Mulching Potatoes: Aspects of Mulch Management Systems and Soil Erosion

Linnell M. Edwards[1], Anja Volk[2], and Jack R. Burney[3]*

[1]Research Scientist, Research Centre, Agriculture and Agri-Food Canada, P.O. Box 1210, Charlottetown, Prince Edward Island, C1A 7M8, Canada.
[2]Graduate Student, Physical Geography Department, University of Trier, 54286 Trier, GERMANY.
[3]Professor, Biological Engineering Department, DalTech, Dalhousie University, P.O. Box 1000, Halifax, Nova Scotia B3J 2X4, Canada.
*Corresponding Author: Tel: (902)-494-3913, FAX: (902)-423-2423, e-mail: Jack.Burney@Dal.CA .

ABSTRACT

Intensive potato production occupies much of the sloping arable land of Prince Edward Island, Canada, and is at the center of soil erosion concerns in this province. Corrective considerations have turned recent attention to mulching, but there is limited knowledge of its workability or effectiveness in potato systems. This study looks at the effect of mulching on soil loss from potatoes grown on standard erosion plots, and examines a relatively simple approach to assessing soil-surface splash detachment (splash erosion) under mulch-management systems with potatoes. Three sizes of splash cup (25, 50, and 100 mm in diameter) were used under simulated rainfall at 150 mm•h^{-1} for 10 minutes to measure splash erosion on potato plots under mulch-management systems which, respectively, left surface coverage of ~ 5%, ~ 15%, and ~ 20%. The lowest straw coverage gave up to 56% more erosion than either of the two higher coverages. The 25-mm splash cup yielded 14% more sediment splash than the 100-mm splash cup on the basis of unit surface area of soil in the splash cup (unit area). Regression modeling of unit-area splash against straw cover showed an exponential decay in splash detachment with increasing straw cover. On the erosion plots, soil loss with mulching was half of what it was without mulching; and soil water retention was 5% greater with mulching.

INTRODUCTION

Surface mulching is one of the most cost effective means of crop residue usage against soil erosion in annual row-cropping on sloping lands (Dickey *et al.* 1985; Shelton *et al.* 1995). Thus, mulching management is the basis of a resurgent soil conservation ethic in much of the USA (Shelton *et al.* 1995). It makes use of crop residues and is not limited by field conditions. In Prince Edward Island (PEI) where annual row-cropping is dominated by potatoes, mulching is strongly promoted based on the results of local scientific research and field observations (Edwards *et al.* 1995).

As observed by Shelton *et al.* (1995), the concept of mulch management and associated tillage is new to many farmers. In many cases, farmers expect to get full soil-protection benefit of a given quantity of applied mulch after tillage. Only no-till systems approach this ideal (Shelton *et al.* 1995). For crops like potatoes, which do not easily adapt to surface mulch application after the main crop is planted and where some form of mulch usage is perceived as beneficial, it would be useful to have some ready and demonstrable measure of the effectiveness of soil conservation management systems that are farmer friendly.

Measurement of soil conservation effectiveness can be accomplished using natural erosion plots (Wischmeier and Smith 1978) or simulated-rainfall field plots (Meyer 1965). Both methods have been used in PEI for direct measurement of soil loss in potato production (Burney and Edwards 1994b; Parsons *et al.* 1994); but these methods exact much time and labor. Where the required resources or conditions are limited, simple techniques such as splash measurements may provide beneficial relative information and demonstrate the effectiveness of specific management practices. The authors recognize the difficulty of translating splash data into farmer-friendly, soil-loss information, but we consider it useful for purposes of ranking treatment effectiveness.

Splash detachment of soil by raindrop impact is a major factor in soil-surface disruption on cultivated farmland. It is a motivating effect for sediment production on interrill areas

Accepted for publication December 20, 1999.
ADDITIONAL KEY WORDS: Splash erosion, splash cups, residue management.

(Meyer *et al.* 1975; Foster 1982) and can be a major cause of crusting. Splash detachment is implicated, therefore, in interrill erosion and in the extent of runoff from crusting soils. Because of its pivotal role in the erosion process, variations in splash detachment could be justifiably estimated relative to soil-surface conditions (Govers 1991).

Quantitatively, splash (interrill) erosion is commonly defined for bare soil by the equation (Schwab *et al.* 1993):

$$D_i = K_i \, i^2 \, S_f \qquad (1)$$

where:

D_i = interrill erosion rate, kg•m^{-2}•s^{-1},

K_i = interrill erodibility of soil, kg•s•m^{-4},

i = rainfall intensity, m•s^{-1},

S_f = slope factor = 1.05 - 0.85 $e^{-4 \sin \theta}$, and θ = slope angle in degrees.

Increased mulch coverage reduces splash erosion (Schwab *et al.* 1993) exponentially with increasing ground coverage (Mati 1994) and this effect may be incorporated in Equation 1 through mutiplication by a crop-management factor, C_i, where $C_i < 1$ (Burney and Edwards 1996). Mulching works by reducing splash detachment and subsequent transport; it also intercepts the splashed soil, thus limiting its trajectory movement (Schwab *et al.* 1993).

Splash erosion measurement is versatile and, as accomplished in the present study, splash studies can be readily superimposed on existing (host) field experiments. Measuring equipment range in size and complexity from splash traps (Mati 1994) to splash cups (Bolline 1980; Morgan 1981; Poesen and Torri 1988). Splash cups have been used under varying research circumstances as sediment receptors (Bolline 1980; Boiffin 1984; Poesen 1986) or as soil targets (Seiler 1980; Morgan 1983) and have been studied in a range of diameters (Poesen and Torri 1988). From these, splash loss data have emerged, and splash mass functions have been developed relative to cup size. Most of this information, however, is limited in its validity or direct applicability to PEI soils, and might not account for the changes in soil surface conditions under local influences of climate and management.

The objectives of the present study were to assess the relative effectiveness of mulching on (i) plot erosion; and (ii) splash erosion (splash detachment) under the systems of mulching management most often used in farm demonstrations. The first objective was achieved using existing erosion plot facilities, and the second, using a target splash cup that we designed for this purpose.

MATERIALS AND METHODS

The study sites were both characterized by a Charlottetown fine sandy loam (Orthic Podzol) developed on medium to strongly acidic glacial till (MacDougall *et al.* 1988) under an average annual precipitation of 1097 mm. The average soil C content was 16.0 g C.kg^{-1} and the pH varied from 6.2 to 6.7.

Erosion Plots

These facilities comprise two sets of three contiguous 22.1-m-long by 4-m-wide plots bordered at the top and along the sides, having a covered flow concentrator at the lower end as described by Burney and Edwards (1994b). The plots form part of a long-term watershed study (Burney and Edwards 1994a) and are used to measure erosion under different cropping or soil management systems. The present study (1996-1997)—part of a medium-term natural-amendments study—utilized two sets (reps) of three plots (treatments) planted to Russet Burbank potatoes (*Solanum tuberosum* L.) in a randomized complete block design. The plots had a history of three-year potato rotations with barley (*Hordeum vulgare* L.) and mixed forages, and were under two blanket years of potatoes just preceding this study. The sets of plots came as three treatments with each rep viz. straw mulch, compost, and a control, but only the mulch treatment was considered for the purpose of this study. The mulch material (barley straw) was applied (4 mg•h^{-1}) by hand after the potatoes were planted and before hilling. Planting and subsequent field operations followed regional recommendations for commercial growers (Anonymous 1993; Anonymous 1998). Straw mulch coverage, measured by line transect after the final hilling operation, averaged more than 20%. Erosion was measured on an event basis as runoff volume and sediment dry mass sampled from a sequence of collection barrels (Burney and Edwards 1994b).

Some measurements were made of soil physical characteristics related to soil erosion, and comprised water content, aggregate stability, penetration resistance, shear strength, and bulk density. Penetration resistance and shear strength were measured *in situ* using a penetrometer and a torvane (respectively), and bulk density was measured using cylindrical cores (80 mm i.d. x 80 mm). Soil aggregate stability, adopted as a measure of soil structure was determined by wet sieving. Sampling was done in the spring and fall of each year when soil water was at field capacity. Measurement procedures were as adopted in an earlier study by Edwards (1988).

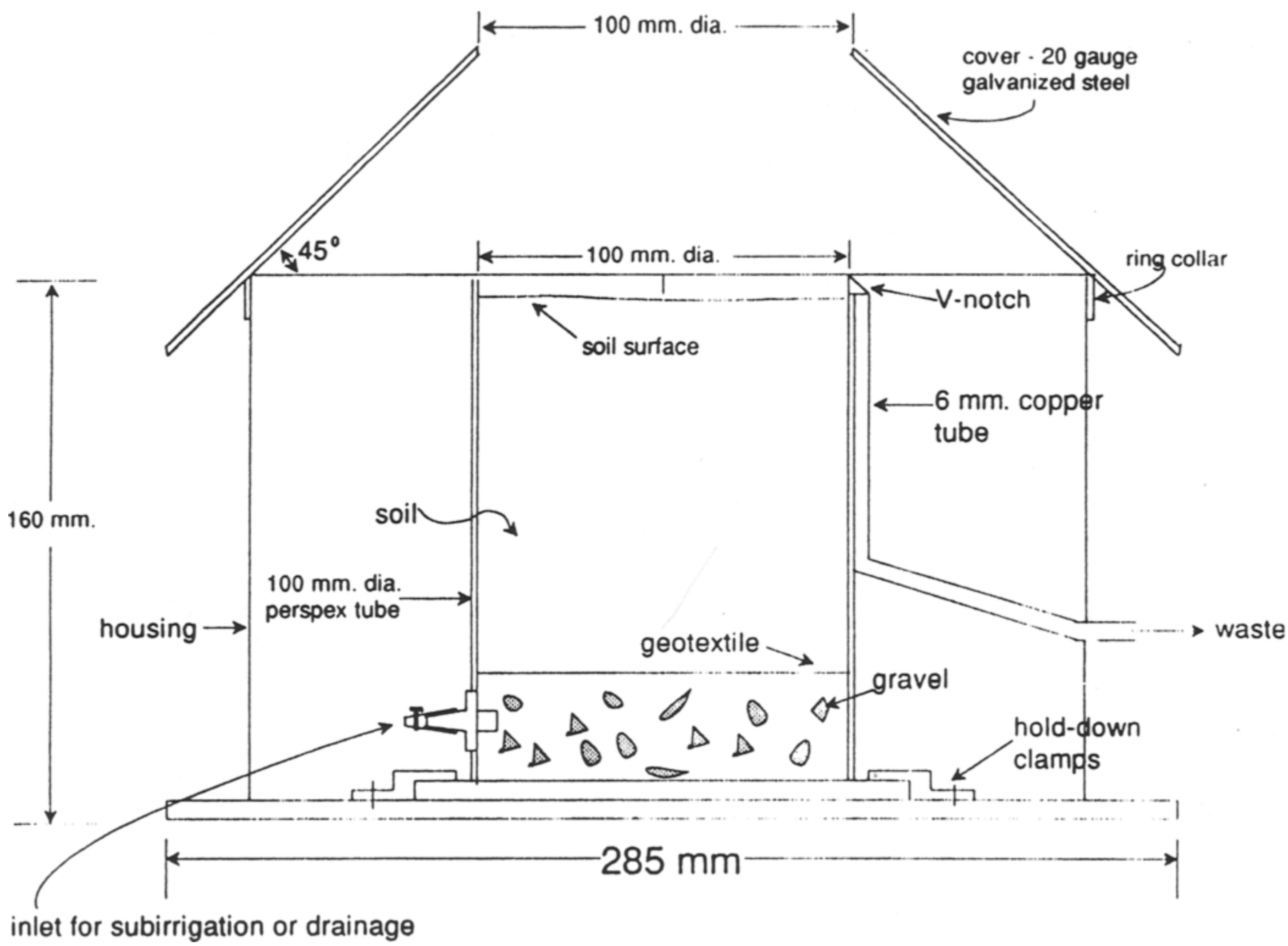

FIGURE 1. Sectional view of the 100 mm diameter splash cup enclosed in its housing.

Splash Erosion

For the second part of this study, we used a splash cup that we designed and built from perspex tubing to stand vertically on a perspex base and hold the test soil (Figure 1). It was fitted with a plug near the bottom to allow saturation or drainage, and designed with a vee-notch at the top to allow the escape of water from the surface of the soil. Three cup sizes were used, with diameters of 25, 50, and 100 mm. The cup was set in a metal chamber (housing) designed to contain all of the splash and exclude rainfall superfluous to the specific splash test. The chamber was conical and made of galvanized steel sheeting open at the top only sufficiently (for respective cup sizes) to admit the administered rainfall. The splash unit, comprising cup and housing, was about 250 mm in maximum diameter and 170 mm in height.

A small rainfall simulator (Burney and Edwards 1989) was used to apply simulated rainfall, and consisted of a 1 m sq frame subtended by telescopic legs of 1 to 1.5 m tall. The frame held a nozzle of the type used by Tossell *et al.* (1990) at the center (Figure 2). During the splash tests, nozzle pressure was 70 kPa, which produced a spray intensity of 150 mm•h^{-1}. Rainfall duration was 10 min for each splash test. The test soil (original soil) was placed intact in the perspex tubing up to about 20 mm from the top and became the target for raindrops while the metal chamber became the sediment splash receptor.

Soil samples were extracted in August 1995 from a site that was in barley under-seeded to clover for one year before the initiation of a mulch management experiment (the host experiment) in the fall of 1994. This experiment consisted of three replicates of a randomized complete block design with

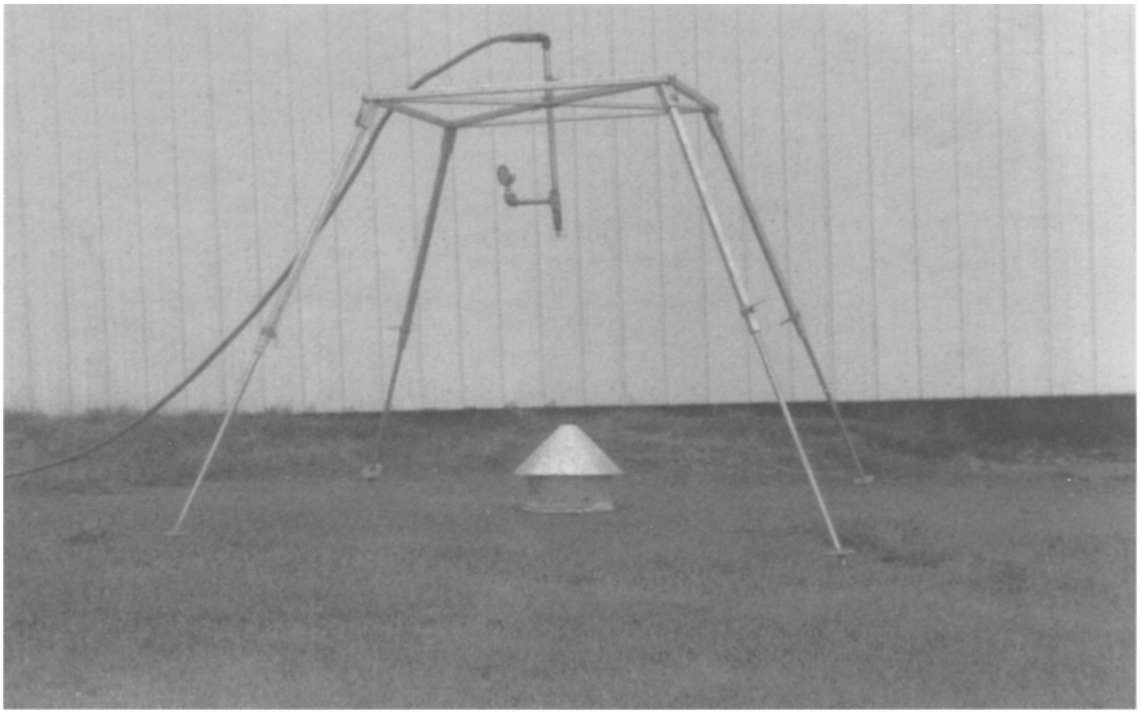

FIGURE 2. Rainfall simulator set up over a splash cup enclosed in the housing shown.

the following three treatments for managing barley straw mulch:

i. fall moldboard plowing and conventional spring tillage comprising one pass with discs and one pass with harrows, leaving approximately 5% straw coverage;
ii. a single fall pass with a chisel plough, and conventional spring tillage, leaving approximately 15% straw coverage; and,
iii. a fall and a spring pass with a chisel plough leaving approximately 20% straw coverage.

A blanket application of barley straw at a rate of 4 t•ha^{-1} preceded tillage in all treatments. Straw mulch coverage was estimated by line quadrat. Potatoes were planted in spring 1995.

Sampling Procedure

Soil sampling for splash testing took place during August 1995 when the soil was close to field capacity. Five samples were taken from the top of the potato rows from each of the nine plots on a diagonal transect using hollow stainless steel soil corers. The soil corers were knife-edged and sized appropriately to facilitate careful extraction of intact soil columns and their respective transfer to the perspex cylinder of the splash cups without disturbance. At each sampling station, the potato vegetation was carefully cut close to the ground to facilitate sampling.

Splash Testing Procedure

The splash cups with soil were taken to a closed laboratory that housed a rainfall simulator connected to the main water supply via a self-regulating pump to maintain an even water pressure to the nozzle. The simulator was calibrated to deliver rainfall at 150 mm•h^{-1} for which nozzle pressure was set at about 70 kPa at a nozzle exit height of 1 m. Recalibration, to ensure constant intensity of application, was done after every second run.

Splash test samples were saturated overnight and drained for at least 30 min before splash testing. Duplicate samples were randomly selected from each plot for splash tests. Each splash cup was fitted with appropriate chambers and splash units placed immediately beneath the nozzle. The simulator was then turned on for 10 min. The content of the splash chamber was transferred to beakers and filtered to secure the sediment, which, together with filter paper of known dry mass, was oven dried (105 C) to constant mass. The filter paper was stabilized overnight in a desiccator before and after filtration to minimize errors due to spontaneous water absorption from the atmosphere. Sediment dry mass was used to compute sediment yield as mass of sediment produced per unit surface area of the target (original) soil (in t•ha^{-1}).

Statistical Analysis

Experimental data were subjected to analysis of variance and mean separation (LSD). Regression analysis was done to assess the relation of splashed sediment to (i) splash cup diameter and (ii) straw coverage. The level of significance used was $P<0.05$ unless otherwise stated.

RESULTS AND DISCUSSION

Erosion Plots

Soil loss from erosion plots of mulched potatoes was only half as much as it was from unmulched (control) plots (Table 1). These results confirm a basic expectation (Mannering and Meyer 1963; Singer and Blackard 1978; Foster *et al.* 1985), and are thus not surprising at any level of agronomic or hydrologic scrutiny.

Runoff volume in the present study was not affected by mulching. A similar observation was made in a previous mulching study with 0.9-m-long by 0.3-m-wide mini-plots (Edwards *et al.* 1995) where straw was surface-incorporated at rates ranging from 2 to 8 t•ha^{-1} in the same Charlottetown fine sandy loam soil as used in this study.

Straw mulching afforded a significant increase in soil moisture retention, which was 5.3% greater than it was for the control plots. This bears out the general principle of mulching for soil-water conservation (Russell 1973). Dryland potato production in PEI is naturally subjected to some moisture stress on an approximate five year recurrence interval, and mulching has the potential to alleviate the effects of at least the lesser of these drier years.

Of the soil physical characteristics examined, only penetration resistance—as a measure of compaction—was affected (Table 1), and was 15% greater in the presence of straw than in its absence. This might reflect an increased soil strength, in terms of vertical resistance, that the straw (partially incorporated) imparts.

TABLE 1.—*Effect of straw mulching on soil erosion and soil physical characteristics of potato plots.*†

Response	Sampling depth (cm)	Treatment		
		Straw mulch	Control	Significance level (P)
Soil loss (kg.ha^{-1}.yr^{-1})	-	137(b)[a]	270(a)	<0.05
Runoff (mm.yr^{-1})	-	24(a)	37(a)	N.S.
Penetration resistance (t.m^{-2})	0 - 15	5.3(a)	4.8(b)	<0.001
Shear strength (t.m^{-2})	0 - 15	8.1(a)	8.4(a)	N.S.
Moisture (%)	0 - 15	24.0(a)	22.8(b)	<0.05
Aggregate stability (%)	0 - 15	74.9(a)	72.2(a)	N.S.

†Standard length (Wischmeier 1976) erosion plots: 22.1 m (72.6 ft) long by 4 m wide.
[a]Values in the same row followed by the same letter are not significantly different.

TABLE 2.—*Straw mulch management: effect of straw cover percentage on splash erosion (mg sediment dry mass) in potatoes.*

	Straw cover (%)		
	~5	~15	~20
Dry weight† (mg)	202(a)	144(ab)	130(b)

†Dry weight values in the same row followed by the same letter are not significantly different.

Splash Erosion

Straw coverage had a significant effect on sediment dry mass due to splash, which was 36% less with 20% straw coverage than with 5% straw coverage (Table 2). Tillage was, undoubtedly, a major confounding factor in the effect that surface straw had on splash amounts, but, at a practical level, it forms the basis of the mulch management systems tested and in-use on some farms.

Splash cup size (diameter) had a significant effect on sediment, and in absolute terms, the largest (100 mm) cup yielded twice the mass of sediment as did the smallest (25 mm) cup (Table 3). However, on the basis of sediment pro-

TABLE 3.—*Straw mulch management: effect of splash cup size (mm diameter) on splash erosion (mg sediment dry mass) in potatoes.*

	Splash cup diameter		
	Large (100mm)	Medium (50mm)	Small (25mm)
Dry weight† (mg)	220(a)	156(ab)	100(b)

†Dry weight values in the same row followed by the same letter are not significantly different.

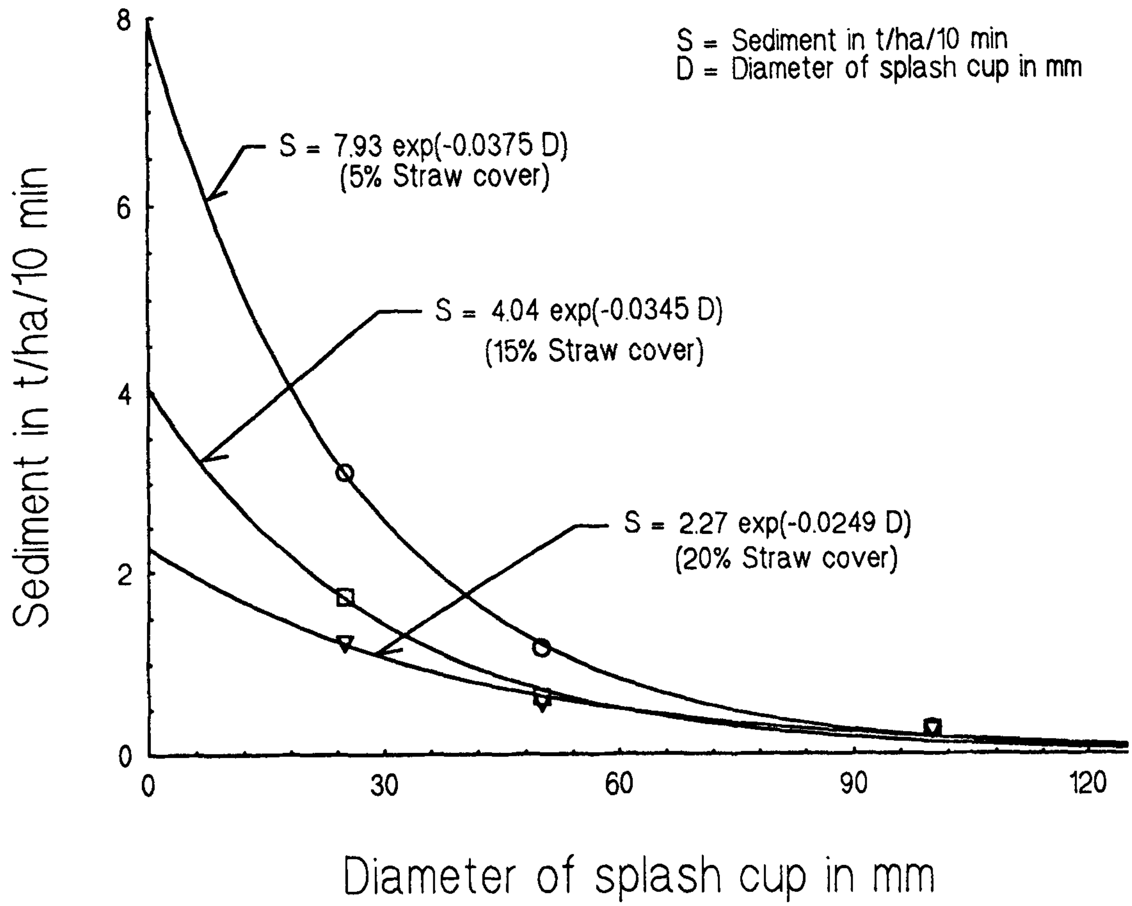

FIGURE 3. Sediment in splash as a function of splash cup diameter for varying straw cover.

duced per unit of target (soil surface) area, the largest splash cup yielded only 14% of that from the smallest cup, and 35% of that from the mid-size cup (Table 4).

Sediment splash per unit area was plotted against splash cup diameter for each of the straw cover levels and extrapolated to zero cup diameter to obtain an estimate of point losses (Figure 3). These zero splash cup diameter values were then plotted as the upper curve in Figure 4. Extrapolation of this curve to zero cover provides an estimate of the soil interrill erodibility, K_i, as given in Equation 1, and is 5.7 Gg•s•m^{-4} for this study. This value is slightly higher than the range of 0.6 to 3.5 Gg•s•m^{-4} fitted by use of the COSSEM model (Burney and Edwards 1996) on recorded hydrographs and sedigraphs obtained from laboratory and field rainfall simulator runs and watershed recordings on the same soil. The remaining portion of this upper curve (point loss) in Figure 4 indicates an expected exponential decay in splash detachment with increasing levels of straw cover.

PERSPECTIVE

On the assumption that mulch usage has a place in potato agronomy, whether to minimize erosion and soil-surface crusting or to build soil organic matter, the concept of mulch management has to be sold to farmers and appropriate field practices recommended based on the main components, viz. mulching material and tillage. Adoption of mulch usage in potatoes may be determined by how much surface cover is ultimately needed in a particular situation. Furthermore, the level of adoption is foreseen to be limited by the maximum quantity of mulching material that is manageable by the farmer while achieving or maintaining the desired seedbed.

Since tillage is the other main variable in mulch management, any adoption strategy used must consider the lower limits of tillage that will provide the required mulch coverage. It is questionable that these lower limits of tillage will be

TABLE 4.—*Straw mulch management: sediment dry mass in tonnes/ha/10 min. for splash erosion measurements from three splash cup sizes (diameters) under three levels of straw cover in potatoes.*

Straw cover (% area cover)	Splash cup diameter (mm)		
	100	50	25
5	$0.29^{c,a}$	$1.17^{b,a}$	$3.12^{a,a}$
15	$0.28^{c,b}$	$0.64^{b,b}$	$1.73^{a,a}$
20	$0.27^{c,b}$	$0.58^{b,b}$	$1.24^{a,a}$
Mean	$0.28^{c,-}$	$0.79^{b,-}$	$2.03^{a,-}$

[x,y]Differing x values in a given row indicate significant cup diameter effects: differing y values in a given column indicate significant treatment effects within each management system.

acceptable or even practical in a set culture of intensive potato cultivation, as in Prince Edward Island. However, the cultivation of potatoes is at the center of this province's soil erosion problems (Edwards *et al.* 1998). This puts an onus on researchers, extension agents, and all producers to define and to adhere to a system of balances or accommodations that minimize soil erosion, while allowing high crop output.

Expanding market opportunities for potatoes tempt local farmers to relax soil conservation vigilance, or to ignore even simple agronomic procedures that are fundamental to soil-surface stability. The value of monitoring or assessing soil-surface stability is considerable because potato cropping under present PEI circumstances could lead to a soil that is so degraded by tillage and heavy vehicular traffic that it becomes a structureless medium with little intrinsic value to

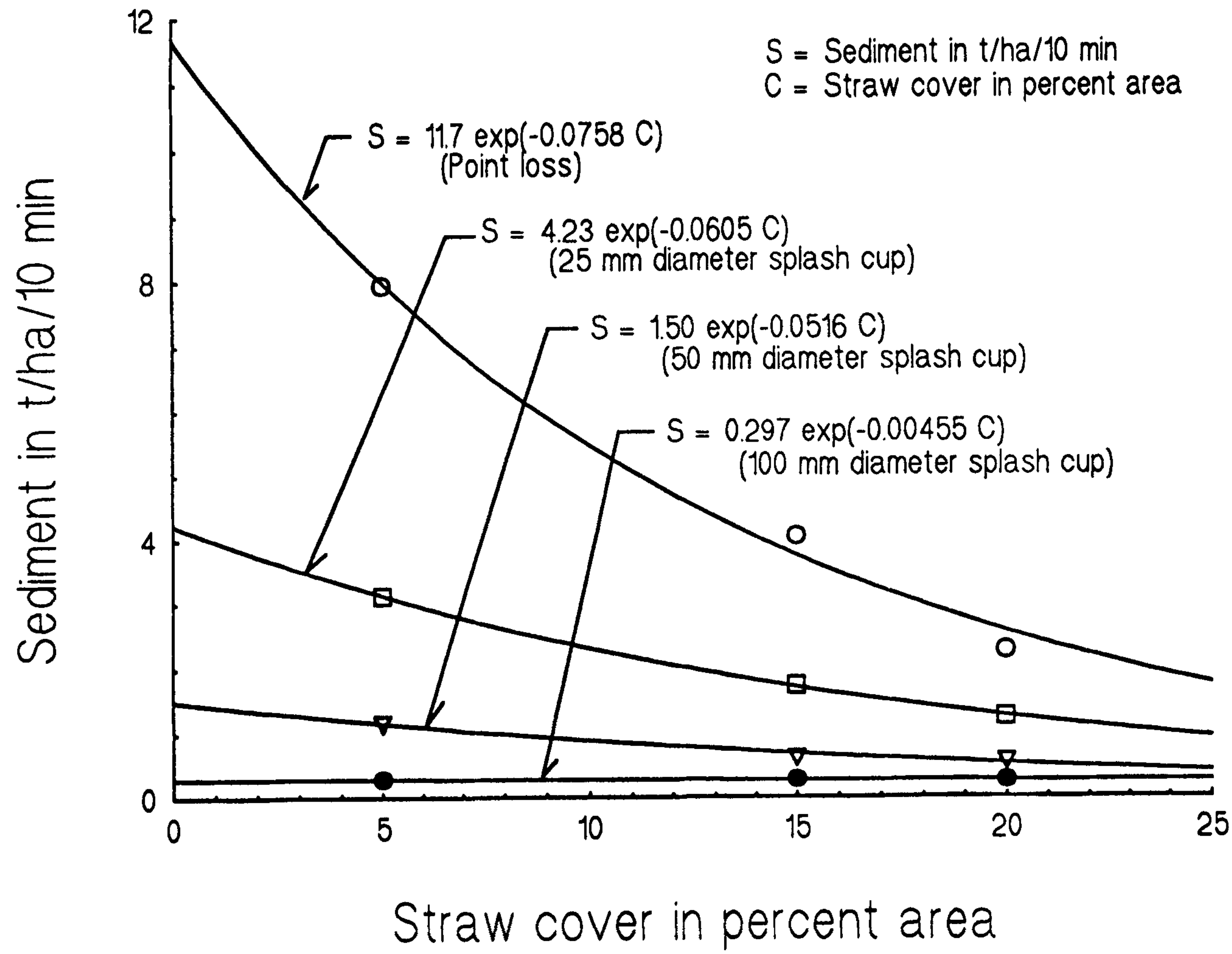

FIGURE 4. Sediment in splash as a function of straw cover for varying source areas.

the potato plant. Perhaps the time is right for a relatively simple splash detachment procedure, as developed in this study as a diagnostic tool, that farmers can understand and extension agents can use to generate indices of soil-surface physical health. The equipment used here can be adapted to laboratory or field use (with natural or simulated rain). Its operation is, therefore, without limit by season or weather.

ACKNOWLEDGMENTS

The authors thank Delmar Holmstrom for allowing samples to be taken from his plots, and Allan MacRae, Irene Power and Harry Younie for technical assistance.

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