Effect of Planting Depth and Hilling Practices on Total, U.S. No. 1, and Field Greening Tuber Yields

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ABSTRACT

Previous research suggests that field greening of potato tubers can be minimized by planting seedpieces at an appropriate depth along with sufficient hilling to minimize exposure to sunlight. The appropriate planting depth and hilling practices to minimize field tuber greening have not been determined for newer cultivars. Two separate studies, each conducted for three years, are reported here. The first measured the effect of seedpiece planting depth on the yield, quality, and field greening tuber yield of 'Russet Burbank', 'Frontier Russet', and 'Shepody' potatoes. Seedpieces were hand-planted in pre-formed hills at 8, 15, or 23 cm measured from the top of the seedpiece to the top of the hill. Planting at 23 cm resulted in significantly lower total yield compared with the 8- and 15-cm depths for Russet Burbank and Frontier Russet, but planting depth did not affect total yield of Shepody. U.S. No. 1 yield of Russet Burbank was not affected by planting depth, but U.S. No. 1 yield of Frontier Russet was significantly less at the 23-cm depth. For Shepody, the 8-cm depth caused a significant reduction in U.S. No. 1 yield compared with the 15-cm depth. Field greening tuber yield of Russet Burbank was significantly less at the 23-cm planting depth compared to 8 cm. For Frontier Russet and Shepody, planting at 15 or 23 cm resulted in significantly less field tuber greening compared to the 8-cm depth.

The second experiment examined the effects of planting depth and hilling practices on yield, quality, and field tuber greening of Russet Burbank and Gem Russet potatoes. Six planting depth and hilling treatment combinations were used. Seedpieces were planted at a depth of either 8 or 15 cm, then hilled to either 15 or 23 cm at emergence or after plants had formed a rosette of leaves approximately 10 cm in diameter (post-emergence hilling). At-emergence hilling treatments had no effect on total or U.S. No. 1 yields of Russet Burbank compared with the 15-cm planting depth, non-hilled control. However, all post-emergence hilling treatments significantly reduced Russet Burbank total and U.S. No. 1 yields. Planting Russet Burbank at 8 cm and hilling to 23 cm at emergence, or planting at 8 or 15 cm and hilling to 23 cm post-emergence reduced field tuber greening of Russet Burbank. The effects of planting depth and hilling on Gem Russet total and U.S. No. 1 yields were less definitive than for Russet Burbank, and no treatments significantly reduced field tuber greening yield compared with the control.

RESUMEN

Investigaciones previas sugieren que el verdeo de los tubérculos de papa en el campo se puede minimizar colocando la semilla a una profundidad apropiada, conjuntamente con un aporque conveniente como para reducir su exposición a la luz solar. No se han determinado las prácticas apropiadas de aporque y profundidad de siembra para reducir el verdeo del tubérculo en los nuevos cultivares. Se reportan aquí los experimentos de dos estudios realizados separadamente durante tres años. En el primero se midió el efecto de la profundidad de siembra sobre el rendimiento, calidad y verdeo en el campo del producto cosechado en los cultivares 'Russet Burbank', 'Frontier Russet' y 'Shepody'. Los tubérculos semilla se sembraron a mano en montículos preformados

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a 8, 15 o 23cm medidos de la semilla a la parte más alta del montículo. La siembra a 23cm de profundidad redujo significativamente el rendimiento comparado con 8 y 15cm en Russet Burbank y Frontier Russet, pero no tuvo efecto sobre el rendimiento total de Shepody. La profundidad de siembra no afectó el rendimiento de US No. 1 en Russet Burbank, pero en Frontier Russet fue significativamente menor a 23cm de profundidad. Para Shepody, los 8 cm de profundidad causaron una sensible reducción en el rendimiento de US No.1 en comparación con la profundidad de 15cm. El rendimiento de tubérculos verdeados de Russet Burbank en el campo fue significativamente menor a 23cm de siembra comparado con los 8cm. Para Frontier Russet y Shepody la siembra a 15 o 23cm de profundidad dio como resultado un significativamente menor verdeo de tubérculos en comparación con 8cm de profundidad.

El segundo experimento examinó los efectos de la profundidad de siembra y aporque sobre el rendimiento, calidad y verdeo del tubérculo en el campo de los cultivares Russet Burbank y 'Gem Russet'. Se utilizaron seis profundidades de siembra y combinaciones de tratamientos de aporque. La semilla fue sembrada a profundidades de 8 o 15cm y luego se aporcó a los 15 o 23cm de la emergencia o después de que las plantas hubieron formado una roseta de hojas de aproximadamente 10cm de diámetro (aporque de post-emergencia). Los tratamientos de aporque a la emergencia no tuvieron efecto sobre el rendimiento total de Russet Burbank US No. 1 comparado con 15cm de profundidad de siembra y testigo no aporcado. Sin embrago, todos los tratamientos de aporque post-emergencia redujeron el rendimiento de US No.1 de Russet Burbank. Sembrando Russet Burbank a 8cm de profundidad y aporcando a 23cm a la emergencia o sembrando a 8 o 15cm y aporcando a los 23cm post-emergencia, redujo el verdeo de tubérculos en Russet Burbank. Los efectos de profundidad de siembra y aporque sobre Gem Russet y rendimiento de US No.1 fueron menos definitivos que para Russet Burbank y ningún tratamiento redujo significativamente el número de tubérculos verdeados en el campo en comparación con el testigo.

INTRODUCTION

Tubers in the field exposed to sunlight through cracks in the soil or protruding from the hill that turn green before harvest are graded out as unmarketable, which lowers the U.S. No. 1 yield for potato producers. Field tuber greening has been a concern of potato producers for many decades, and early production guides for potato producers recommended deep planting to reduce the amount of green tubers.

The effects of planting depth on the yield of green tubers and other agronomic characteristics have been reported (Jarvis 1973; Lewis and Rowberry 1973; Lorenz 1945; Moursi 1953), but may not be pertinent to newer cultivars and current production practices.

Moursi (1953) planted 'Kerr's Pink' at depths of either 5 or 13 cm. There was no significant difference in the yield resulting from the two planting depths even though plants began to emerge sooner from the shallower planting depth. Lewis and Rowberry (1973) reported there was no significant difference in total or Ontario No. 1 yields of 'Kennebec' or 'Sebago' potatoes planted at 5 or 10 cm when averaged over several hilling treatments. They also reported that hilling, when averaged over a 5- and 10-cm planting depth, had no significant effect on total and Ontario No. 1 yields of Sebago, but forming an approximately 13-cm hill at planting, as measured from the bottom of the furrow, resulted in significantly higher total and Ontario No. 1 yields of Kennebec compared with no hilling in one year of a two-year study.

Mosley (1975a) reported that U.S. No. 1 yield of 'Shurchip' potatoes was significantly higher when planted at a 15-cm depth compared to 5 or 10 cm, and the percentage of green tubers was significantly reduced. In another study, Mosley (1975b) reported lower total and U.S. No. 1 yields when Kennebec was planted at 5 cm compared with 10 or 15 cm. Nineteen percent of the tubers at the 5-cm planting depth were green compared with 10% or less at the other planting depths.

Moreau (1999) reported that the marketable yield of 'Shepody' was reduced when hilled 39 and 53 days after planting or 39, 48, and 57 days after planting, but the yield of 'Russet Burbank' was not affected. Hilling more than one time did not reduce the incidence of field tuber greening in either Russet Burbank or Shepody.

Stalham et al. (2001) reported that a planting depth of 15 or 20 cm resulted in a lower incidence of green tubers without

a reduction in total yield compared to a planting depth of 10 cm in the private chipping cultivar FL 1953.

Although there is published information on planting depth and hilling practices, much of it may not be applicable to newer cultivars being grown using current potato management practices. Our objectives were to determine the effect of seedpiece planting depth on rate of emergence, yield, quality, and field tuber greening of Russet Burbank 'Frontier Russet,' and Shepody potatoes, and to determine the effects of planting depth in combination with hilling practices on the rate of emergence, yield, quality, and field tuber greening of Russet Burbank and 'Gem Russet' potatoes.

MATERIALS AND METHODS

Two separate studies were conducted. One examined the effects of planting depth (depth study), and the second investigated the effects of planting depth in combination with hilling depth and time of hilling in relation to plant development (hilling study). The two studies had the following common procedures. Both were conducted at the University of Idaho Research and Extension Center, Aberdeen, ID, in a Declo silt loam soil. Certified, generation two (third field year) seed tubers were obtained from the University of Idaho Tetonia Seed Farm. Seed tubers were hand-cut into pieces weighing approximately 70 g, and no seedpiece treatment was applied. Potatoes were fertilized according to University of Idaho fertility recommendations (Stark and Westerman 2003) and were irrigated with a solid-set sprinkler system to maintain available soil moisture at 65 percent or more. All data were analyzed using Proc ANOVA in a PC SAS program (SAS 1990), and means were separated using Fischer's Protected LSD.

Depth Study

A planting depth field study was conducted 1995 through 1997 using Russet Burbank, Frontier Russet and Shepody (1996 and 1997 only) potatoes. Potato hills with a flat top were formed prior to planting seedpieces by hand in early to mid-May. Five seedpieces of each cultivar were planted at an in-row spacing of approximately 30 cm in each of three rows spaced 91 cm. A manual post-hole digger was used to remove sufficient soil for planting tubers at a depth of 8, 15, or 23 cm. Planting depth was measured from the top of the seedpiece to the top of the hill, and the seedpieces were placed with the cut surface down. The center row was used for data collection and analysis. Plots were arranged in a randomized complete block design with five replications.

Days to reach 100% emergence were recorded by frequently counting plants until all had emerged. Vines were killed in late August with a chemical desiccant (diquat dibromide) at labeled rates. Time interval between planting and harvest was 139, 123, and 125 days in 1995, 1996, and 1997, respectively. Depth from the top of the hill to the top of the uppermost and lowermost tubers of all plants in the data-collection row was measured prior to harvest. Tubers that were protruding out of the top of the hill resulted in the depth being recorded as a negative number.

Tubers were removed from the hills after measuring tuber depths, which constituted harvest. Tubers were graded by weight into total and U.S. No. 1 yields and total defects. In 1996 and 1997, tubers with any amount of green skin surface were separated out and weighed to determine field tuber greening yield. In 1995, tubers with greening were included in the non-marketable cull yield. Tubers were counted at harvest to calculate tubers per plant and average tuber size.

There were significant year-by-treatment interactions for tubers per plant for Russet Burbank, and for total yield, depth to lowermost tuber, and days to 100% emergence for Frontier Russet. The experiment, however, was designed to analyze data over years within each cultivar, and the interactions were significant due to the degree of magnitude and not dissimilar responses resulting from planting depth. There was homogeneity of error variances between years; therefore, the data for all years within each cultivar were combined and an analysis of variance was performed.

Hilling Study

A study to measure the effect of planting depth in combination with hilling depth and when hills were formed in relation to plant development was conducted 1998 through 2000 using Russet Burbank and Gem Russet potatoes. All plots were planted at a depth of 15 cm in rows spaced 91 cm with an intra-row spacing of 25 cm in early to mid-May using a two-row hand-assist planter. To obtain a planting depth of 8 cm, a stiff-toothed garden rake was used to remove approximately 7 cm of soil following machine planting by pulling the rake perpendicularly across each row. Planting depth was measured from the top of the seedpiece to the top of the hill. Plots consisted of four 2.5-m rows with 10 plants per row, and the center two rows were used for data collection. Plots were

arranged in a randomized complete block design with four replications.

Hilling treatments were completed by manually moving soil with a shovel from the furrow between the rows to the top of the hill. Treatments were (1) planted seedpieces at 15 cm with no hilling treatment (control); (2) planted 8 cm deep and hilled to 15 cm at emergence (P8-H15); (3) planted 8 cm deep and hilled to 23 cm at emergence (P8-H23); (4) planted 15 cm deep and hilled to 23 cm at emergence (P15-H23); (5) planted 8 cm deep and hilled to 15 cm after the plants had formed a rosette of leaves approximately 10 cm in diameter (P8-H15 PE) (PE = post-emergence); (6) planted 8 cm deep and hilled to 23 cm post-emergence (P8-H23 PE); and (7) planted 15 cm deep and hilled to 23 cm post-emergence (P15-H23 PE). Depth of hilling was measured from the top to the seedpiece to the top of the final hill.

To determine days to 90% emergence, daily counts were made of plants that had protruded through the soil surface. For those plots that had a hilling treatment applied, the number of days for the plants to re-emerge was counted. Consequently, data reported are the number of days from planting until plants emerged after a hilling treatment.

Vines were killed in early September using a chemical desiccant (diquat dibromide) at labeled rates. Time interval between planting and harvest was 126, 124, and 139 days in 1998, 1999, and 2000, respectively. Depth from the top of the hill to the top of the uppermost and lowermost tubers of two plants in each data-collection row (four plants per rep) was measured prior to harvest.

Following machine harvest, tubers were graded by weight into total and U.S. No. 1 yields and total defects. Tubers with any amount of green on the surface were removed and weighed separately to calculate field tuber greening yield. Tubers in each size category were counted, and that number was used to calculate tubers per plant and average tuber size.

There was a significant year-by-treatment interaction for days to 90% emergence for both cultivars, and a significant year-by-treatment interaction for U.S. No. 1 yield of Russet Burbank. This study was designed to determine the average days to 90% emergence, so data were combined in the overall analysis, but are reported by year and over years. There was homogeneity of error variances between years for Russet Burbank U.S. No. 1 yield; therefore, the data for all years within each cultivar were combined and an analysis of variance was completed.

RESULTS

Depth Study

For Russet Burbank, analysis of variance revealed significant treatment effects for days to 100% emergence, total yield, tuber depth, field tuber greening yield, and tubers per plant. For Frontier Russet, there were significant treatment effects for days to 100% emergence, total and U.S. No. 1 yields, tuber depth, field greening tuber yield, and tubers per plant. Planting depth resulted in significant effects for days to 100% emergence, U.S. No. 1 yield, tuber depth, field greening tuber yield, and average tuber size for Shepody.

For all three cultivars, days to 100% emergence was delayed approximately 1 week by planting seedpieces at 23 cm vs 8 cm (Table 1). Planting Russet Burbank and Frontier Russet seedpieces at 23 cm delayed days to 100% emergence 6 and 5 days, respectively, compared with the 15-cm planting depth,

TABLE 1—*Days to 100% plant emergence, average tuber size, tubers per plant, and depth to uppermost and lowermost tuber of Russet Burbank, Frontier Russet (average of 3 years), and Shepody (average of 2 years) potatoes as affected by planting depth.*[1]

Cultivar and Planting Depth	Days to 100% Emergence DAP[2]	Average Tuber Size g	Tubers per Plant No.	Depth of Uppermost Tuber[3] cm	Depth of Lowermost Tuber[3] cm
Russet Burbank					
8 cm	26 a	170 a	9.0 a	0.6 a	9.4 a
15 cm	28 b	174 a	8.1 ab	1.4 a	16.2 b
23 cm	34 c	167 a	7.1 b	3.3 b	18.8 c
Frontier Russet					
8 cm	28 a	185 a	8.1 a	0 a	7.0 a
15 cm	30 b	197 a	7.3 a	2.7 b	14.7 b
23 cm	35 c	217 a	5.9 b	5.6 c	19.7 c
Shepody					
8 cm	26 a	258 a	5.9 a	–0.7 a[4]	7.7 a
15 cm	30 b	338 b	5.0 a	2.0 b	12.9 b
23 cm	32 c	261 a	6.2 a	2.2 b	18.6 c

[1]Numbers within a column within a cultivar followed by the same letter are not significantly different at $P \leq 0.05$.
[2]DAP = days after planting.
[3]Measured from top of the hill to the top of the tuber.
[4]Average tuber depth was 0.7 cm above the top of the hill.

whereas planting Shepody at 23 cm delayed days to 100% emergence only 2 days compared with the 15-cm depth.

Planting at 23 cm resulted in significantly lower total yield compared with the 8- and 15-cm planting depths for Russet Burbank and Frontier Russet. Planting depth did not affect total yield of Shepody (Figure 1).

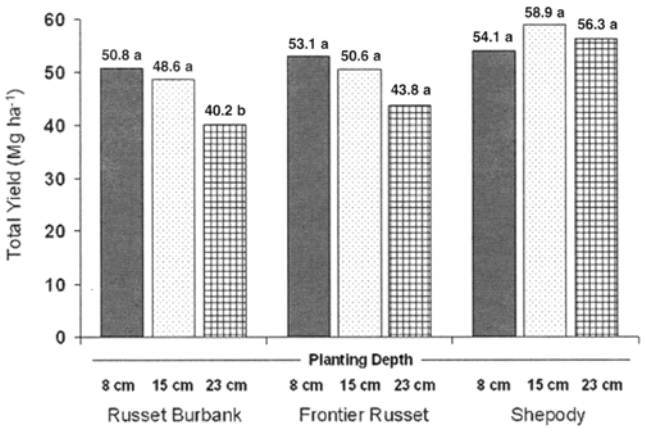

FIGURE 1.
Effect of planting depth on total yield averaged over years for Russet Burbank and Frontier Russet in 1995 to 1997 and Shepody in 1996 and 1997. Seedpiece depth was measured from top of hill to top of seedpiece. Numbers followed by the same letter within a cultivar are not significantly different at $P \leq .05$.

U.S. No. 1 yield of Russet Burbank was not significantly affected by planting depth (Figure 2). However, there was a trend for lower U.S. No. 1 yield at the 23-cm depth. Frontier Russet produced significantly less U.S. No. 1 yield at the 23-cm planting depth compared with the other two depths, and for Shepody the 8-cm planting depth caused a significant U.S. No. 1 yield reduction compared with the 15-cm depth.

Planting deeper did not affect the average tuber size of Russet Burbank and Frontier Russet, while the 15-cm planting depth resulted in a larger average tuber size for Shepody (Table 1). As planting depth increased from 8 to 23 cm, the average number of tubers per plant decreased for Russet Burbank and Frontier Russet, but planting depth did not affect average number of tubers per plant of Shepody.

For all three cultivars, planting at 23 cm resulted in the uppermost tuber being significantly deeper in the hill compared with the 8-cm planting depth, but only in Frontier Russet were there significant differences in distance to the uppermost tuber in the hill between all three planting depths (Table 1). The depth to the lowermost tuber in the hill approximated the seedpiece planting depth except for the 23-cm planting depth treatment, and each increase in planting depth resulted in a significant increase in depth of the lowermost tuber.

Although tubers were deeper in the hill, there was not a significant difference in field greening tuber yield between the 15- and 23-cm planting depths for the three cultivars (Figure 3). Planting at 8 cm resulted in a significantly higher field green-

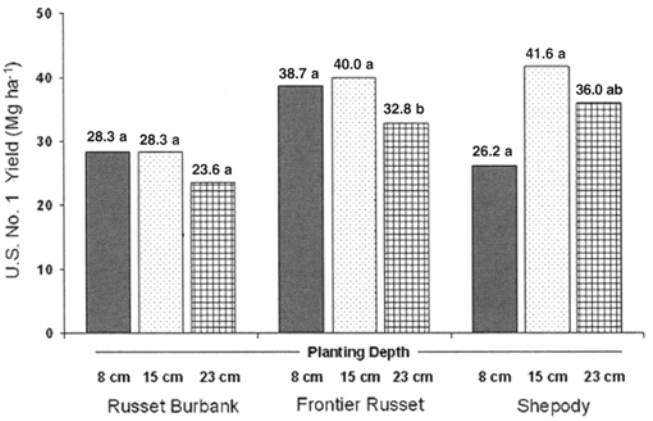

FIGURE 2.
Effect of planting depth on U.S. No. 1 yield averaged over years for Russet Burbank and Frontier Russet in 1995 to 1997 and Shepody in 1996 and 1997. Seedpiece depth measured from top of hill to top of seedpiece. Numbers followed by the same letter within a cultivar are not significantly different at $P \leq .05$.

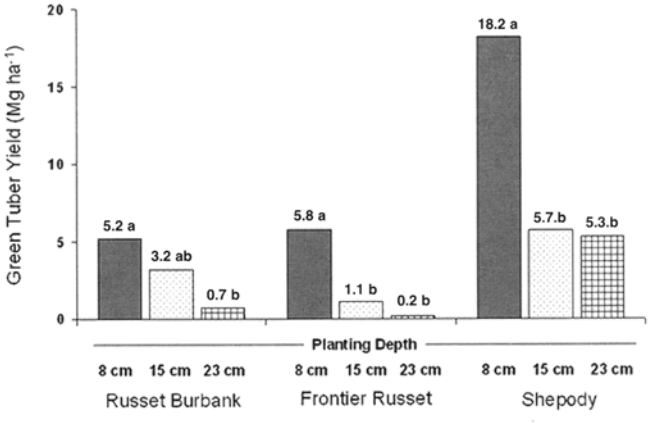

FIGURE 3.
Effect of planting depth on yield of green tubers averaged over years for Russet Burbank and Frontier Russet in 1995 to 1997 and Shepody in 1996 and 1997. Seedpiece depth measured from top of hill to top of seedpiece. Numbers followed by the same letter within a cultivar are not significantly different at $P \leq .05$.

ing tuber yield when compared to the 23-cm planting depth for Russet Burbank. For Frontier Russet and Shepody, the 8-cm planting depth resulted in significantly more field greening tuber yield compared to 15 and 23 cm.

Hilling Study

For Russet Burbank and Gem Russet, analysis of variance revealed significant treatment effects for days to 90% emergence, total yield, U.S. No. 1 yield, tuber depth, and tubers per plant. There were significant treatment effects for field greening tuber yield for Russet Burbank, but not for Gem Russet.

For both cultivars, it took significantly more days for 90% of the plants to emerge from the P8-H23 PE treatment in 1998 and 1999 than the non-hilled control or any other treatment (Table 2). In 2000, Russet Burbank plants in the P8-H15 treatment emerged significantly faster than all other treatments, but not significantly more rapidly than the control. There was no difference in rate of emergence for Gem Russet in 2000. Averaged over years, it took each cultivar longer for 90% of the plants to emerge from the P8-H23 PE treatment than any other treatment or the control.

At-emergence hilling treatments had no effect on total or U.S. No. 1 yields of Russet Burbank compared with the non-hilled control (Figures 4

TABLE 2—*Effect of planting depth and hilling depth and timing on days to 90% plant emergence of Russet Burbank and Gem Russet potatoes. Control = seedpieces planted at 15 cm and not hilled. P8-H15, P15-H23, and P8-H23 = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm at emergence, respectively. P8-H15 PE, P15-H23 PE, and P8-H23 PE = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm post-emergence after plants had formed a rosette of leaves approximately 10 cm in diameter, respectively. Seedpiece depth measured from top of hill to top of seedpiece.*

	DAP[2]			
Cultivar and Treatment	1998	1999	2000	Average
Russet Burbank				
Control	30 a[1]	28 a	33 ab	30 ab
P8-H15	30 a	30 a	30 a	30 a
P15-H23	29 a	30 a	38 bc	32 b
P8-H23	33 b	34 b	39 c	35 c
P8-H15 PE	34 b	39 c	40 c	37 c
P15-H23 PE	35 b	40 c	37 bc	37 c
P8-H23 PE	39 c	45 d	41 c	42 d
Gem Russet				
Control	31 a[1]	32 a	32 a	31 a
P8-H15	32 ab	32 a	33 a	32 a
P15-H23	35 c	37 b	40 a	37 b
P8-H23	35 c	40 b	38 a	38 b
P8-H15 PE	36 c	38 b	37 a	37 b
P15-H23 PE	35 bc	37 b	37 a	36 b
P8-H23 PE	40 d	46 c	34 a	40 c

[1]Numbers within a column within a cultivar followed by the same letter are not significantly different at $P \leq 0.05$.
[2]DAP = days after planting.

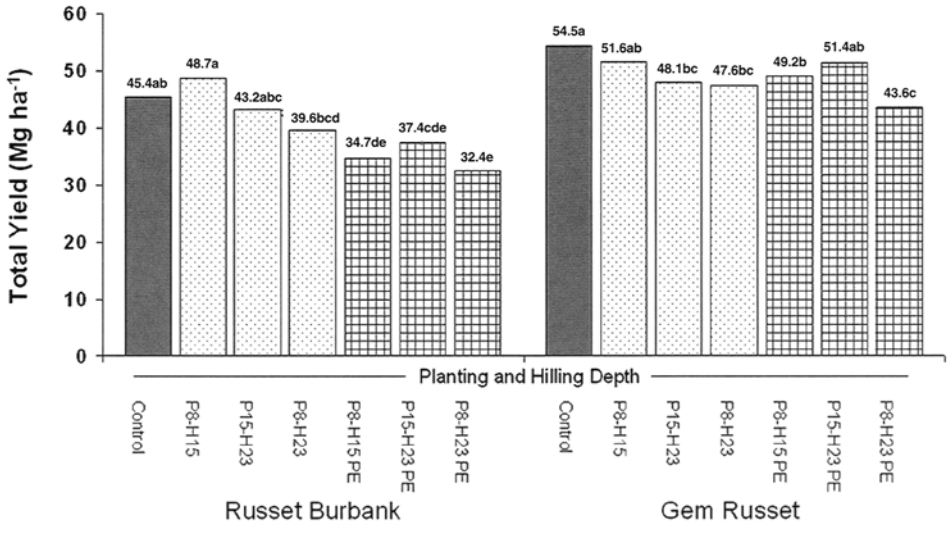

FIGURE 4.
Effect of planting depth and hilling depth and timing on total yield of Russet Burbank and Gem Russet potatoes averaged over three years. Control = seedpieces planted at 15 cm and not hilled. P8-H15, P15-H23, and P8-H23 = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm at emergence, respectively. P8-H15 PE, P15-H23 PE, and P8-H23 PE = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm post-emergence after plants had formed a rosette of leaves approximately 10 cm in diameter, respectively. Seedpiece depth measured from top of hill to top of seed piece. Numbers followed by the same letter within a cultivar are not significantly different at $P \leq .05$.

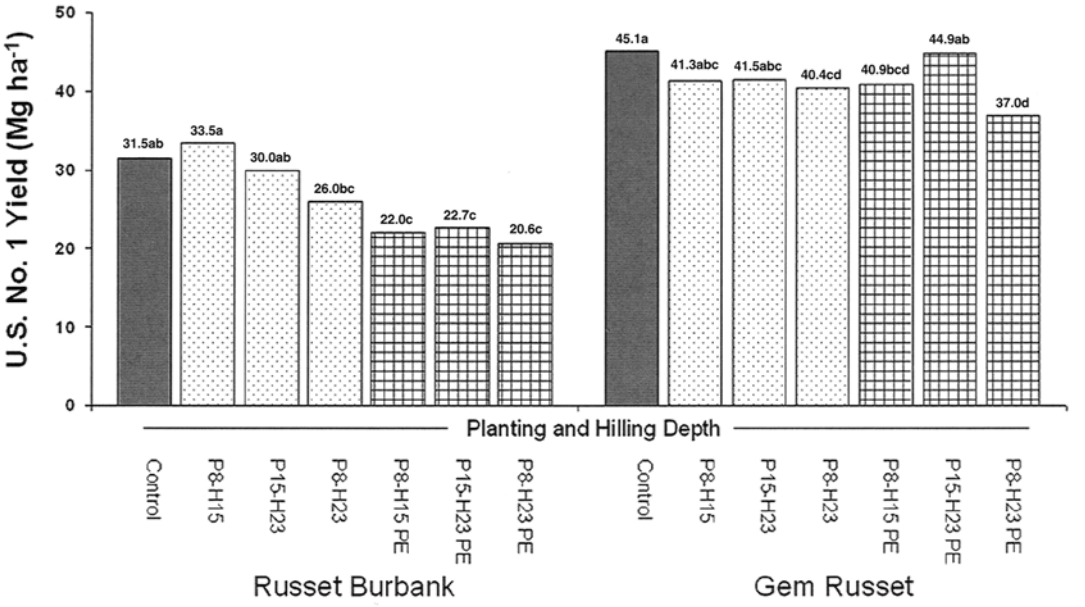

FIGURE 5.
Effect of planting depth and hilling depth and timing on U.S. No. 1 yield of Russet Burbank and Gem Russet potatoes averaged over three years. Control = seedpieces planted at 15 cm and not hilled. P8-H15, P15-H23, and P8-H23 = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm at emergence, respectively. P8-H15 PE, P15-H23 PE, and P8-H23 PE = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm post-emergence after plants had formed a rosette of leaves approximately 10 cm in diameter, respectively. Seedpiece depth measured from top of hill to top of seedpiece. Numbers followed by the same letter within a cultivar are not significantly different at $P \leq .05$.

and 5). In contrast, all post-emergence hilling treatments significantly reduced total and U.S. No. 1 yields compared with the control. The effect of hilling treatments on total and U.S. No. 1 yields of Gem Russet is less clearly delineated. All treatments except the P8-H15 and P15-H23 PE treatments had significantly lower total yield compared with the non-hilled control (Figure 4). The same two treatments (P8-H15 and P15-H23PE) as well as the P15-H23 treatment had no effect on U.S. No. 1 yield of Gem Russet (Figure 5).

No significant differences in average tuber size for either cultivar resulted from the treatments imposed. For both cultivars, all planting depth/hilling treatments except P8-H15 resulted in fewer tubers per plant compared with the control (Table 3).

For Russet Burbank, only the P15-H23 PE treatment significantly increased the depth to the uppermost tuber in the hill compared with the control (Table 3). For Gem Russet, all treatments except P8-H15 and P8-H15 PE had uppermost tubers significantly deeper in the hill than the control. For both cultivars, depth to the lowermost tubers in the hill was significantly increased compared to the control when final seedpiece depth was 23 cm regardless of initial planting depth or time of hilling (Table 3).

For Russet Burbank, the P8-H23, P15-H23 PE, and P8-H23 PE treatments significantly reduced field greening tuber yield compared with the control, but none of the planting depth/hilling treatments significantly reduced field greening tuber yield of Gem Russet (Figure 6).

DISCUSSION

Planting seedpieces at 23 cm vs 8 cm without hilling delayed emergence, and is in agreement with previous studies (Lorenz 1945; Moursi 1953). Collectively looking at the data for Russet Burbank from the depth study and hilling study, it can be seen that planting deeper delays emergence, and hilling at emergence or later will further delay emergence in some years. This delay in plant emergence is likely partially responsible for some of the yield reductions in our studies.

Lewis and Rowberry (1973) reported that hilling within 1 week of planting delayed emergence in both years of a two-year

TABLE 3—*Effect of planting depth and hilling depth and timing on average tuber size, average number of tubers per plant, and depth to uppermost and lowermost tuber in the hill of Russet Burbank and Gem Russet potatoes. Control = seedpieces planted at 15 cm and not hilled. P8-H15, P15-H23, and P8-H23 = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm at emergence, respectively. P8-H15 PE, P15-H23 PE, and P8-H23 PE = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm post-emergence after plants had formed a rosette of leaves approximately 10 cm in diameter, respectively. Seedpiece depth measured from top of hill to top of seedpiece.*

Cultivar and Treatment	Average Tuber Size g	Average No. Tubers per Plant	Depth of Uppermost Tuber cm	Depth of Lowermost Tuber cm
Russet Burbank				
Control	202 a[1]	5.5 a	4.2 abc	14.0 a
P8-H15	216 a	5.4 ab	2.3 a	12.8 a
P15-H23	225 a	4.6 bc	6.0 cd	16.7 b
P8-H23	204 a	4.6 bc	5.4 bcd	17.8 b
P8-H15 PE	185 a	4.4 c	3.3 ab	13.7 a
P15-H23 PE	202 a	4.5 c	7.5 d	18.3 b
P8-H23 PE	181 a	4.3 c	5.5 bcd	18.1 b
Gem Russet				
Control	199 a[1]	6.6 a	3.3 a	12.9 a
P8-H15	194 a	6.2 ab	3.7 a	13.0 a
P15-H23	214 a	5.2 de	6.5 bc	18.7 c
P8-H23	207 a	5.3 cde	7.7 c	19.4 c
P8-H15 PE	198 a	5.8 bcd	5.1 ab	14.8 ab
P15-H23 PE	203 a	5.9 bc	6.4 bc	15.9 b
P8-H23 PE	201 a	5.1 e	8.0 c	20.6 c

[1]Numbers within a column within a cultivar followed by the same letter are not significantly different at $P \leq 0.05$.

study for Kennebec, but only during one year for Sebago. We also found that cultivars respond differently to hilling each year. Days to 90% emergence of Russet Burbank was delayed by at least one or more of the planting depth/hilling treatments in the hilling study in all three years of our study, whereas hilling had no effect on emergence of Gem Russet in the third year in 2000. Additionally for Russet Burbank, increasing planting depth increased the days to 100% emergence. Producers concerned about rapid emergence should realize that with each incremental increase in planting depth, there is an associated increase in time for emergence, and hilling can further delay final emergence of the crop.

Planting Russet Burbank and Frontier Russet at 23 cm resulted in significantly lower total yield than the 8- and 15-cm planting depths, and is in agreement with Lorenz (1945) who reported that total yield of 'White Rose' was significantly reduced when planted at 23 cm compared with 15 cm in a sandy loam soil. Effects of planting depth, however, can be cultivar specific as can be seen in our study where total yield of Shepody was not affected by

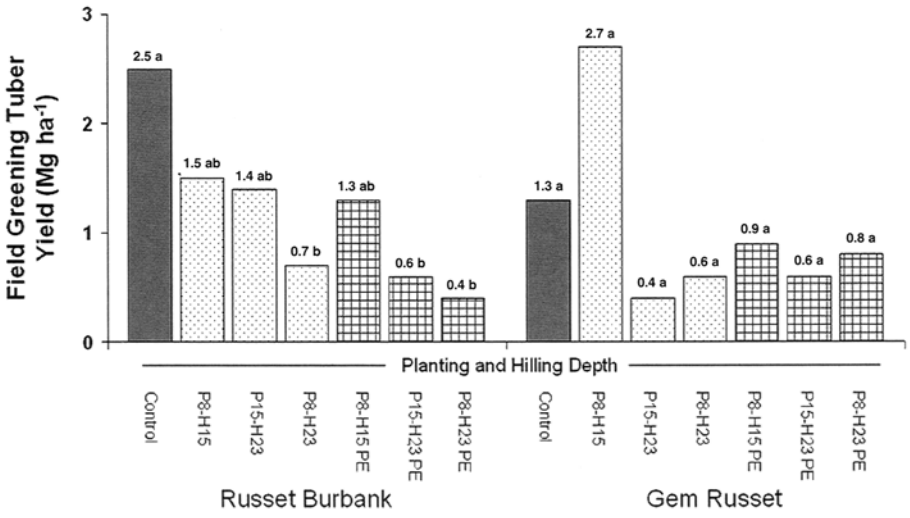

FIGURE 6.
Effect of planting depth, and hilling depth and timing on field greening tuber yield of Russet Burbank and Gem Russet potatoes averaged over three years. Control = seedpieces planted at 15 cm and not hilled. P8-H15, P15-H23, and P8-H23 = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm at emergence, respectively. P8-H15 PE, P15-H23 PE, and P8-H23 PE = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm post-emergence after plants had formed a rosette of leaves approximately 10 cm in diameter, respectively. Seedpiece depth measured from top of hill to top of seedpiece. Numbers followed by the same letter within a cultivar are not significantly different at $P \leq .05$.

planting depth. Additionally, in our depth study U.S. No. 1 yield was also cultivar dependent. Russet Burbank had equal U.S. No. 1 yields at 8, 15, or 23 cm. Frontier Russet had significantly more U.S. No. 1 yield at 8 and 15 cm than at the 23-cm planting depth, while Shepody had more U.S. No. 1 yield at the 15-cm planting depth compared to the 8-cm depth.

Close examination of the data shows that significant effects on total yield due to planting depth for Russet Burbank, Frontier Russet, and Shepody cannot be attributed only to delayed emergence, but also, depending on cultivar, to effects on average tuber size and tubers per plant. For Russet Burbank, a lower total yield can be explained mainly by a lower number of tubers per plant as planting depth increased. For Frontier Russet, there was a trend ($P > F = .07$) for a larger average tuber size as planting depth increased, but this was offset by a reduction of 2.2 tubers per plant as planting depth increased from 8 to 23 cm resulting in a significantly lower total yield. The total yield of Shepody was not affected because as average tuber size increased, there was a trend ($P > F = .15$) for the number of tubers per plant to decrease. Consequently, even though there was a significantly higher average tuber size at the 15-cm planting depth, there was approximately one less tuber per plant at the 15-cm depth compared with the 8- and 23-cm planting depths.

Effect of planting depth/hilling on yield was also cultivar dependent. At-emergence hilling had non-significant or only a slight effect on total and U.S. No 1 yields of Russet Burbank and Gem Russet. However, post-emergence hilling of Russet Burbank caused total yield to decrease approximately 23%, whereas total yield in Gem Russet was only decreased an average of about 12%. The effect of post-emergence hilling on U.S. No. 1 yield of Russet Burbank was even more dramatic. U.S. No. 1 yield of Russet Burbank was decreased approximately 31% compared with the non-hilled control, but post-emergence hilling reduced U.S. No. 1 yield of Gem Russet only about 9% compared with the non-hilled control. Clearly, these two cultivars respond differently to completely covering plants with soil in a post-emergence hilling operation.

When comparing 10- and 15-cm planting depths of Kennebec potatoes, Mosley (1975b) was able to show a significant decrease in green tuber yield without affecting total or U.S. No. 1 yields. Similarly, our depth study showed a significant decrease in field greening tuber yield without affecting total or U.S. No. 1 yields of Frontier Russet when comparing a planting depth of 8 vs 15 cm. Total and U.S. No. 1 yields of Russet Burbank were also not affected when comparing planting depths of 8 vs 15 cm, but the 15-cm planting depth did not significantly reduce field greening tuber yield. This indicates that the effect of planting depth on yield and field greening tuber yield depends on the cultivar.

A commonly used planting depth in Idaho and many potato-producing areas is approximately 15 cm. For the three cultivars used in the depth study, planting deeper than 15 cm resulted in a significant increase in depth to the uppermost tuber in the hill. Although tubers were deeper in the hill, there was not a significant difference in field greening tuber yield

TABLE 4—*Relative effects of planting depth and hilling depth and timing on total yield, U.S. No. 1 yield, depth of uppermost tuber in the hill, and field greening tuber yield compared with the control. Control = seedpieces planted at 15 cm and not hilled. P8-H15, P15-H23, and P8-H23 = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm at emergence, respectively. P8-H15 PE, P15-H23 PE, and P8-H23 PE = seedpieces planted at 8, 15, and 8 cm and hilled to 15, 23, and 23 cm post-emergence after plants had formed a rosette of leaves approximately 10 cm in diameter, respectively. Seedpiece depth measured from top of hill to top of seedpiece.*[1]

Cultivar and Treatment	Total Yield	U.S. No. 1 Yield	Depth of Uppermost Tuber	Green Tuber Yield
Russet Burbank				
P8-H15	NC	NC	NC	NC
P15-H23	NC	NC	NC	NC
P8-H23	NC	NC	NC	,
P8-H15 PE	,	,	NC	NC
P15-H23 PE	,	,	·	,
P8-H23 PE	,	,	NC	,
Gem Russet				
P8-H15	NC	NC	NC	NC
P15-H23	,	NC	·	NC
P8-H23	,	,	·	NC
P8-H15 PE	,	,	NC	NC
P15-H23 PE	NC	NC	·	NC
P8-H23 PE	,	,	·	NC

[1]NC = no change, · = significant increase, , = significant decrease compared with control.

between the 15- and 23-cm planting depths. Consequently, the amount of green tubers does not appear to be solely dependent on tuber depth, and may also be influenced by hill shape, soil type, stolon length, or other factors.

Exploring the effects of planting depth/hilling further, the P8-H23 treatment in the hilling study significantly decreased field greening tuber yield of Russet Burbank by about 72% compared with the control (2.5 Mg ha^{-1} vs 0.7 Mg ha^{-1}). From a production standpoint and looking only at the effects of this treatment on reducing field greening tuber yield, planting seedpieces 8 cm deep and hilling at emergence to 23 cm appears to be a suitable practice to use because total and U.S. No. 1 yields were not significantly reduced. However, total yield and U.S. No. 1 yield did trend downward by 5.8 and 5.5 Mg ha^{-1}, respectively, as a result of the P8-H23 treatment. This yield decrease may be at least partially caused by adding a considerable amount of soil (8 cm) to the top of the hill. In a separate one-year study not reported here, a mechanical hilling-machine similar to what producers use was not able to add more than approximately 3 to 5 cm of soil to the top of a hill. Therefore, it is unlikely that a producer could build a 23-cm hill even if such a hill was desired.

The effect of planting depth and hilling practices (hilling study) on total and U.S. No. 1 yields, depth to uppermost tuber, and field greening tuber yield are summarized in Table 4. For Russet Burbank, note that only the P8-H23 treatment decreased field greening tuber yield without also significantly decreasing total and U.S. No. 1 yields. No hilling treatments significantly reduced field greening tuber yield of Gem Russet, although four of the six treatments increased the average depth to the uppermost tuber in the hill. Furthermore, results from the depth study show that tubers will set deeper in the hill as planting depth is increased.

CONCLUSIONS

Data from the depth study and hilling study would suggest that planting depth in combination with hilling practices beyond what is typical in commercial potato production cannot be utilized to significantly decrease field greening tuber yield without also affecting total and U.S. No. 1 yields. Precisely planting to a depth of 15 cm is an effective method for minimizing green tubers without compromising yield, but this can also be cultivar dependent. Further research needs to be conducted to determine if hill shape has a significant effect on minimizing field greening tuber yield. Additionally, such factors as tuber growth characteristics and stolon length of cultivars needs to be studied to determine the best hill height and shape to minimize field greening tuber yield without sacrificing total or U.S. No. 1 yields.

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