

Laboratory measurement and modelling the effects of mulching and furrowing on post-harvest soil water erosion on potato land

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Leyte, J.C., Edwards, L. and Burney, J.R. 1997. **Laboratory measurement and modelling the effects of mulching and furrowing on post-harvest soil water erosion on potato land.** *Can. Agric. Eng.* 39:001-007. A laboratory experiment was run on a short length of reconstructed post-harvest potato furrow to facilitate evaluation of runoff and soil erosion parameters for modelling 'cool season' soil loss from potato lands. The experiment comprised the use of a cold-room facility to evaluate the separate and integrated effects of furrow side (interrill) and furrow bottom (rill) erosion on a 3.15 m long section of furrow subjected to prior freeze-thaw cycling. A factorial arrangement was run with four replications of three treatments comprising bare and straw-mulched surfaces at slopes of 3, 5, and 7%, under sequential 20 min simulated rainfall applications of 47 and 94 mm/h. Sediment flux was separately measured on two sections of furrow side and on the furrow bottom during each rainfall application. Flow velocity was measured in the furrow bottom using the dye method. The straw-mulch cover factor for furrow side erosion was 0.21 for the lower intensity rainfall and 0.44 for the higher intensity. However, the greatest effect of the straw mulch was in diminishing rill erosion in the furrow bottom. An example is presented illustrating the use of parameters calibrated from this and previous experiments to facilitate modelling of soil loss from furrows of practical field length using the COSSEM simulation model. **Keywords:** soil water erosion, simulated rainfall, hill-and-furrow, freeze-thaw, slope, straw-mulch, COSSEM model.

On a construit, en laboratoire, un sillon semblable à ceux laissés au champ après la récolte des pommes de terre, afin d'évaluer les paramètres de ruissellement et d'érosion des sols nécessaires à la modélisation des pertes de sol d'un champ de pommes de terre durant la saison froide. Les expériences se sont déroulées dans une chambre froide où un sillon de 3.15 m soumis préalablement à des cycles de gel-dégel a servi à mesurer les impacts distincts et combinés de l'érosion sur les côtés et le fond du sillon. On a mené une expérience à facteurs multiples comprenant quatre répétitions de trois traitements (surfaces nues et recouvertes d'un paillis avec des pentes de 3, 5 et 7%) qui ont tous été soumis à des séquences de précipitations simulées de 20 minutes à des intensités de 47 et 94 mm/hr. On a mesuré séparément les charges de sédiments provenant des deux côtés et du fond du sillon au cours de chacune des séquences de précipitations. On a utilisé la méthode de la teinture pour mesurer la vitesse du courant au fond du sillon. Le facteur de couvert du paillis pour l'érosion provenant des côtés du sillon était de 0.21 pour la précipitation de plus faible intensité et de 0.44 pour la précipitation plus forte. Cependant, le paillis a surtout permis de réduire l'érosion en rigoles au fond du sillon. On présente ici les résultats d'une simulation, avec le modèle COSSEM, des pertes de sol provenant de

sillons de longueur réelle en utilisant les paramètres calibrés lors de cette expérience et d'expériences précédentes. **Mots-clés:** érosion hydrique, pluie simulée, gel et dégel, pente, paillis.

INTRODUCTION

Farmland planted to potatoes is very susceptible to soil erosion under the humid climate of Prince Edward Island (PEI) where these fields have traditionally been planted in long narrow rows, up-and-down the natural slope which commonly reaches about 7% (Nowland 1975). Most of the soil loss from these fields occurs during the cool period of late fall to early spring (Burney and Edwards 1995).

Potato land is especially vulnerable to soil erosion: (a) prior to canopy development where furrowed seedbeds are subject to spring rains, and (b) following harvesting which leaves remnant hills and furrows subject to cool-period rains and snowmelt. Furrows concentrate flow and therefore serve as pre-formed rills.

The high-traffic practices of intensive tillage and mechanical harvesting of potatoes using heavy machinery cause soil structural breakdown (Edwards 1988). The practice of top-killing the potatoes just before harvest and the resulting lack of crop residue offers no residual resource for ground protection. Surface freeze-thaw during the cool period reduces the aggregate stability of the soil (Edwards 1991) and, in conjunction with the low hydraulic conductivity of a frost layer, leads to an increased potential for soil loss (Edwards and Burney 1989).

Preceding erosion studies of PEI soils have used a variety of laboratory (Frame et al. 1992) and field (Parsons et al. 1994) procedures with simulated or natural (Edwards et al. 1995) precipitation to measure interrill or rill erosion from soils cultivated to potatoes; but none of these procedures simultaneously measured the separate components in an integrated system.

Increased soil erosion in a hill-and-furrow system, with conventional steep furrow side slopes, has long led to speculation of the merits of flat cultivation or minimum tillage systems for potatoes. Chow and Rees (1994), in the neighbouring province of New Brunswick, measured soil losses from potatoes planted up-and-down slope in a hill-and-furrow

of four times that from flat planted potatoes. The hill-and-furrow system is, nevertheless, deeply rooted in international potato-growing tradition with sound agronomic rationalization. In PEI this system is accepted as integral in 'potato farming culture' and is likely to remain so for the foreseeable future.

At present, potato production in PEI is caught up in the dynamics of greatly increased markets for potatoes with resultant pressure to expand onto steeper slopes and to increase intensification of currently used land. Concurrently, there is public pressure for 'sustainable' production systems and farmer sensitivity to society's desire for implementation of environmental farm planning. As indicated in Edwards et al. (1995), the practice of post-harvest mulching of potato lands as a relatively inexpensive cool season soil conservation measure has expanded rapidly in PEI. However, the quantitative effectiveness of this practice is unknown and prohibitively expensive to measure directly. The objective of

which the characteristics are described by MacDougall et al. (1981). Blanket pretreatment comprised saturation and freeze-thaw cycling of soil formed into a central furrow flanked by adjacent furrow sides. Treatment variables were slope, simulated rainfall intensity, and surface mulching.

Soil bin

The soil bin was 3.65 m long by 0.65 m wide and was constructed from sheets of 0.85 mm thick galvanized steel. A 0.15 m wide trough (Fig. 2) was attached along each lengthwise side to balance soil splash into and out of the test sections. The bin was divided across its width to give: (i) a 0.5 m upslope portion comprising two furrow sides (each 250 mm long, projected horizontally) facing inwards to separate collection troughs for furrow-side only measurements, and (ii) a 3.15 m long downslope portion for full furrow measurements. The downslope furrow bottom outflow was sampled from a vertically-adjustable end-gate which enabled the operator to preclude interference with rill development.

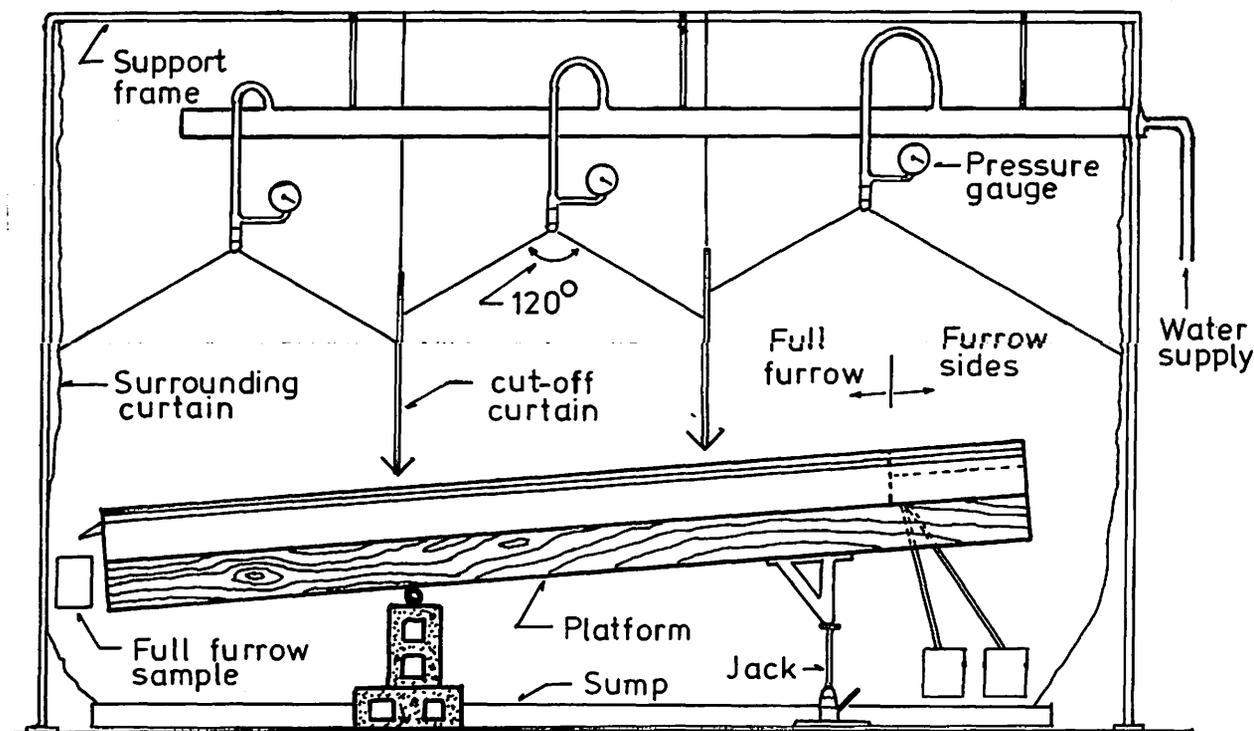


Fig. 1. Soil bin and rainfall simulator unit.

this study was to obtain data under controlled laboratory conditions for calibration and utilization of the COSSEM model (Burney and Edwards 1996) to enable prediction of field effects under a wide range of site and event specific conditions.

EXPERIMENTAL EQUIPMENT

A laboratory system was devised to measure furrow-side runoff and sediment flux together with integrated full furrow measurements in a single soil bin. The soil bin and ancillary equipment (Fig. 1) were constructed and housed in a temperature-controlled room described previously by Edwards and Burney (1989). The test soil was a Charlottetown fine sandy loam, the province's dominant arable soil under potatoes, for

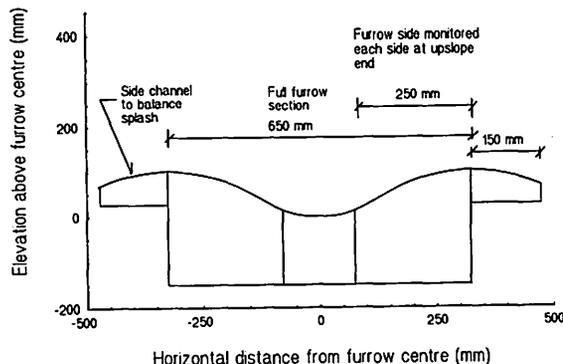


Fig. 2. Cross-section of soil bin.

Four equally-spaced perforated copper pipes which ran down the full length of the bottom of the soil bin facilitated sub-surface saturation (and removal of excess surface ponding) of each soil bed prior to the freeze-thaw pretreatment. The entire bin was lined with 50 mm of styrofoam insulation to ensure a natural pattern of freezing and thawing (from the surface downwards). The bin was supported by a wooden platform mounted downslope on a pivot and upslope on hydraulic jacks that permitted slope variation from 0 to 7%.

Rainfall simulation

Rainfall simulation at 47 and 94 mm/h (with measured uniformity coefficients of 85%) was supplied by three independent nozzle units each mounted centrally over the upper, central, and lower third of the soil bin. Each unit comprised a pressure gauge, solenoid valve and a 6.4 mm 10W (Spraying Systems Co., Chicago, IL) brass full-jet nozzle (in the same series as used by Tossell et al. 1990). Any of the units could be adjusted vertically to enable the applicable nozzle to be set at 1 m above the mean of the bed surface. Spray overlap from the nozzles was curtailed with the use of plastic curtains suspended mid-way between adjacent nozzles. A metal trough along the bottom edge of each side of each curtain diverted intercepted spray over the side of the soil bin.

The higher intensity of 94 mm/h was obtained by using two nozzles (at 180 mm apart) on each unit.

Furrow forming

Based on post-harvest microtopographical surveys using a profile meter in the field, a wooden roller was constructed to produce a full scale furrow profile comprising two half-hills and a central furrow (Fig. 2). Cone penetrometer readings taken in the field in late November, after potato harvest and before freeze-up, were used to determine the amount of added weight and number of roller passes required for realistic compaction of the furrow surfaces.

Freeze-thaw cycling

A timer was installed to automate daily freeze-thaw cycling. The minimum temperature was set to -5°C and the maximum varied between 18 and 20°C as affected by the outside laboratory temperature. Rainfall application was initiated at the end of the last freeze period. The temperature of the water supply to the nozzles and the air temperature in the enclosure were maintained as close to freezing (0°C) as feasible during testing.

EXPERIMENTAL PROCEDURE

Experimental design

A factorial arrangement of a randomised complete block design was used in four replications. The treatments were: (i) slope (3, 5 and 7%), (ii) rainfall intensity (47 and 94 mm/h) and (iii) surface mulching (bare surface and straw mulch at 4 t/ha). The rainfall intensities were run sequentially on the same bed surface.

Soil preparation

With the soil bin in a horizontal position, the soil bed for each test was shaped and compacted in layers using a fixed

number of passes of the wooden roller. Where appropriate, straw was spread on the surface at a rate of 4 t/ha as used in PEI farm practice (Edwards et al. 1995).

The soil was then saturated by subirrigation using the subsurface pipes attached to a constant-head (0.3 m) water supply. The pipes were capped for 30 min to ensure even saturation, and excess water (localised ponding) was then removed by drainage back through the pipes.

With the soil bin still in a horizontal position, the refrigeration unit was activated to provide 4.5 daily freeze-thaw cycles. Rainfall application began at the end of the last freeze period.

Test run procedures

For each bed surface, the soil bin was set to the appropriate slope and the 47 mm/h rainfall intensity was applied for a period of 20 min (5 year recurrence interval for PEI) followed by an approximate 10 min break during which each of the single nozzles was replaced by a double nozzle set. The 94 mm/h rainfall intensity was then applied for a period of 20 min (100 year recurrence interval). The same data collection procedures were used for each run.

Runoff was collected from three locations - the two furrow side plots and the full furrow plot. For the furrow side plots the volumes of runoff were relatively small and therefore the entire amount was collected for the periods of 0-2, 2-4, 4-8, 8-12, 12-16 and 16-20 minutes. For the full furrow plot, a 10-second sample was taken centrally within each of the above time periods.

Runoff flow velocity was measured down the furrow bottom during the last half of each run using a fluorescent dye. The dye was injected into the flow 2.5 m from the outlet end of the furrow. Timing began when the most concentrated part of the plume passed a marker 2 m from the end, and the time at which it passed a 1 m mark and the end were noted. This procedure was repeated three times and the average velocity over each metre length was determined.

Data analyses

All data were subjected to analysis of variance (ANOVA) and mean separation. A 5% level of significance was observed unless otherwise stated.

RESULTS AND DISCUSSION

Changes in the slope of the furrow bottom had negligible effect on the furrow side slopes and therefore ANOVA was carried out only for cover and rainfall intensity effects for the furrow side plots.

Total sediment

As shown in Table I for the furrow side plots, doubling of the rainfall intensity resulted in a significant, approximately fourfold, increase in soil loss. When split according to cover (cover x intensity interaction) the straw mulch was more effective in protecting against soil loss at the lower intensity.

For the furrow plot (Table II), there was no significant difference between the mean soil loss mass from the 3 and the 5% slope treatments. However, each of these means was significantly different from that at the 7% slope. Meyer and Harmon (1985) similarly reported little effect of slope on soil

Table I: Effects of treatments on soil loss (g/m^2) for furrow side (interrill) plots

Treatment	Rainfall intensity	
	47 mm/h	94 mm/h
Overall	176.0 ^a	752.5 ^b
	(Cover x rainfall intensity)	
Bare	289.2 ^a	1045.3 ^b
Straw	62.9 ^c	459.8 ^a

Means of any treatment not followed by the same letter are significantly ($P \leq 0.05$) different.

Table II: Effects of treatments on soil loss (g) for furrow plot

Treatment	Slope		
	3%	5%	7%
Overall	787 ^a	923 ^a	1661 ^b
	(Slope x cover)		
Bare	1302 ^a	1407 ^a	2874 ^b
Straw	272 ^c	439 ^c	447 ^c
	(Slope x rainfall intensity)		
47 mm/h	207 ^c	353 ^c	542 ^c
94 mm/h	1368 ^a	1493 ^a	2779 ^b

Means of any treatment not followed by the same letter are significantly ($P \leq 0.05$) different.

loss from furrows for slopes between 2 and 5%, but substantial effects as slope increased above 6.5%. When split according to cover (cover x slope interaction), bare soil produced significantly greater soil loss than the mulched surface at each of the slopes. The higher rainfall intensity similarly resulted in significantly higher soil losses.

Sediment rate

The average soil loss rate from the furrow side plots is presented as a function of time in Fig. 3. The average soil loss rate from the full furrow is similarly presented in Fig. 4. In each of these two figures, simulated rainfall application was 47 mm/h for the period of 0 to 20 min and 94 mm/h for the plotted period of 30 to 50 min. The fixed break of 10 min, used for plotting purposes, approximated reality.

Runoff flow velocity

Flow velocity was measured over each of the lower 2 m of the furrow bottom during the latter part of each run. Velocity increased only slightly over the last meter of flow and is presented according to treatment in Fig. 5. As shown, velocity was highly dependent on cover and rainfall intensity.

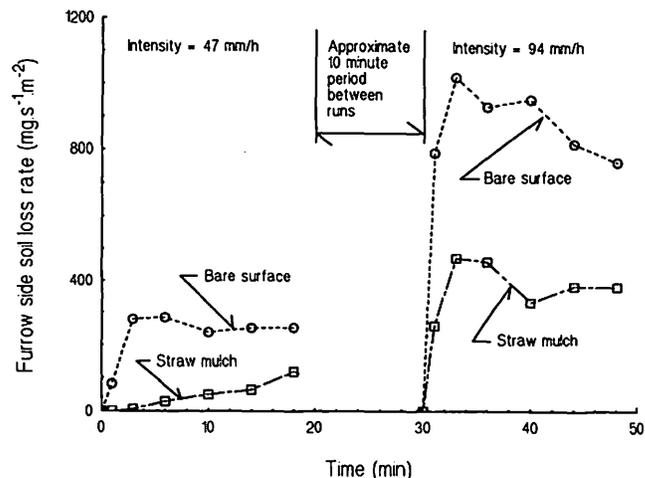


Fig. 3. Soil loss rate from furrow side (interrill) plots.

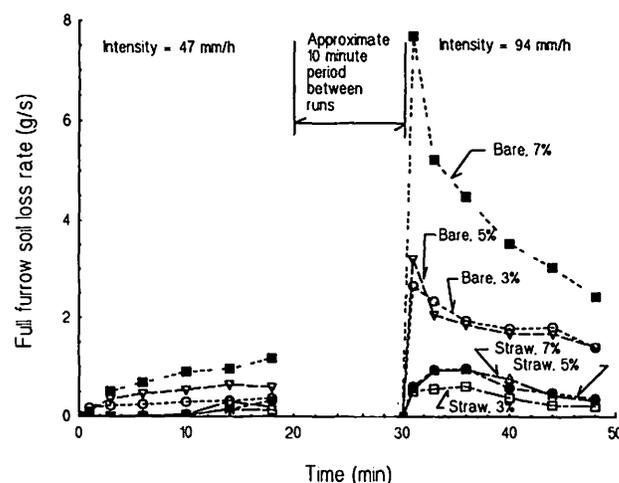


Fig. 4. Soil loss rate from furrow end.

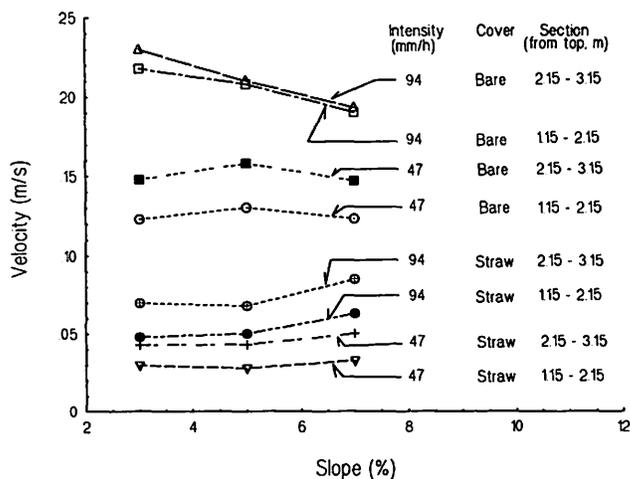


Fig. 5. Measured flow velocities in furrow bottom.

However, velocity was not significantly affected by bed slope.

Furrow side erodibility

Soil interrill erodibility is commonly defined by an equation given by Elliot et al. (1989) and used in the WEPP model. As

used in the COSSEM simulation model (Burney and Edwards 1996) to incorporate a cropping-management factor, this equation may be written as:

$$D_i = C_i K_i A I^2 SF \quad (1)$$

where:

- D_i = measured soil loss (kg/s),
- C_i = cropping-management factor,
- K_i = soil interrill erodibility ($\text{kg}\cdot\text{s}\cdot\text{m}^{-4}$),
- A = area of surface (m^2),
- I = rainfall intensity (m/s), and
- SF = slope factor.

The slope factor (Elliot et al. 1989) is:

$$SF = 1.05 - 0.85 \exp(-4 \sin \theta) \quad (2)$$

where: θ = slope angle in degrees.

Based on an average uniform slope and soil loss during the final 8 min of each run, values of the product $K_i C_i$ are presented in Table III. The mulch factor is the ratio of $K_i C_i$ values of the straw mulch to bare soil and represents the effect of mulching.

Table III: Effects of treatments on $K_i C_i$ ($\text{Gg}\cdot\text{s}^{-1}\cdot\text{m}^{-4}$) for furrow side (interrill) plots

Treatment	Rainfall intensity	
	47 mm/h	94 mm/h
Bare	1.70	1.54
Straw	0.37	0.68
Mulch factor	0.21	0.44

Furrow bottom erodibility

Soil detachment by hydraulic shear along the furrow bottom depends on side inflow characteristics, soil resistance, cropping-management, and the transport capacity of the flow. Parameter values could not be directly evaluated for the conditions of these experiments.

Sediment source

The outflow of sediment as measured at the end of the furrow represented the sum of soil loss on the furrow sides and in the furrow bottom, less deposition in the furrow bottom. This effect is illustrated in Fig. 6, in which a value of zero deposition in the furrow means that the furrow bottom was neither accumulating nor losing soil. In the mass balance, therefore, soil loss comprised through-flow from furrow side erosion.

Slight deposition or soil loss occurred in the furrow bottom for all treatments other than the high intensity rainfall on bare soil. For this treatment combination, there was no effect of slope from 3 to 5% but a dramatic increase in soil loss from 5 to 7% where rill erosion started to take effect. The protection afforded by the straw mulch, therefore, dramatically increased with degree of slope beyond 5% under the higher intensity rainfall.

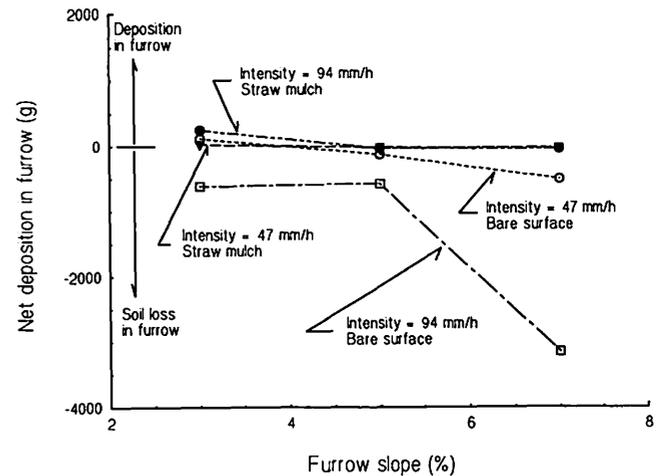


Fig. 6. Deposition and soil loss from furrow bottom.

MODELLED FIELD APPLICATION

Up-and-down slope furrows

The measured data set generated in the laboratory was necessarily restricted to a maximum furrow length of 3.15 m. To generate data for practical field furrow lengths, the values of the runoff and sediment parameters optimised for COSSEM (as presented for bare soil in Burney and Edwards (1996)) were used to extrapolate the furrow length for the lower intensity event. Cover-management factors were separately optimised for this study.

The furrow side (interrill) soil erodibility, K_i , and cover-management, C_i , (Eq. 1) values used for modelling were $1.70 \text{ Gg}\cdot\text{s}\cdot\text{m}^{-4}$, and 0.21 (Table III), respectively. The furrow bottom soil erodibility parameters used were as given in Burney and Edwards (1996). The cover-management factor (C_f) for furrow bottom hydraulic shear, determined by the use of COSSEM, was optimally 0.13 . This compared favourably with a calculated value of 0.12 for the rill erosion test data of Frame et al. (1992) on the same soil type and similar cover.

Modelled soil loss, on a conventional USLE mass per unit area basis, is presented in Fig. 7 for (a) a bare and (b) a straw mulched furrow of up to 100 m in length for the conditions of this study (a uniform rainfall of 47 mm/h and 20 min duration). Under field conditions these curves illustrate (a) the severity of soil loss due to a single 'cool season' storm event on furrowed bare soil and (b) the effectiveness of straw mulch in preventing or reducing rill erosion. However, in field practice displacement of the straw cover by wind or runoff can reduce the overall benefit.

Uniform plane

For comparison purposes, COSSEM also was used to simulate runoff and soil loss for a specific example of a uniform plane of 100 m length and 7% slope for the same rainfall event and calibrated parameters. Predicted soil loss values were 16 t/ha (bare) and 0.65 t/ha (straw mulched), which is low compared to 61 t/ha (bare) and 2.6 t/ha (straw mulched) for up-and down slope furrows (Fig. 7).

Comparable USLE single storm soil loss estimates for bare soil (for a USLE soil erodibility, K , value of $0.04 \text{ t}\cdot\text{h}\cdot\text{MJ}^{-1}\cdot\text{mm}^{-1}$) are 12 t/ha based on rainfall (EI) erosivity (Foster et al. 1981),

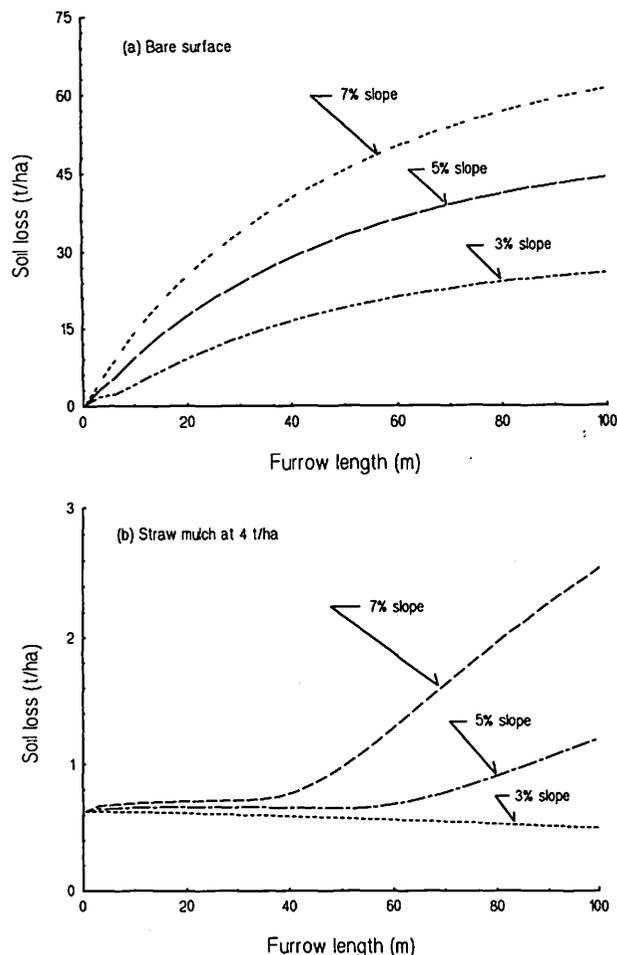


Fig. 7. Modelled soil loss for uniform rainfall of 47 mm/h for 20 min of uniform application for (a) bare surface and (b) straw mulch at 4 t/ha.

and 17 t/ha based on runoff (MUSLE equation) erosivity (Williams 1975). For a USLE cropping-management (C-factor) value of 0.04 (Wischmeier and Smith 1978) predicted soil losses under straw mulch are then 0.48 t/ha and 0.68 t/ha, respectively.

For this specific example, up-and-down slope furrows result in an approximate fourfold increase in soil loss over that of a uniform plane (as also found under growing season conditions by Chow and Rees (1994)) for both cover conditions. Transverse levelling of up-and-down slope furrowed land following harvesting therefore appears to be highly beneficial in reducing cool season soil loss. However, the magnitude of benefit can only be evaluated through site specific modelling.

CONCLUSIONS

Based on this study it is concluded that:

1. Single storm events on bare furrowed soil during the 'cool season' in Prince Edward Island can lead to severe soil losses.
2. Straw cover at the conventionally used rate of 4 t/ha is highly effective in reducing soil loss into and from the troughs of furrowed land surfaces.

3. When straw cover is used under the circumstances of this laboratory experiment, net deposition in the furrow bottom is positive or only very slightly negative for all slopes and rainfall intensities, indicating that only inter-rill erosion occurs. Extrapolation of furrow length by modelling indicates the limitations of this effect as slope inclination and furrow length increase.

4. On steeper slopes up-and-down hill furrowing increases soil loss approximately four-fold. Immediately following harvesting tillage should be carried out to leave the land surface level across the slope, roughened and compacted prior to mulching.

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