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EROSION AND INFILTRATION OF FURROW IRRIGATED POTATO FIELDS AS AFFECTED BY ZONE SUBSOILING

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ABSTRACT

Soil compaction is a problem in many potato fields of the Pacific Northwest. It was hypothesized that zone subsoiling could increase infiltration, potato (*Solanum tuberosum* L., cv Russet Burbank) yield, or quality and decrease bed bulk density, runoff, and sediment loss of furrow irrigated fields, while maintaining trafficability and irrigability of furrows. A two year field study was established in Fall 1988 near Kimberly, Idaho, on a Portneuf silt loam soil (coarse-silty, mixed mesic Durixerollic Calciorthids). In the Fall of each year plots were in wheat stubble (1988) or bean stover (1989) the previous season, and were either disked (10-12 cm), chiselled (25-30cm), or moldboard plowed (20-25cm) in the Fall. Fall tillage plots were split in Spring, half of each plot receiving in-row zone subsoiling after planting. The overall effect of zone subsoiling on infiltration in 1989 was small as a result of variation of its effect in the different fall tillage treatments. In 1990 zone subsoiling increased infiltration an average of 10% in all fall tillage treatments. Sediment loss by treatments were generally related to runoff, decreasing with zone subsoiling. Zone subsoiling was generally more effective at reducing erosion than at increasing infiltration as indicated by 2-3 fold decreases in the ratio of sediment loss to water infiltrated with zone subsoiling. The relative effectiveness of zone subsoiling at increasing infiltration and reducing sediment loss was greater in 1990 when the study was conducted on a field with a greater slope than in 1989 and at higher water application rates than in 1989. Yield of #1 tubers was increased 3.8 t ha^{-1} and quality was improved by zone subsoiling in 1989. Overall yield was not significantly increased ($P = 0.05$), but showed a favorable trend. Yield data were not available for 1990 at this writing, but early season growth analysis indicate a positive response to subsoiling. Zone subsoiling would require extra attention on the part of the irrigator early in the season to insure uniform irrigation but offers the potential to conserve both soil and water while raising quality and possibly yield in Russet Burbank potatoes.

INTRODUCTION

Approximately 1.5 million hectares are surface irrigated in Washington, Oregon, and Idaho. In 1988 205,000 hectares were in potato production. In recent years there has been a substantial shift away from furrow to sprinkler irrigation for production of Russet Burbank potatoes. Two important factors driving this shift have been related to soil erosion and production quality.

Soil erosion is a severe threat to the sustainability of Pacific Northwest agriculture. Irrigated soils in the region are derived from ash and loess, generally low in organic matter and clay, and usually are devoid of significant structure or durable aggregates. From 5 to 50 t ha^{-1} yr^{-1} can be lost from typical fields, and nearly three times that amount from near the furrow inlets (Berg and Carter 1980, Kemper et al., 1985). Mech (1959) reported the loss of 50.9 t ha^{-1} from a single 24 hr irrigation. In some fields this has caused the complete loss of surface horizons in only decades. Since many arid soils are underlain with subsurface horizons rich in calcium carbonates, their exposure, or mixing with eroded surface soil, can cause severe plant nutrient deficiencies and physical degradation. These so-called "white soils" usually reduce crop productivity and can increase the inputs required to sustain yields (Carter et al., 1985).

Recent studies conducted at Kimberly, Idaho, have implicated inadequate wetting of the hill in furrow irrigated fields of Russet Burbank potatoes as a problem affecting quality (T. J. Trout and D. C. Kincaid, unpublished data). Plants are either stressed by inadequate water during hot weather, or tubers are exposed to a combination of dry soil and high soil temperature in the beds, especially before complete canopy coverage. Compaction on some of these soils exacerbates these problems by limiting rooting into the areas with better moisture, and by forcing tuber set higher in the bed where temperatures and moisture are less favorable. In some cases compaction may not prevent rooting or tuber set, but tubers may become physically constrained as they increase in volume, further packing the soil around them.

Furrow erosion and/or soil loss can be reduced by a variety of approaches, including settling ponds (Brown et al., 1981), minibasins and buried pipe to control runoff (Carter, 1985), straw placed in furrows (Berg, 1984; Brown, 1985), and sodded furrows (Cary, 1986). All of these alternatives are costly and/or management intensive. Sediment collected in settling ponds and minibasins must be respread on fields periodically to effectively combat erosion.

In the long term, compaction management can only be accomplished by reducing traffic, confining traffic to limited traffic lanes, and by use of rotations and cultural practices (such as residue incorporation) that promote soil organic matter conservation and soil aggregation. In the short term, some form of deep loosening is required (Glinski and Lipiec, 1990). Zone subsoiling (sometimes called precision subsoiling or in-row subsoiling) is more cost effective than overall loosening, and has the additional advantage of maintaining a firm traffic lane for later field entry. Deep loosening research in irrigated potatoes has demonstrated the potential for yield and quality improvement (Bishop and Grimes, 1978; Campbell and Moreau, 1979; Ross, 1986; Miller and Martin, 1987; Ibrahim and Miller, 1989; Parker et al., 1989), particularly for the Russet Burbank variety. Most studies were conducted under sprinkler rather than furrow irrigation. This is because the ability to confine water delivery down the intended furrow can be impaired if deep loosening is extensive (broadcast). It was not clear if this would occur if subsoil loosening were confined to the zones directly under the bed, leaving the furrow area undisturbed.

One strategy to combat erosion is to increase infiltration, thereby raising irrigation efficiency and reducing runoff. The reduction in soil bulk density and increased porosity associated with deep loosening usually provides for such an increase in infiltration. The objectives of this study were to determine the influence of zone subsoiling on the infiltration, runoff, and sediment loss from furrow-irrigated Russet Burbank potatoes and evaluate zone subsoiling effects on yield and quality.

METHODS AND MATERIALS

A two year field study was established near Kimberly, Idaho, in the fall of 1988. Different fields were employed for each year of the study to avoid disease problems in the second potato (*Solanum tuberosum* L. cv Russet Burbank) crop. In 1988 potatoes were preceded by winter wheat (*Triticum aestivum* L. cv Fieldman). In 1989 potatoes were preceded by beans (*Phaseolus vulgaris* L. cv Viva Pink). Soils in both fields (i.e. each year) were classified as Portneuf silt loam (coarse-silty, mixed mesic Durixerollic Calciorthids). The two fields used for the study were located less than 0.5 km from one another. The field slopes were 0.68% field and 0.91% in 1989 and 1990 respectively.

In the fall of 1988 and 1989 tillage main plots were established. The three fall-tillage treatments were disked (10-12 cm), chiselled (25-30cm), or moldboard plowed (20-25cm). The experimental area was soil sampled each spring and fertilizer requirements were determined according to University of Idaho soil test recommendations. The study area was broadcast fertilized with 60 and 100 kg ha^{-1} of P and mixed with 3.9 kg a.i. ha^{-1} Eptam (EPTC) in 1989 and 1990 respectively in early April. Plots were subsequently split for broadcast nitrogen application as 224 kg N ha^{-1}. The study areas were then disked (10-12 cm) and roller harrowed (2-4 cm) to incorporate chemicals and fertilizer.

Potatoes were planted on April 27, 1989, and May 2, 1990. Planting was accomplished with a custom-built, two-row semi-automated planter/bedder. Split plots that had previously received no broadcast nitrogen were banded with the same rate and formulation of nitrogen as the broadcast plots in a band at the same depth and 10 cm to the side of the seed piece during the planting operation. In 1989 Temik (Aldicarb) was placed at 3.4 kg a.i. ha^{-1} with the seed. In 1990 Thimet (Phorate) was placed with the seed and Dyfonate (Forofos) was lightly incorporated in the hill at 2.8 and 4.5 kg a.i. ha^{-1} respectively.

Following planting, tillage main plots were split for zone subsoiling, which was performed on May 2, 1989, and May 4, 1990. Zone subsoiling was accomplished with a Tye Paratill[1]. The Paratill model used (described by the company as a "potato special") consisted of four Paratill shanks mounted on a 4.6 m welded frame consisting of a triple 10.2 cm by 10.2 cm tool bar for mounting of paratill shanks and subsidiary tillage tools. Paratill shanks were mounted 15.2 cm and 167.6 cm from the centerline on each side of the tractor, with the innermost shank angled outward and the outermost shank angled inward. The center two shanks were staggered longitudinally on the frame to prevent interaction of the two close-spaced shafts. This arrangement of the Paratill provided a 30.5 cm zone of undisturbed soil in non-wheel furrows and a slightly wider, but less definite zone of undisturbed soil in wheel-track furrows. These undisturbed areas were formed in the same pass into 60 degree, 20 cm deep (approximately), V-shaped furrows using weighted furrow forming tools on the rear tool-bar. The statistical design in 1989 was a split-plot, split-block in four replicates, with randomized fall tillage main plots and with blocks split randomly for zone subsoiling after planting or undisturbed after planting. Zone subsoiling split blocks were non-randomly split for band vs broadcast nitrogen application. The statistical design in 1990 was a randomized split-split plot design in three replicates, with fall tillage main plots randomly split for broadcast vs band application of nitrogen and for zone subsoiling after planting vs undisturbed after planting.

Plots in both years were eight rows wide with 91.5 cm inter-row spacing. Potatoes were planted at 30 cm intra-row spacing for a planted population of 36,500 seed pieces ha^{-1}. In both years emerged stand was essentially 100% of planted stand. Tillage subplots were approximately 67 m long in 1989 and 107 m long in 1990. The exact length of each tillage subplot was determined and used for making dependent calculations of water application, runoff, infiltration, and sediment loss, as described below.

Water application in both 1989 and 1990 were by gravity-fed furrow irrigation. Each monitored furrow was individually adjusted to identical application rates. With minor exceptions application rates were held constant at a given application rate throughout the monitored course of an irrigation event. Depending on field conditions, application rates were varied slightly among irrigation events to achieve adequate furrow advance in all treatments. Application rates were usually 10-20% higher for the first two irrigations in each season, and for irrigations after the onset of vine senescence (late August). Median application rates for 1989 and 1990 were 13.25 l min^{-1} per irrigated furrow and 15.14 l min^{-1} per irrigated furrow respectively. During each irrigation event every other furrow was irrigated, alternating between wheel track furrows and non-wheel furrows with each successive irrigation event. The duration of each pair (wheel and non-wheel) of irrigations was varied through the season to meet the crop water demand. Irrigations were twice (one in wheel furrows, one in non-wheel furrows) weekly except very early and very late in the season when irrigation intervals were extended. Runoff was determined from time and runoff flow rate, using calibrated V-notch flumes which were manually read at 1-2 hr intervals (or shorter) through the course of the irrigation set. The 60 degree V-notch flumes, originally developed and calibrated by Robinson and

[1]Mention of trademarks, proprietary products, or vendors does not constitute a guarantee or warranty of the product by the USDA or the Idaho Agricultural Experiment Station, and does not imply its approval to the exclusion of other products or vendors that may be suitable.

Chamberlain (1960) are marketed by Jack Powlus Manufacturing, Twin Falls, ID, and satisfy the hydraulic requirements for long-throated flumes (Bos et al., 1984) up to a flow depth of 9 cm (a gauge reading of 10 cm, or 100 l min^{-1} flow rate). Net furrow infiltration values were determined from the difference of inflow and run-off volumes.

Sediment samples were collected with each flume reading. Sediment was collected in one liter of free-flowing discharge from flumes. Weight of sediment per liter of runoff was determined from the settling volume of sediment in Imhoff cones (Sojka et al., 1989). This technique uses a calibrated empirical relationship between the volume of settled sediment and the weight of sediment as determined by filtration and weighing of reference samples of filtrate. For this soil the calibration between Imhoff cone settling volume and weight of filtrate has an r^2 of 0.99, and the technique is reliable for sediment contents greater than 0.5 g l^{-1}. Sediment monitoring was discontinued when sediment content of runoff fell below this range.

Bulk density was determined to 0.45 m in 0.15 m increments in June and August of 1989 and in August of 1990 using gamma ray backscatter. Only disked, plowed, and plowed+paratilled treatments were characterized. Mid-season potato samples from 1.5 m of row were dug by hand each year to characterize bulking and developmental trends as the season progressed. Final yield and quality was determined at season's end on 15.2 m machine-harvested samples, taken from the center two rows of one of the two four-row paratill passes in each plot. Non-paratilled plots were harvested identically from the corresponding rows in those plots. Potato quality was determined using the standard USDA grading scheme (Anonymous, 1971) and potato specific gravity was determined using the weight in air minus weight in water method (Anonymous, 1983; Kleinschmidt et al., 1984).

RESULTS AND DISCUSSION

Crop Responses.

Crop response to fertility is beyond the scope of this report, and methodology on this aspect was only included to provide a proper description of experimental layout and statistical design. Similarly, yield and other crop responses are largely beyond the focus of this report and are confined to a brief presentation of yield and quality effects of the zone subsoiling operation in 1989. At this writing final harvest for the 1990 season has not occurred, but 1990 mid-season and late season sampling data support the 1989 findings.

In 1989 Total tuber yield, yield of combined percent #1 and #2 tubers greater than 10 oz (284 g), and tuber specific gravity did not differ statistically at the 5% level of probability, although all three showed favorable trends with zone subsoiling. Zone subsoiling increased the yield of #1 tubers by 3.8 t ha^{-1}, which was significant at the 3.5% level of probability. These results reflected similar favorable responses from other tests involving zone subsoiling conducted in Idaho in 1989 (Sojka et al., 1990). In 1989 zone subsoiled plots had more vigorous early season growth which probably contributed to the observed increase in quality (yield of tubers >113.5 g), however this was not quantified.

In 1990 top growth dry weight of non-subsoiled treatments on June 5th was only 69% of plots that had been zone subsoiled (data not shown). Individual plant size was also more uniform with zone subsoiling. Similarly, 1.5 m of row sampled on July 18 and August 27 indicated greater top dry weight, tuber fresh weight, and tuber dry weight for zone subsoiled treatments.

Bulk Density.

The effect of zone subsoiling on soil bulk density was assessed in the center of beds from three of the six tillage treatments at mid-season twice in 1989 and once in 1990 (Table 1). The most common field preparation for potatoes in Idaho corresponds to the fall plowed without spring zone subsoiling treatment in this study. Fall disking without spring subsoiling represents the most compaction-prone tillage practice likely to be encountered in normal commercial production, and the fall plowed plus spring zone subsoiled treatment represents the greatest compaction disruption likely feasible for commercial production. Comparison of bulk densities from these three treatments shows that zone subsoiling with the Paratill significantly reduces bulk density in the surface 30 cm of the potato beds. The earliest bulk density values were obtained more than a month after the subsoiling operation, with several intervening irrigations which may have induced some consolidation. Yet, lower bulk densities were still apparent, and these differences remained until late into the season. It is likely that the looser beds of the zone subsoiled treatments also contributed to a slight warming (approximately 0.5 C) of the beds in the first month after subsoiling (data not shown). The warmer and looser beds of zone sub-

Table 1. Bulk densities determined in the center of beds of three tillage treatments, using gamma ray backscattering.

	Bulk Density g cm^{-3}*								
	Disk Only			Plow Only			Plow + Zone Subsoil		
	---1989---		1990	---1989---		1990	---1989---		1990
Depth cm	6/28	8/16	8/02	6/28	8/16	8/02	6/28	8/16	8/02
15	1.27a	1.26a	1.15a	1.25a	1.25a	1.11a	1.15b	1.23a	1.05a
30	1.35a	1.33ab	1.41a	1.36a	1.38a	1.36a	1.24b	1.24b	1.16b
45	1.35a	1.36a	1.52a	1.38a	1.44a	1.45ab	1.37a	1.37a	1.37b

*Values in the same row for the same date with the same letter do not differ at the 5% level of probability.

soiled treatments were likely responsible for their earlier more vigorous emergence.

Infiltration.

Cumulative infiltration patterns for the tillage treatments are presented in Figures 1 and 2 for 1989 and 1990 respectively. A summary of the statistical significance of seasonal totals of treatment related infiltration and sediment loss effects is presented in Table 2. Seasonal summaries of water application, runoff, and net infiltration for 1989 and 1990 appear in Table 3. For all the data, net infiltration of wheel track furrows is less than net infiltration of non-wheel furrows. In 1989 infiltration of wheel track furrows from zone subsoiled treatments was equal to or higher than from non-subsoiled treatments. The relative effects of zone subsoiling in the disk treatment and in the wheel track furrows of the plow treatment remained unchanged throughout the 1989 season (slopes were the same at any given date). Infiltration differences between wheel track furrows and non-wheel furrows continued all season (slopes were different on any given date). Similarly, infiltration differences between zone subsoiled and non-subsoiled treatments in the chisel treatment and the non-wheel furrows of the of the plow treatment also continued all season. In all cases except with fall plowing in 1989 zone subsoiling infiltration exceeded or was equal to non-subsoiled treatments.

Because planting was with two-row equipment and zone subsoiling was with four-row equipment, the wheel traffic patterns of zone subsoiled plots and non-subsoiled plots were different. Non-subsoiled plots had a true non-wheel furrow, whereas the non-wheel furrow of zone subsoiled treatments corresponded to the wheel-track furrow of non-subsoiled treatments. This fact and the soil moisture differences at the time of planting and subsoiling probably explain the substantial response reversal of the fall plowed treatment with or without subsoiling between the two years. The surface 30 cm of soil was relatively dry in the spring of 1989 at the time of both planting and subsoiling, therefore the true non-wheel furrow of the fall plow treatment received little compaction prior to irrigation.

In 1990, however, the spring was wetter than in 1989. Planting and subsequent subsoiling had to be delayed because of untimely rain. Even though spring field operations were kept to a minimum the application of fertilizer, disking, and roller harrow operations prior to planting resulted in more surface compaction in the field than in 1989. These operations lowered the infiltration of the true non-wheel furrows, particularly in the fall plow treatment which was the loosest of the three treatments, and therefore most susceptible to recompaction under the wetter soil conditions.

In 1990 there was a consistently higher net infiltration in non-wheel furrows regardless of fall tillage. Similarly, net infiltration was greater for zone subsoiled plots regardless of fall tillage and irrespective of wheel or non-wheel furrow. In 1990 the increased infiltration of the zone subsoiled treatment for non-wheel furrows was caused almost entirely by differences in the first irrigation. Thereafter slope changes for subsoiled vs non-subsoiled accumulation curves of non-wheel furrows were nearly identical, and

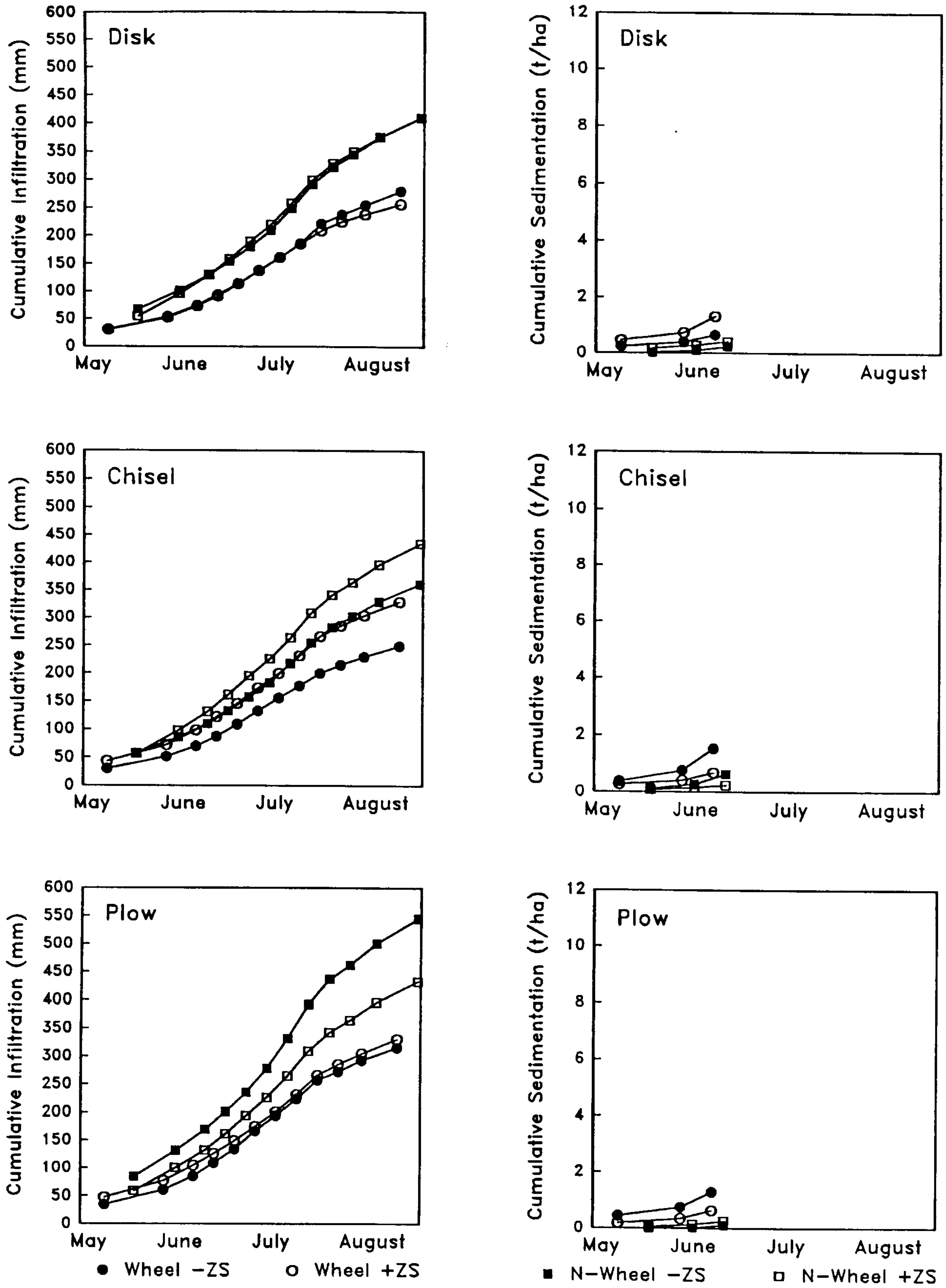

Figure 1. Seasonal Cumulative Infiltration and Sedimentation for 1989.

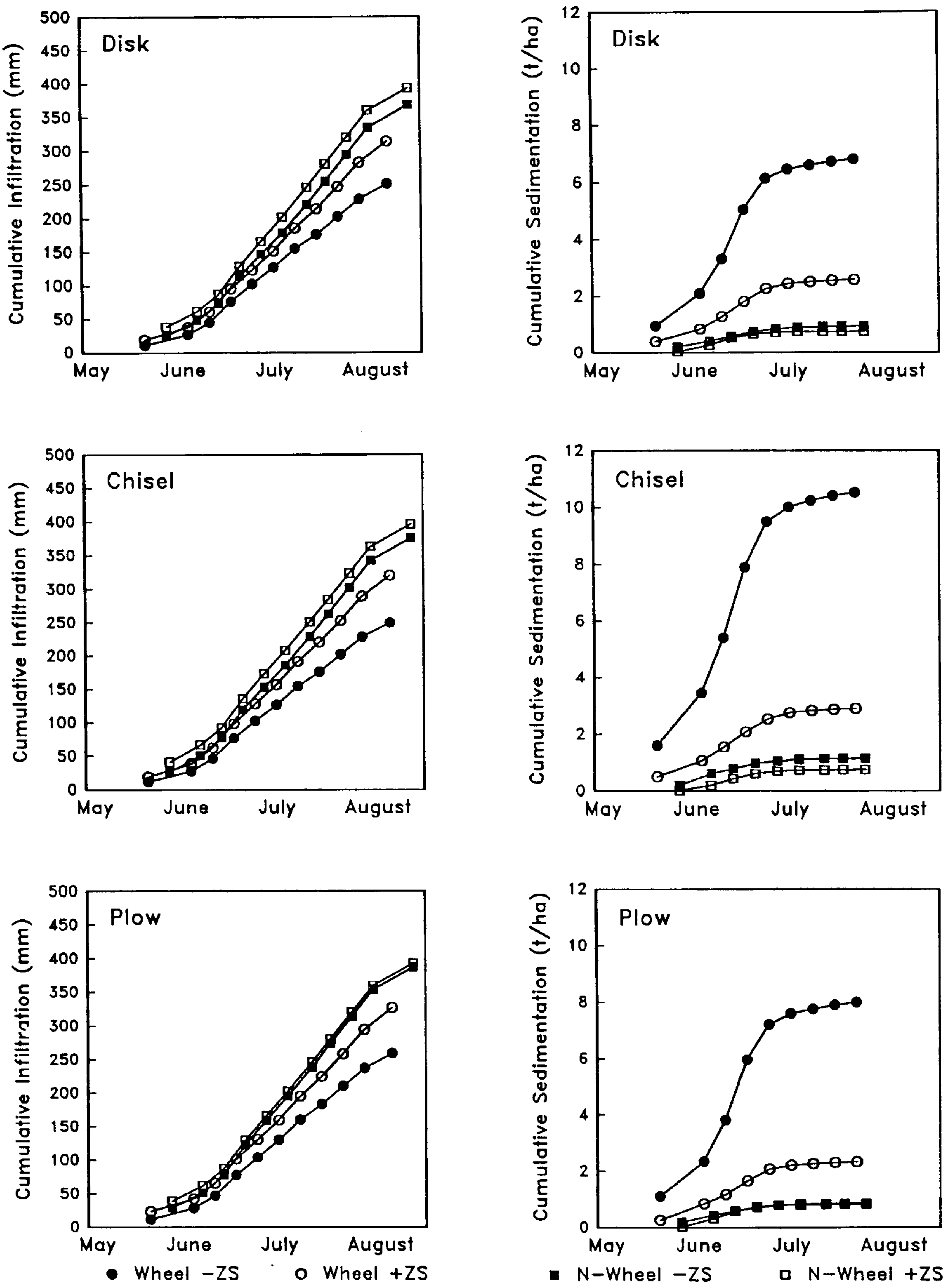

Figure 2. Season Cumulative Infiltration and Sedimentation for 1990.

Table 2. Probability levels for seasonal cumulative infiltration and seasonal cumulative sediment loss for 1989 and 1990 (infiltration and sediment values appear in tables 3 and 4) for major sources of variance.

Source of Variance	Probability (P>) 1989 Infiltr.	1989 Sediment	1990 Infiltr.	1990 Sediment
Fall Tillage	0.0016	0.3381	0.5336	0.1293
Zone Subsoiling	0.7704	0.4096	0.0001	0.0010
Fall Tillage X ZS	0.0538	0.0950	0.9112	0.4049
Wheels	0.0001	0.0001	0.0001	0.0009
Fall Tillage X Wheels	0.0232	0.7776	0.9322	0.5975
ZS X Wheels	0.0073	0.2806	0.0001	0.0007
F. Till. X ZS X Wheels	0.0007	0.1094	0.4784	0.4067

were merely offset by the difference that occurred on the first irrigation. Net infiltration differences with or without zone subsoiling in wheel track furrows, however, continued through the entire season, as is evident from the steadily changing slope difference between these pairs of accumulation curves in all three fall tillage treatments. The seasonal accumulation in Table 3 shows that greater infiltration occurred in non-wheel furrows and that infiltration increased in the order disk < chisel < plow. This ranking is consistent in 1990 with or without zone subsoiling except for a minor discrepancy between the non-subsoiled disk and chisel wheel furrow infiltration amounts, which were nearly identical.

A practical consideration that warrants noting was the tendency of furrow streams to flow into large soil discontinuities formed by the zone subsoiling operation. This "piping" of water occurred despite the fact that shanks of the Paratill are offset from the furrow and do not actually disturb soil in the furrow. Piping would continue at a given point in the furrow until that local area of the bed became saturated or until the bed slumped at the point of piping, thereby rediverting water down the furrow. Piping was a greater problem in the non-wheel furrows of zone subsoiled treatments. Presumably the more diffuse fracture area and the compaction from wheel passage of the deep tillage operation promoted better furrow shaping and water conveyance. Piping was most pronounced in the first few irrigations of each season, after which it was not as serious. Despite a cloddier seedbed in the second season, a brief surge irrigation to condition the furrows prior to the beginning of regular irrigations reduced but did not eliminate the piping problem. The piping problem would discourage the use of zone subsoiling by some furrow irrigators. With attention to initial furrow shaping and by tending problem furrows in the first few irrigations, however, the piping problem need not preclude use of the zone subsoiling concept under furrow irrigation.

Sediment Loss.

The magnitude of sediment loss increased three to six fold from 1989 to 1990, despite similar amounts of water applied and water infiltrated (Tables 3 & 4). These differences were caused by the differences in field slope each year (0.68% in 1989 and 0.91% in 1990) and differences in median water application rates (13.25 l min^{-1} in 1989 and 15.14 l min^{-1} in 1990). In addition the crop preceding the 1989 study was wheat, which left more residue exposed in all the fall tillage treatments than the small amounts of stover from the bean crop that preceded the 1990 study. Sediment sampling was terminated for the 1989 season in mid June when sediment concentrations decreased below 0.5 g l^{-1} in nearly all plots.

The shallower slope and lower application rate in 1989 minimized both the magnitude of and opportunity to see treatment differences in sediment loss. Among non-subsoiled treatments fall chiselling produced twice the sediment of the other treatments either as mass of sediment per unit area or per unit volume of water infiltrated. Among zone subsoiled

Table 3. Season summary of water application, runoff, and net infiltration for 1989.

	1989									
	Wheel Furrows				Non-Wheel Furrows				Net Infiltration	
Treatment	Flow on	Run off	Net Infiltration		Flow on	Run off	Net Infiltration		All Furrows Total	Mean
	—mm—		mm	%	—mm—		mm	%	mm	%
Disk -ZS*	591	311	280	47.4	602	191	411	68.3	691	57.9
Chisel -ZS	591	342	249	42.1	602	240	361	60.0	610	51.2
Plow -ZS	591	276	315	53.3	602	56	545	90.7	861	72.1
Disk +ZS	591	334	257	43.5	609	199	410	67.4	668	55.6
Chisel +ZS	591	262	329	55.7	609	174	435	71.4	764	63.7
Plow +ZS	591	261	330	55.9	609	176	433	71.1	763	63.6
Mean Disk	591	322	269	45.5	605	195	411	67.8	679	56.8
Mean Chisel	591	302	289	48.9	605	207	398	65.8	687	57.4
Mean Plow	591	268	323	54.6	605	116	489	80.8	812	67.9
Mean -ZS	591	310	281	47.6	602	162	439	73.0	721	60.4
Mean +ZS	591	286	306	51.7	609	183	426	70.0	732	61.0
	1990									
Disk -ZS	446	194	252	56.4	446	78	368	82.5	620	69.5
Chisel -ZS	446	196	250	56.0	446	70	376	84.3	626	70.2
Plow -ZS	446	187	259	58.1	446	59	387	86.9	647	72.5
Disk +ZS	446	132	314	70.5	446	53	393	88.2	708	79.3
Chisel +ZS	446	126	320	71.9	446	50	396	88.9	717	80.4
Plow +ZS	446	119	327	73.3	446	42	404	90.6	731	81.9
Mean Disk	446	163	283	63.4	446	65	381	85.3	664	74.4
Mean Chisel	446	161	285	63.9	446	60	386	86.6	671	75.2
Mean Plow	446	153	293	65.7	446	50	396	88.7	689	77.2
Mean -ZS	446	192	254	56.8	446	69	377	84.6	631	70.7
Mean +ZS	446	125	321	71.9	446	48	398	89.2	718	80.5

*Use or no use of zone subsoiling is indicated by +ZS or -ZS respectively.

treatments fall disking produced twice the sediment of the other treatments. Sediment losses from non-wheel furrows were less than from wheel furrows but were similar regardless of fall tillage. Sediment loss from wheel-track furrows was less from zone subsoiled plots with fall plowing or chiselling but was greater with fall disking. The magnitude of differences were not large in any of the treatments observed, and since early in the season sediment losses dropped below the threshold of the measurement technique used, few additional inferences can be made from the 1989 data.

In 1990 the sediment losses were clearly driven by runoff differences among treatments. Where infiltration was improved, furrow sediment loss was reduced. Wheel track furrows lost more sediment than non-wheel furrows. Non-wheel furrow sediment-loss was not substantially affected by tillage practice, producing low amounts of sediment in all cases. In wheel track furrows, sediment loss was three to four fold greater without subsoiling. Differences in sediment loss rate became nearly non-existent by July (slopes of cumulative sediment loss curves became parallel). This date corresponds to complete canopy coverage and

Table 4. Cumulative sediment loss, and cumulative infiltration restricted to dates of sediment monitoring, and their interrelationship.

	1989							
	Wheel Furrows			Non-Wheel Furrows			All Furrows	
Treatment	Sediment Loss kg ha^{-1}	Net Infiltr. mm	Sed.: Infiltr. kg mm^{-1}	Sediment Loss kg ha^{-1}	Net Infiltr. mm	Sed.: Infiltr. kg mm^{-1}	Sediment Loss kg ha^{-1}	Sed.: Infiltr. kg mm^{-1}
Disk -ZS*	645	75	8.57	227	130	1.75	872	4.25
Chisel -ZS	1530	70	21.78	621	110	5.67	2151	11.95
Plow -ZS	1288	85	15.09	96	169	0.57	1384	5.45
Disk +ZS	1313	74	17.81	405	130	3.12	1718	8.42
Chisel +ZS	676	99	6.86	233	131	1.78	909	3.95
Plow +ZS	626	104	5.99	253	132	1.92	879	3.72
Mean Disk	979	74	13.14	316	130	2.44	1295	6.35
Mean Chisel	1103	84	13.07	427	120	3.55	1530	7.50
Mean Plow	957	95	10.08	175	150	1.16	1132	4.62
Mean -ZS	1154	77	15.00	315	136	2.31	1469	6.90
Mean +ZS	871	92	9.45	297	131	2.27	1168	5.24
	1990							
Disk -ZS	6815	203	33.59	935	295	3.17	7756	15.57
Chisel -ZS	10515	202	52.01	1141	303	3.77	11540	36.85
Plow -ZS	8003	210	38.04	851	314	2.71	8988	16.83
Disk +ZS	2578	248	10.41	750	321	2.34	3297	5.86
Chisel +ZS	2900	253	11.47	748	324	2.31	3674	6.32
Plow +ZS	2334	259	9.03	816	331	2.47	3192	5.34
Mean Disk	4697	225	20.85	842	308	2.74	5527	10.39
Mean Chisel	6708	228	29.48	945	313	3.01	7607	14.15
Mean Plow	5168	234	22.05	834	322	2.58	6090	10.78
Mean -ZS	8450	205	41.16	976	304	3.21	9428	18.52
Mean +ZS	2604	253	10.29	771	325	2.37	3388	5.84

*Use or no use of zone subsoiling is indicated by +ZS or -ZS respectively.

intrusion of vines into the furrows. Although differences in infiltration largely dictated the direction of change in erosion from the various tillage treatments, it is apparently not the only factor. This can be seen by comparing the ratio of sediment loss to infiltration for the tillage treatments over the two years of the study. Although infiltration varied by as much as 20 percentage points among tillage treatments, the ratio of sediment lost to water infiltrated varied by several fold among treatments. The sediment to infiltration ratio was particularly reduced by the use of zone subsoiling. If infiltration alone caused the differences in erosion among the different tillage treatments, these ratios should be nearly constant.

The ranking of sediment loss was not perfectly consistent between years. Generally, however, zone subsoiling substantially reduced sediment loss, especially in the more erosive wheel track furrows. Also, fall chiselling produced more erosion than did fall plowing or fall disking, except with the addition of zone subsoiling. In making these interpretations one must bear in mind that a major mechanism associated with the increase of infiltration and reduction of erosion in the zone subsoiled treatments is the slowing of stream advance. While this legitimately increased infiltration and reduced erosion, it could pose its own management concerns on problem fields or soil types. A slower advance rate implies a greater difference in net infiltration between the top and bottom of an irrigated field. This implies a greater variation in the field away from optimal soil water storage and availability for the crop, and can result in loss of mobile nutrients below the depth of root extractability or into groundwater when the variation in field water regime is on the side of excess infiltration. Use of zone subsoiling, therefore would require greater attention on the part of the irrigator to deliver water uniformly across the field.

CONCLUSIONS

Zone subsoiling offers the potential to improve Russet Burbank potato quality, and possibly also improve overall yield while simultaneously increasing net infiltration and reducing erosion. These parameters were most improved by zone subsoiling when irrigating wheel track furrows, which usually have less efficient intake properties, resulting in greater runoff and erosion. Although the changes in erosion were certainly related to runoff, they were also affected by other unidentified mechanisms associated with the zone tillage technique. This is evident from the lower sediment to infiltration ratios produced by zone subsoiling, which would have been identical if runoff alone was responsible for the erosion differences. The extent of alteration of an otherwise familiar system of irrigating was substantial and would require some adjustment on the part of irrigators to optimize the system on their own farms. Nonetheless, the potential benefits would seem to warrant consideration of the practice where infiltration problems are associated with high rates of erosion or poor production quality.

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