ZONE-SUBSOILING EFFECTS ON POTATO YIELD AND GRADE

R. E. Sojka[1], D. T. Westermann[1,2], D. C. Kincaid[1], I. R. McCann[3], J. L. Halderson[3], and M. Thornton[4]

Abstract

Soil compaction and erosion are problems in many Pacific Northwestern potato fields. We wanted to determine if zone-subsoiling would reduce these problems and improve potato yields and or grade without adversely impacting other production practices. Studies were conducted in Southern Idaho at six locations over two years on different soils and with different irrigation methods to assess the effects of zone-subsoiling immediately after planting on tuber yield and grade. Reservoir-tillage comparisons were made at three locations where sprinkler water application rates were higher than soil infiltration rates. Russet Burbank was represented by eight location-years and Russet Norkotah by two. Zone-subsoiling consistently improved tuber grade or increased tuber size. The biggest improvement was under furrow irrigation. Zone-subsoiling also tended to increase total yield in eight of ten location-years. Reservoir-tillage improved yield and grade, but zone-subsoiling did not without reservoir-tillage when water application rates were high. At no location did zone-subsoiling significantly decrease tuber grade or yield. Zone-subsoiling had no appreciable effects on hill configuration or seed-piece dislocation. Surface cracking and "water piping" occurred under furrow irrigation but were not significant problems. Results were similar for both cultivars. Additional studies will be needed to successfully incorporate zone-subsoiling into commercial production practices.

Compendio

La compactación y erosión del suelo son problemas presentes en muchos de los campos de papa del noroeste del Pacífico. Se quería determinar si una aradura profunda zonal podría reducir estos problemas y mejorar los rendimientos de papa y/o su grado sin impactar negativamente sobre otras prácticas culturales de producción. Se condujeron estudios al Sur de Idaho, en seis localidades, durante dos años, con diferentes suelos y métodos de irrigación, para determinar los efectos, de una aradura

[1]USDA Agricultural Research Service, Soil and Water Management Research Unit, 3793N-3600E, Kimberly, ID 83341.
[2]Corresponding author.
[3]University of Idaho, Aberdeen, ID.
[4]University of Idaho, Parma, ID.
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profunda zonal efectuada inmediatamente después de la siembra, sobre el rendimiento en tubérculos y su grado. Se efectuaron comparaciones de acumulación-aradura en tres localidades donde las tasas de aplicación de agua por aspersión eran más altas que las tasas de infiltración en el suelo. Russet Burbank fue considerada durante ocho localidades-años y Russet Norkotah en dos. La aradura profunda zonal mejoró consistentemente el grado de los tubérculos o incrementó el tamaño de los mismos. La mejora más notable se efectuó bajo irrigación por surcos. La aradura profunda zonal también tuvo la tendencia a incrementar el rendimiento total, en ocho de las diez localidades-años. La acumulación-aradura mejoró el rendimiento y grado, pero no sucedió lo mismo con la aradura profunda zonal sin acumulación-aradura cuando las tasas de aplicación de agua fueron altas. En ninguna de las localidades la aradura profunda zonal disminuyó significativamente el grado de los tubérculos o el rendimiento. La aradura profunda zonal no tuvo efectos apreciables sobre la configuración del lomo del surco o sobre la localización de las secciones de los tubérculos-semillas. Bajo irrigación por surco se produjeron grietas superficiales y aguda licuefacción ('water piping'), pero no constituyeron problemas significativos. Los resultados fueron similares para ambos cultivares. Se requieren estudios adicionales para incorporar exitosamente la aradura profunda zonal entre las prácticas de producción comerciales.

Introduction

Idaho produced 4,647,241 metric tons of mostly Russet Burbank potatoes on 143,000 hectares in 1989 (9). The profitability of potato production is determined by both yield and quality. Tillage practices have a big impact on both.

Soil compaction usually reduces infiltration and increases irrigation runoff and soil erosion. This is directly or indirectly detrimental to tuber development. Compacted areas within the rooting zone reduce root growth and proliferation, and may physically constrain developing tubers. Tuber-set also may be forced higher in the hill where soil temperatures are higher and moisture is variable and may be limiting.

Various deep tillage methods increase infiltration and reduce soil compaction in a variety of crops. Deep tillage generally improves potato yield and grade (3, 5, 8, 10, 11, 12, 13), particularly when soil moisture is not adequate for Russet Burbank production. Tillage practices include preplant deep plowing, chiselling, and in-row subsoiling (precision subsoiling). Deep plowing is not widely practiced because soil inversion can cause serious nutritional disorders on many soils, especially on soils with nutrient deficient subsurface layers. Chiselling is often too shallow to be completely effective; it also can cause soil mixing and sometimes clodiness, a potential problem at harvest.

Erosion is a severe threat to sustainability of Pacific Northwest agriculture (4, 7). The region's irrigated soils are derived from ash and loess, low in organic matter and clay, and have weak structure with few durable aggregates. The surface horizon is completely eroded away from some portions of production fields after a few decades of farming. Many Idaho soils also have a lime-enriched subsurface layer. Its exposure and mixing with the remaining surface soil can cause plant nutrient deficiencies and soil physical problems. These "white soils" reduce crop productivity and increase the inputs required to sustain yields (4).

A new implement, the Tye Paratill[5], permits deep loosening of a well defined soil zone below and on both sides of the planted seed piece. This type of tillage, "zone-subsoiling," uses less energy than total soil loosening and maintains firm traffic lanes for later field entry. Unlike other forms of deep tillage, it can be done after planting to reduce soil compaction from preceding operations. This implement also loosens the subsoil without soil inversion or significant lateral and vertical displacement. Zone-subsoiling a sandy soil in Michigan generally improved Russet Burbank yields and grade compared with conventional tillage practices (12).

Several studies were initiated across southern Idaho to evaluate post-plant zone-subsoiling on yield and grade of irrigated potatoes. This paper combines data from these studies to provide an overview of the effectiveness of zone-subsoiling across the potato growing region of southern Idaho.

Methods and Materials

Standard production practices, and pesticide and fertilizer applications were in accordance with University of Idaho recommendations (2); the location-year, irrigation type, and cultivar used for each study are shown in Table 1. Zone-subsoiling was done within a few days after planting and the last implement to pass through the field before harvest. Four Paratill shanks were positioned on the non-wheel side of hills at 15.2 and 167.6 cm on each side of the tractor's centerline, with the innermost shank angled outward and the outermost shank angled inward. The two center shanks were longitudinally staggered on the frame to prevent their interaction. Subsoiling depth was approximately 46 cm. Zone-subsoiled treatments were compared with identical plots not subsoiled in each study. Studies at locations 3, 4 and 5 included a comparison of zone-subsoiling with reservoir-tillage (Dammer-Diker)[5]. Studies at locations 2, 3, 4 and 5 also contained subtreatments that were pooled to focus on the effects of zone-subsoiling. Soils at the study locations were: Portneuf silt loam (coarse-silty, mixed, mesic, Durixerollic Calciorthids) at Kimberly and Burley; Declo silt loam

[5]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 that may also be suitable.

TABLE 1.—*Idaho zone-subsoiling experimental locations, 1989 & 1990.*

LOCATION	STUDY YEARS	EXPERIMENT TYPE	IRRIGATION TYPE	CULTIVAR
1. Kimberly	89 & 90	Farm-Cooperator	Solid set spr.	Russet Norkotah
2. Kimberly	89 & 90	Experiment Stn.	Furrow	Russet Burbank
3. Kimberly	89 & 90	Experiment Stn.	Overhead Linear	Russet Burbank
4. Aberdeen	89 & 90	Experiment Stn.	Overhead Linear	Russet Burbank
5. Burley	90	Farm-Cooperator	Center Pivot	Russet Burbank
6. Parma	90	Experiment Stn.	Solid set spr.	Russet Burbank

(coarse-loamy, mixed mesic, Xerollic Calciorthids) at Aberdeen; and Greenleaf silt loam (fine-silty, mixed, mesic, Xerollic Haplargids) at Parma.

The studies included various irrigation methods (Table 1). Sufficient irrigation water was applied in all studies to maintain plant available soil moisture above 65% in the top 18 cm. Locations 3 and 4 used a modified linear-move system to simulate high application rates (defined as greater than soil infiltration rates) under center pivot irrigation. Soil bulk densities at locations 1 and 2 were measured early in the season after several irrigations by a gamma ray backscatter density probe (6). In 1989 bulk densities were also measured at location 2 shortly before harvest. Plot sizes, statistical designs and sampling techniques varied between locations. Tubers were graded according to U.S.D.A. grading standards (1). Specific gravities were determined by the weight-in-water, weight-in-air method. All studies used replicated complete blocks and were summarized with the appropriate statistical analysis (14).

Results and Discussion

Soil and Water Observations—Hill configuration was not appreciably changed by zone-subsoiling at any location. Furrow shapes were maintained using shovel openers or weighted furrow shapers attached to the Paratill implement. Excavation of zone-subsoiled hills generally showed no substantial seed piece dislocation nor damage to seed pieces and 2-5 cm sprouts. Soil-root contact was disturbed but emergence appeared unimpaired. Even delaying zone-subsoiling 23 days after planting because of wet, cold weather, did not cause any apparent emergence problems at location 1 in 1990.

Some surface soil cracking occurred in the furrow irrigated hills in 1989 (location 2). This prompted concern that light penetration might cause more tuber greening. However, inspection of tubers at harvest revealed no increased greening with zone-subsoiling.

Furrow irrigation water sometimes "piped" for 10-15 minutes into the soil discontinuity caused by the zone-subsoiling shanks before flow resumed down the furrow. Piping was greater in the non-wheel furrows. Presumably the more diffuse tillage interface and wheel compaction during zone-subsoiling promoted better furrow shaping and water conveyance in the wheel-track furrows. Piping was only significant during the first few irrigations of each season. The 1990 furrow irrigated studies were briefly surge-irrigated during the first irrigation to pre-condition the furrows. This reduced subsequent piping and hill cracking compared with the 1989 experiment. Piping was an inconvenience, but it did not adversely affect tuber yield or grade.

Fall plowing with multiple spring disking and harrowing is the most common tillage regime used by Idaho growers concerned about compaction. The most compaction-prone fall tillage practice encountered in commercial production is disking. Fall plowing plus spring zone-tillage probably represents the least soil compaction regime. Soil bulk densities in the fall-plowed, zone-subsoiled hills averaged 1.14 compared with 1.20 and 1.23 g cm^{-3} for the fall-plowed or fall-disked plots at locations 1 and 2, respectively (16). A slight soil temperature increase of about 0.5 C in the hills the first month after zone-subsoiling was also observed (16). The looser and warmer zone-subsoiled hills probably contributed to the earlier, more vigorous shoot emergence (described below).

In general, zone-subsoiling increased infiltration, and reduced run-off and erosion in the furrow irrigated studies (16). Similar results were also found in the sprinkler-irrigated studies at locations 3, 4, and 5 (15). Where infiltration and runoff were measured zone-subsoiling interacted with tillage factors and wheel traffic (16).

Yield and Grade Observations—In 1989, zone-subsoiling increased Russet Norkotah tuber yields 3.9 t ha^{-1} (Table 2). The percentage of U.S. No. 1 potatoes >284 g (10 oz) increased from 16% to 25% with zone-subsoiling

TABLE 2.—*Yield and grade of solid-set sprinkler irrigated Russet Norkotah potatoes with and without zone-subsoiling, 1989 and 1990 (Location 1).*

Tillage Treatment	Study Year	Yield t ha^{-1}	Percentage U.S. No. 1 >284 g	Percentage U.S. No. 1 114-284 g	Specific[1] Gravity
Zone-subsoil	1989	42.8	25	46	1.074
	1990	27.7	11	62	1.073
Conventional	1989	38.9	16	53	1.076
	1990	29.0	9	64	1.073
Probability	1989	10.1%	3.4%	NS	NS
	1990	NS	5.9%	NS	NS

[1]Determined on a subsample of U.S. No. 1 and 2 tubers combined.

($P < 0.034$), while the percentage of U.S. No. 1, weighing 114-284 g (4-10 oz), decreased from 53% to 46% with zone-subsoiling. Zone-subsoiling did not affect total tuber yield or percentage of small potatoes in 1990 but increased the percentage of tubers >284 g ($P < 0.059$). In 1990 Russet Norkotah potatoes were affected statewide by late frosts and various diseases that contributed to lower yields (Table 2). Zone-subsoiling caused no significant changes in specific gravities.

Zone-subsoiling improved yield and grade both years for the furrow irrigated Russet Burbank potatoes at location 2 (Table 3). Total tuber yield was significantly increased from zone-subsoiling in 1990 but not in 1989 ($P < 0.05$). Zone-subsoiling increased the percentage and yield of U.S. No. 1 tubers both years, while the percentage of large tubers (> 284 g) was not changed. Specific gravities were not affected by any treatment either year.

Plants in the zone-subsoiled plots emerged 3-4 days earlier than those in the conventional tilled plots. The average shoot dry weights in the zone-subsoiled plots at location 2 were 45% larger than those in the conventional plots on June 5, 1990 (data not shown). Similarly, the zone-subsoiled treatments on July 18 and August 27 had greater shoot dry weights, and tuber fresh and dry weights than the conventional treatments (data not shown).

The study at location 3 included a comparison of reservoir-tillage with both tillage treatments (Table 4). In 1989, tuber yield and grade for the conventional and zone-subsoiled plots were nearly identical, while reservoir-tillage improved total yield and percentage of U.S. No. 1 tubers. In 1990 yield and percentage of large tubers (>284 g) tended to be improved by zone-subsoiling. Zone-subsoiling coupled with reservoir-tillage had higher

TABLE 3.—*Yield and grade of furrow irrigated Russet Burbank potatoes with and without zone-subsoiling, 1989 and 1990 (Location 2).*

Tillage Treatment	Study Year	Yield t ha^{-1}	Percent U.S. No.1	Percent[1] >284 g	Specific[2] Gravity
Zone-subsoil	1989	39.3	63	40	1.080
	1990	41.9	64	20	1.083
Conventional	1989	36.3	58	39	1.079
	1990	37.7	57	19	1.083
Probability	1989	NS	3.5%	NS	NS
	1990	0.1%	5.9%	NS	NS

[1]Combined U.S. No. 1 and 2 tubers >284 g.
[2]Subsample of U.S. No. 1 and 2 tubers combined.

yields than either system alone in 1990. Specific gravities were not affected by any tillage treatment either year.

Yield and grade at location 3 were related to the amount of water infiltrating into the root zone even though sufficient water was applied to prevent depleting the plant available soil moisture below 65%. There was little or no runoff from the reservoir-tilled plots both years (15). Runoff was the largest from the conventional plots and intermediate from the zone-subsoiled plots not reservoir-tilled. Zone-subsoiling under these conditions did not improve yield or grade without reservoir-tillage to capture runoff. Combining zone-subsoiling and reservoir-tillage increased water intake and improved tuber yield without affecting relative grade. Others showed that where water intake rates were similar, subsoil loosening improved tuber yields and grades (8, 10, 12, 13).

In 1989, total tuber yields at location 4 were slightly lower in the zone-subsoiled treatment, but the percentage of all U.S. No. 1 tubers were higher (Table 5). Zone-subsoiling had a slightly greater yield of large tubers than the other treatments (4.9 t ha^{-1} vs 4.2 t ha^{-1}). In 1990 the U.S. No. 1 tuber size fractions were nearly identical. Total tuber yields averaged 35.1 t ha^{-1} with zone-subsoiling and 34.5 t ha^{-1} without zone-subsoiling in 1990.

The study at location 5 was conducted in 1990 under a commercial center-pivot irrigation system. Treatments were similar to those described

TABLE 4.—*Yield and grade of sprinkler irrigated (overhead linear) Russet Burbank potatoes as affected by zone-subsoiling and reservoir-tillage, 1989 and 1990 (Location 3).*

Tillage Treatment	Study Year	Yield t ha^{-1}	Percent U.S. No.1	Percent[1] > 284 g	Specific[2] Gravity
Zone-subsoil	1989	31.9	31	13	1.076
	1990	36.3	60	22	1.080
Conventional	1989	31.9	32	19	1.078
	1990	35.8	66	12	1.078
Conventional + Reservoir-till.	1989	35.1	49	16	1.077
	1990	35.7	71	14	1.081
Zone-subsoil + Reservoir-till.	1989	---	--	--	------
	1990	41.4	68	17	1.081
Probability	1989	NS	5.8%	4.9%	NS
	1990	NS	2.4%	NS	NS

[1]Combined U.S. No. 1 and 2 tubers >284 g.
[2]Subsample of U.S. No. 1 and 2 tubers combined.

TABLE 5.—*Yield and grade of sprinkler irrigated (overhead linear) Russet Burbank potatoes with and without zone-subsoiling, 1989 and 1990 (Location 4).*

Tillage Treatment	Study year	Yield t ha^{-1}	Percentage U.S. No. 1 > 284 g	Percentage U.S. No. 1 114-284 g	Specific[1] Gravity
Zone-subsoil	1989	30.9	16	52	1.081
	1990	35.1	17	43	1.082
Conventional	1989	32.6	13	53	1.082
	1990	34.5	19	44	1.082
Probability	1989	NS	0.3%	NS	NS
	1990	NS	NS	NS	NS

[1]Determined on U.S. No. 1 tubers, 114-284 g.

for location 3. Again, water intake and runoff (data not shown) were affected by tillage as described for location 3. Tuber grade differences among tillage treatments were not different (Table 6), although the U.S. No. 1 percentages were slightly larger with zone-subsoiling, reservoir-tillage, or the two combined. Similarly, the percentage of tubers graded as culls were higher for the conventionally tilled treatment. There was also a trend ($P < 0.11$) for larger yields with zone-subsoiling, reservoir-tillage, or the two combined.

The study at location 6 was conducted in 1990 under solid set sprinklers. This study was a simple comparison of zone-subsoiling and conventional tillage. No yield or grade differences were observed even though there was a distinct traffic-tillage pan at this site. The total yields from this location (47.9 t ha^{1}, 94% U.S. No. 1's) were among the highest observed in this study. This may illustrate a lower probability of benefits from zone-subsoiling where all other management practices are optimium.

Conclusions

These studies were executed with a variety of objectives and with some variation in plot management and data collection. Certain results are consistent enough to warrant summarization. Zone-subsoiling was performed one to two weeks after planting in a normal year without damaging sprouted (2-5 cm) seedpieces. Zone-subsoiling lowered soil bulk densities in the hill that may impact harvesting operations. Other studies (15, 16) showed that it increased infiltration and reduced runoff and erosion. These effects also persisted until harvest. Zone-subsoiling increased tuber size in most studies. In no studies were total tuber yields or grades significantly reduced by zone-subsoiling. When water application rates were higher than soil infiltration

TABLE 6.—*Yield and grade of sprinkler irrigated (overhead linear) Russet Burbank potatoes with or without zone-subsoiling, 1990 (Location 5).*

Tillage Treatment	Yield $t\ ha^{-1}$	—Percent U.S.— No. 1	No. 2	Culls
Zone-subsoil	30.5	45	30	25
Conventional	24.2	40	24	36
Reservoir-tillage	31.8	50	24	26
ZS + RT	28.2	52	19	29
Probability	11%	NS	NS	NS

rates, zone-subsoiling only increased tuber yields and quality if combined with reservoir tillage. The largest increase in tuber yields and grade from zone-subsoiling were in the furrow irrigated studies. Good tuber quality is generally harder to obtain with furrow irrigation than with sprinkler irrigation. Zone-subsoiling caused some hill cracking and piping in the furrow irrigated system. This was an inconvenience but was manageable and caused no yield or grade reduction. Earlier emergence where zone-subsoiled could increase the risk of late spring frost damage in some areas. Zone-subsoiling has the potential to improve the yield and grade of potatoes grown in southern Idaho, similar to that reported for Michigan (12). Several considerations will require further investigation before zone-subsoiling can be integrated into the current production practices.

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