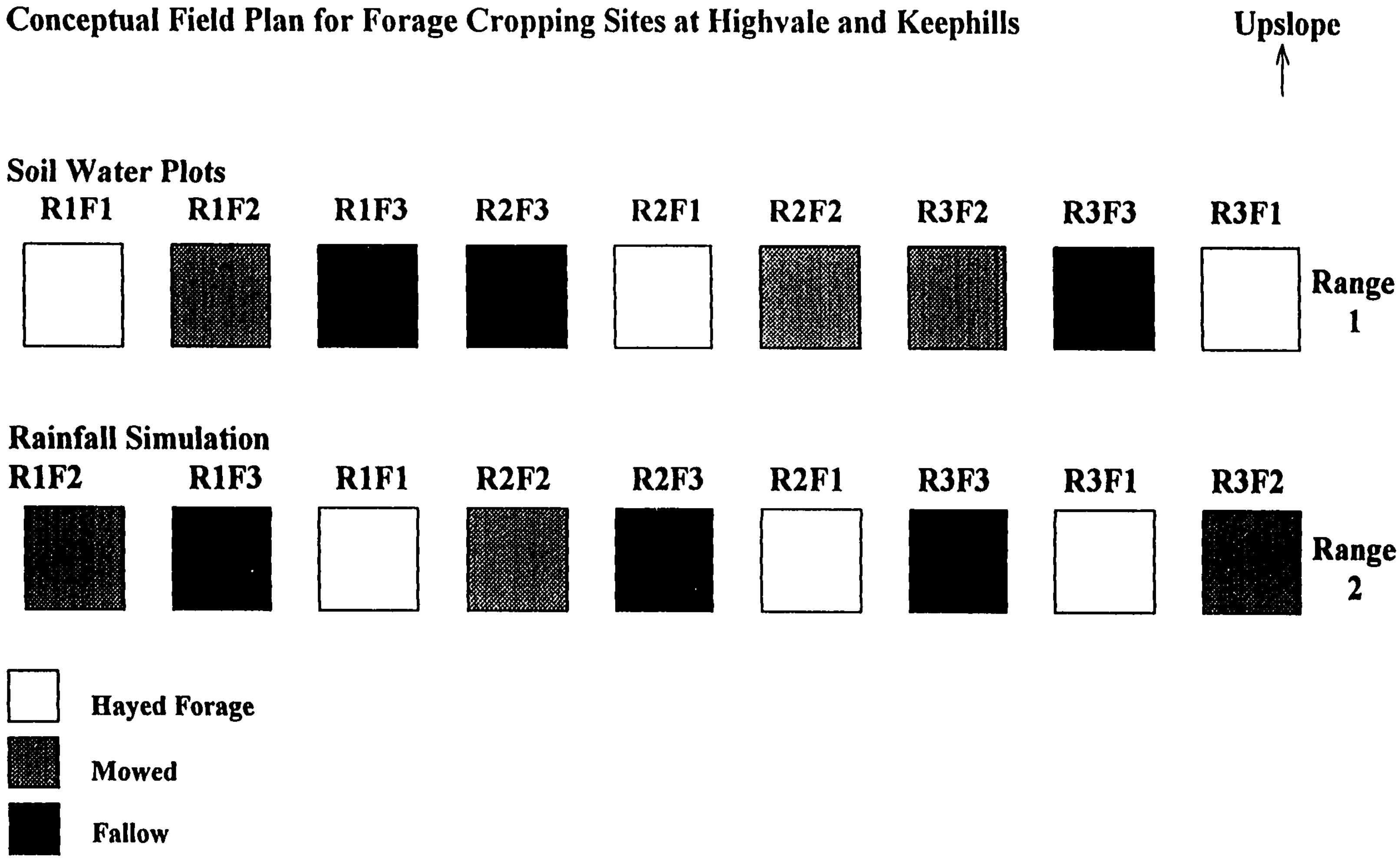
b) A more detailed examination of steady state or equilibrium infiltration rates could be conducted to evaluate the relative similarity between reclaimed and unmined profiles of the same soil texture.

c) Monitoring the effect of grazing at different intensities and durations on soil water of reclaimed lands. Such results could be compared to those under similar grazing regimes in unmined areas in the surrounding region. This information would provide a background understanding which could be used in assessing the grazing potential of reclaimed mine land given the number of years since reclamation.

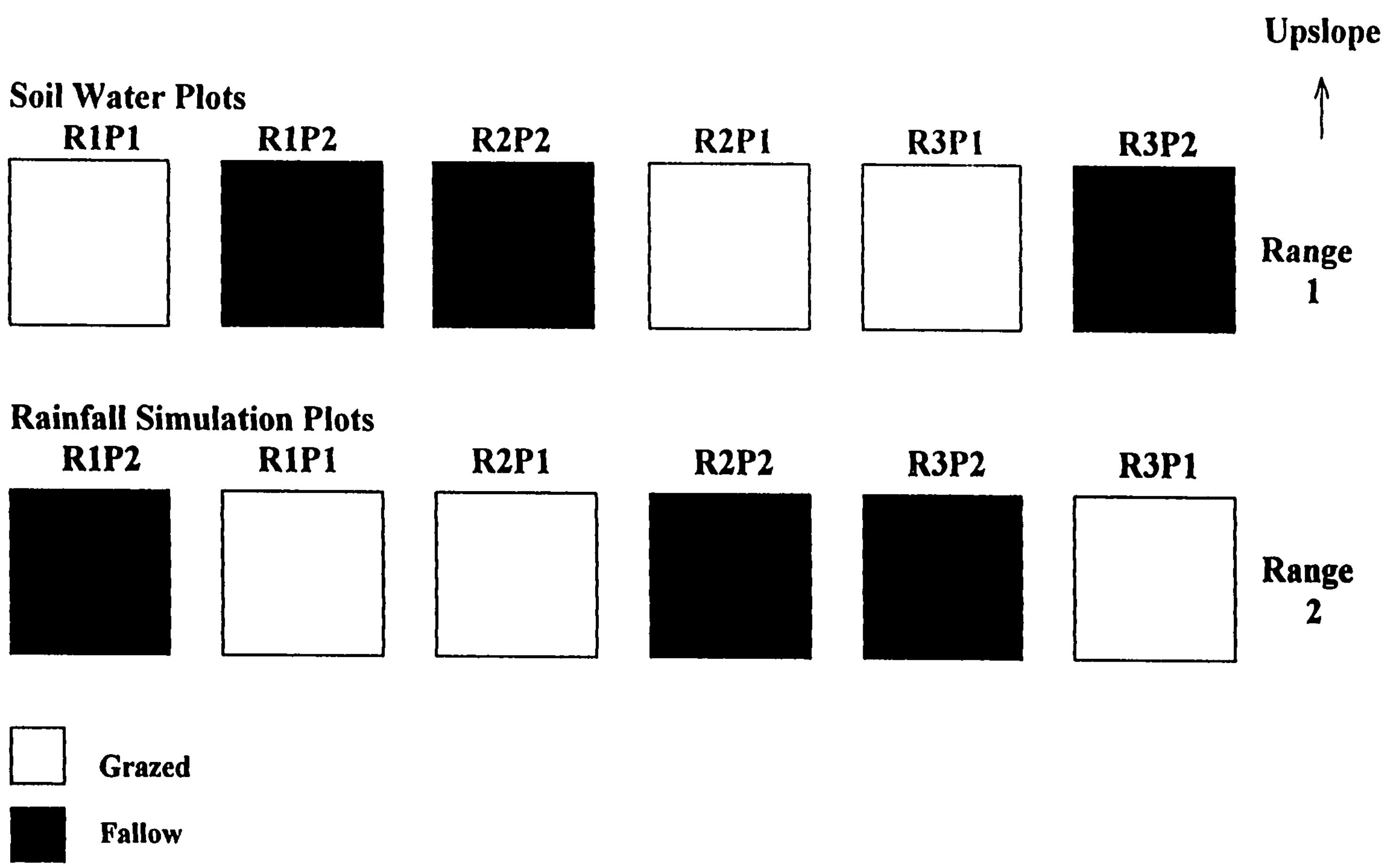
d) Additional research could be conducted into 5-min IR, initial abstraction and degree of saturation and their relationships for vegetated areas. Such information could prove valuable in modelling applications as well as in simple inferences about runoff potential.

6. Appendix A

Conceptual Field Plan for Forage Cropping Sites at Highvale and Keephills



Conceptual Field Plan for Pasture Sites at Keephills



7. Appendix B

Technical information on rainfall simulation

Rainfall simulators that create drops of narrow, uniform size distribution are best used for studies investigating rainsplash or particle detachment (Tossel et al., 1987). More recent development in simulator operation has refined equipment which is capable of producing a wide range of randomly distributed drop sizes using water sprayed through a nozzle; these include F-types which spray upwards continuously, rotating boom, oscillating, rotadisk and continuous downward flow spray simulators (Tossell et al., 1987).

The most practical type of rainfall simulator for use in runoff studies is the nozzle-type simulator since it produces a random distribution of drop sizes, most similar to that created by natural precipitation events (Tossell et al., 1987). By specifying a constant rainfall intensity, it becomes possible to determine runoff volume per time increment, runoff coefficients, infiltration rate and saturated infiltration rate (or a crude approximation of saturated hydraulic conductivity), as well as to calculate other numerical relationships such as runoff curve numbers.

Although there are many different types of simulator equipment, extensive research has been conducted on the Guelph Rainfall Simulator (GRS II) to determine its suitability and reliability in simulating natural event rainfall (Tossel et al., 1987, Tossel et al., 1989; Tossel et al., 1990). This nozzle-type simulator is portable and can be set up and dismantled quickly in field conditions without disturbing the site (Tossell et al., 1987). It is capable of producing a very wide range of rainfall intensities simply by varying pressure, height above ground surface and nozzle size (Tossel et al., 1989).

To determine the similarity between natural and simulated rainfall using the GRS II simulator, Tossel et al. (1990) analysed drop size distribution, drop velocity, liquid water content, momentum and kinetic energy flux density. They found that the GRS II produced drop distributions comparable to those for natural rainfall in all size classes except the smallest (0.95 mm), where a greater proportion of drops were produced -

confirmed by the greater liquid water content of simulated rain in small diameter drop classes. Also, at equivalent rainfall intensities, natural rainfall contained a greater proportion of large, more erosive drops than rainfall simulated using Fulljet nozzles.

Drop velocities of simulated rainfall were lower than those of natural rain with an increase in the number of impacts at low energy levels, making it difficult to conclude that simulated rainfall has detachment characteristics similar to those of natural rain (Tossel et al., 1990). At heights greater than 2 m, larger drops fell at velocities lower than their terminal velocity: peak drop diameter was 3.3 mm which would reach an average velocity of 6.6 m s^{-1} compared with 5.0- to 5.5-mm drops falling at a terminal velocity of 9.3 m s^{-1}.

Since soil detachment by water is dependent on the kinetic energy of falling raindrops, rainfall kinetic energy flux density (EFD) can be used as a measure of their power. EFDs of rainfall simulations were consistently lower than those estimated for natural events nor were they constant for all rainfall intensities. The ratio of simulated rain EFD to natural rain EFD increased with an increase in rainfall intensity - low intensity (50 mm h^{-1}) simulated rainfall produced 31% the EFD of natural rainfall (Tossel et al., 1990). At higher intensities (350 mm h^{-1}), simulated rain EFD was 61% that of natural rain EFD. It was also determined that the drop velocities for the 9.5- and 3.2-mm nozzles were less than that for the 12.7-mm nozzle, resulting in a much lower EFD than that of natural rain.

Rainfall simulation has been used in many studies as a means of controlling rainfall characteristics, nearly exclusively for studies of erosion. The value of using such simulation equipment is also realized in its versatility to be assembled on any type of terrain or soil setting. Agricultural applications are numerous: splash detachment studies on different soil types, management practices and antecedent water conditions (Freebairn et al., 1989; Truman and Bradford, 1990); soil loss and runoff studies based on simulation date and tillage effects (Andranski et al., 1985a; Andranski et al., 1985b; McIsaac and Mitchell, 1992); soil physical conditions, tillage-time water conent and residue management (Sood and Chaudhary, 1980); infiltration and runoff characteristics on pastures (Tromble et al., 1974; Frasier et al., 1995).

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8. Appendix C

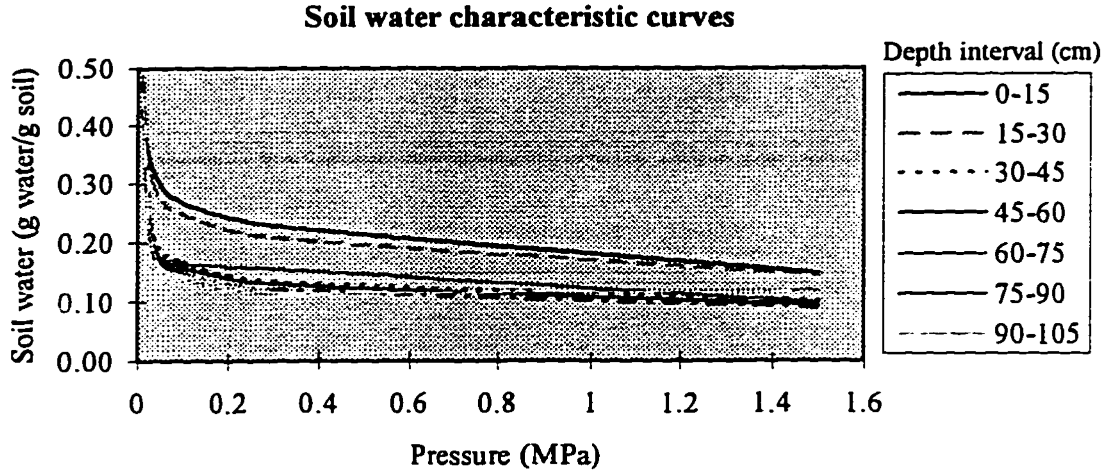

Figure 8.1 Soil water retention curves for Site 1.

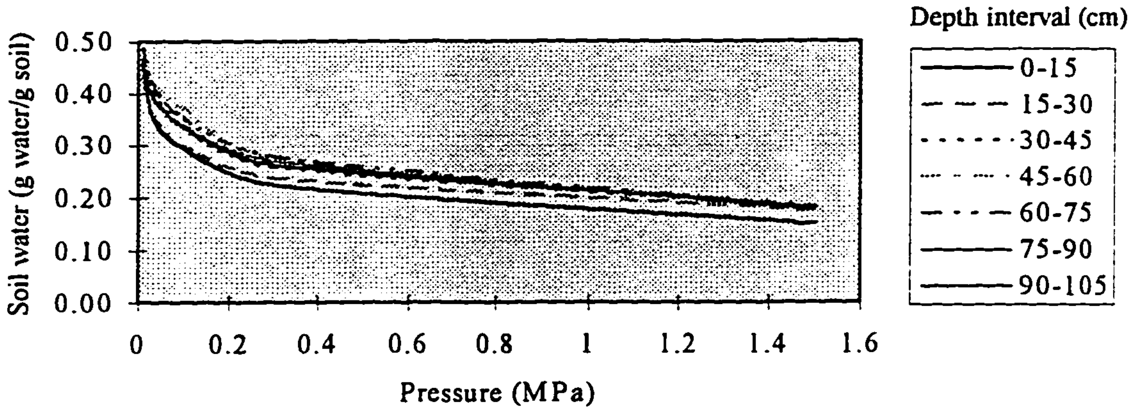

Figure 8.2 Soil water retention curves for Site 2.

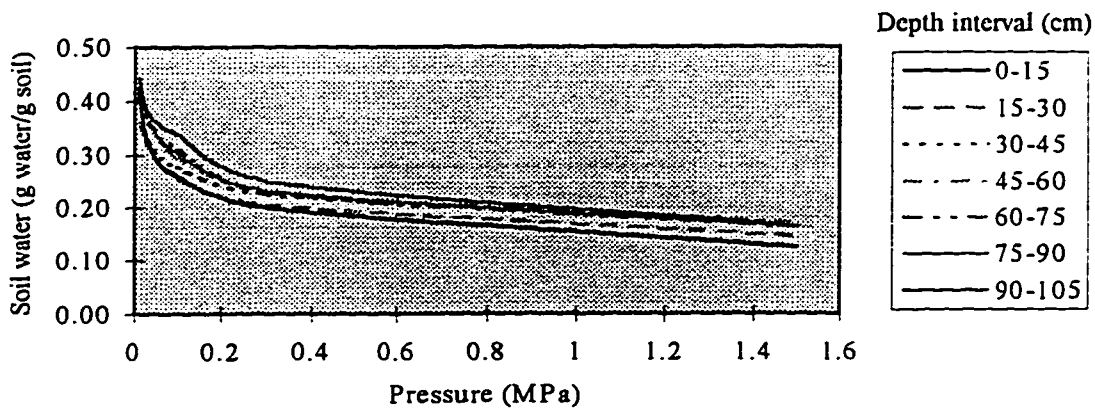

Figure 8.3 Soil water retention curves for Site 3.

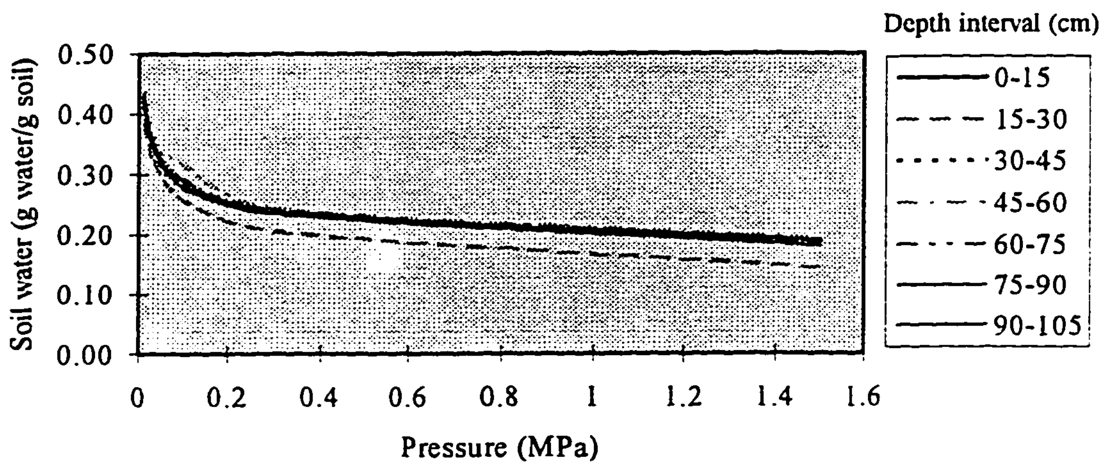

Figure 8.4 Soil water retention curves for Site 4.

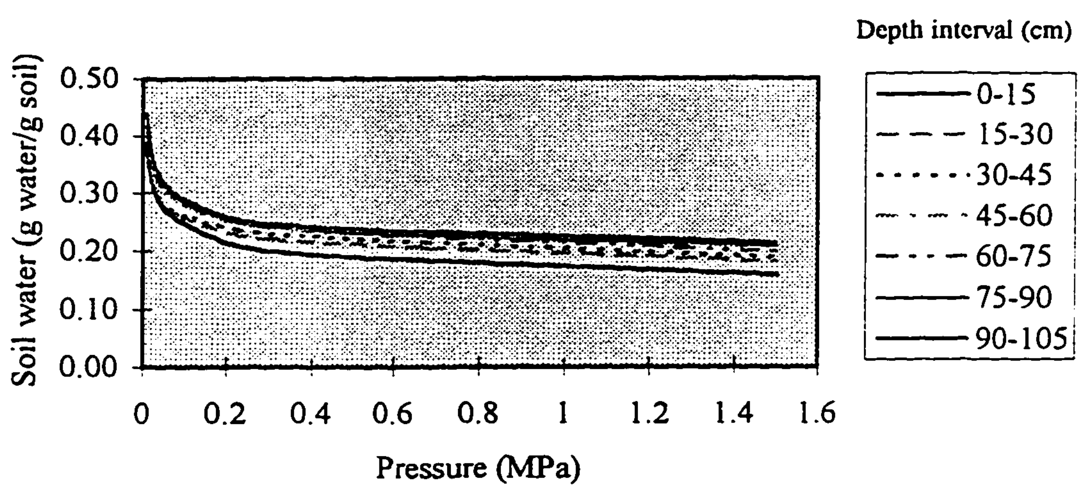

Figure 8.5 Soil water retention curves for Site 5.