Tillage and Seed-Sprouting Strategies to Improve Potato Yield and Quality in Short Season Climates

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ABSTRACT

Management practices that accelerate crop development and allow earlier harvest would be beneficial in short-season potato (*Solanum tuberosum* L.) production areas. Yield and quality of the potato cultivar 'Russet Burbank' were evaluated in a 2-yr study in northern Maine to determine effects of soil tillage and seed-sprouting treatments designed to dry soil early in the spring and hasten seed emergence. The tillage treatments, consisting of fall raised bed (RB), fall ridge till (RT), and spring chisel plow (CH), were tested in combination with green-sprouted and non-sprouted seed tubers on a Caribou gravelly loam (coarse-loamy, mixed, frigid, *Typic Haplorthod*). Plants from green-sprouted seed emerged earlier than from non-sprouted seed tubers (87%-96% vs 21%-37%, respectively, at 18 days after planting [DAP] in 2000; and 73%–88% vs 18%-23%, respectively, at 20 DAP in 2001). Green-sprouted seed tubers in RB yielded 4.6 to 5.9 T ha^{-1} more than non-sprouted seed tubers in RB. However, non-sprouted seed tubers yielded higher than green-sprouted seed tubers in RT by 2.9 to 4.2 T ha^{-1} and in CH by 1.1 to 4.1 T ha^{-1}. Similarly, green-sprouted seed tubers in RB and non-sprouted seed tubers in RT and CH produced higher marketable yield, greater tuber length, and greater tuber diameter than the corresponding seed-sprouting treatment. In the comparatively wetter year (2000), the use of green-sprouted seed tubers in RB significantly increased total and marketable yields, and produced longer and larger tubers than all other treatments. However, in 2001 (relatively dry year), yield and quality from green-sprouted seed tubers in RB did not differ from non-sprouted seed in RT or CH. Green-sprouted seed produced fewer sunburned and rotten tubers, but more misshapen tubers than non-sprouted seed in RB tillage. The technique of producing Russet Burbank potatoes in raised beds is a promising system in regions with short growing seasons for enhancing early soil drainage during spring and improving soil water retention during critical periods of crop growth and development.

RESUMEN

Las prácticas de manejo que aceleran el desarrollo del cultivo y permiten una cosecha temprana serían beneficiosas en las áreas de producción de papa (*Solanum tuberosum* L.) de ciclo corto. Se evaluó el rendimiento y calidad del cultivar de papa 'Russet Burbank', en un estudio de dos años en el norte de Maine para determinar los efectos del tipo de labranza, y de brotamiento diseñados para suelo seco en primavera y para acelerar la emergencia. Los tratamientos de labranza consistieron en: a) camellones levantados con superficie plana y mas ancha que lo acostumbrado, construidos en el otoño (RB), camellones estándar hechos con cultivadora construidos en el invierno (RT) y camellones estándar hechos con un implemento llamado "chisel plow" construídos en la primavera antes de la siembra (CH). Estos tratamientos fueron probados en combinación con el uso de semilla de tubérculos con brotes verdes y semilla no brotada, en suelos arcillo-arenosos tipo Caribou (mezcla arcilla y arena gruesa, glacial, *Hoplorthod típico*). Las plantas provenientes de tubérculos brotados emergieron antes que las de tubérculos no brotados (87%-96% vs 21%-37% respectivamente, 18 días después de la siembra [DAP], en el 2000 y 73%-88%

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vs 18%–23% respectivamente a los 20 días después de la siembra en el 2001). Semilla brotada en RB rindió 4.6 a 5.9 ton/ha^{-1} más que la semilla no brotada. Sin embargo, semilla no brotada rindió 2.9 a 4.2 ton/ha^{-1} más que la semilla brotada en RT. Similarmente, semilla brotada en RB y no brotada en RT y CH produjo mayor rendimiento comercial, tubérculos más alargados y mayor diámetro de tubérculo que el correspondiente tratamiento con semilla brotada. En el año comparativamente más húmedo (2000), el uso de semilla brotada en RB incrementó significativamente el rendimiento total y comercial y produjo tubérculos más largos y más grandes que en los otros tratamientos. Sin embargo, en el año 2001 (relativamente año seco), el rendimiento y calidad de la semilla brotada en RB no se diferenció de la de semilla no brotada en RT o CH. La semilla brotada produjo menos tubérculos dañados por el sol y menos podridos, pero más tubérculos deformes que los de semilla no brotada en RB. La técnica de producir papas Russet Burbank en camellones levantados es un sistema prometedor en regiones con período corto de cultivo, por que intensifica el drenaje temprano del suelo durante la primavera y mejora la retención de agua del suelo durante los períodos críticos de crecimiento y desarrollo del cultivo.

INTRODUCTION

The northern United States is characterized by a relatively short growing season, causing fluctuations in both supply and quality of potatoes (*Solanum tuberosum* L.). Soil temperatures in northern climates are often too low at planting to optimize emergence and early plant growth (Radke 1982). Reports suggest that ridge tillage in the fall may increase soil temperature early in the growing season (Radke 1982) and accelerate crop emergence (Rathore et al. 1983).

Soil surface configuration such as ridge tillage and raised beds may also allow manipulation of soil water content (Papendick et al. 1976). Raised bed and ridge till technology can not only overcome the constraints of waterlogging (Van Cooten and Borrell 1999), but can also capture and store water in the furrows during periods of low rainfall (Borrell et al. 1998). Radke (1982) reported fastest drying rates in ridged soils. Borrell et al. (1998) obtained higher crop yields by planting early into raised beds compared to ridged soils, thereby mitigating the effects of end-of-season drought. These studies indicate the potential for earlier planting and harvesting of potatoes grown in raised beds and ridges.

Other benefits of ridge tillage have also been reported. Soil and nutrient losses are reported to be as much as 68% less under ridge tillage than conventional tillage (Romkens et al. 1973; Felsot et al. 1990). Ridge tillage has also been shown to control/suppress plant pathogens (Thurston and Schultz 1981; Lumsden et al. 1987).

Few studies have examined the use of raised beds for potato production. Fall-formed raised beds can reduce soil resistance to root and tuber penetration, promote deep rooting, and reduce water stress injury during periods of inadequate rainfall (Miller and Martin 1987). Kouwenhover (1970) observed increased yield, increased tuber size, decreased tuber dispersion and fewer green potatoes in raised beds. He attributed these observations to higher soil water content. Morse (1998) and Fisher et al. (1995) concluded that yield enhancement in raised beds (vs conventional tillage) also resulted from improved drainage. Prestt and Carr (1984) reported that a flat-top raised bed conserved more water than a sharply sloped ridge, and hastened potato seedpiece emergence by 4-5 d. Also, soil water was more evenly distributed through the flat-topped raised bed, and the soil surface was more conducive to infiltration. In sharply sloped ridges, dry areas tended to form beneath the sides of the ridges, and the steep sides encouraged runoff.

Green-sprouting (chitting, pre-sprouting or sprouting) of seed potatoes involves exposing seed tubers to natural or artificial light in a warm environment before planting to allow tubers to develop short, strong, green sprouts. Growth begins almost immediately after such tubers are planted because green-sprouting increases the physiological age of the seed tuber (Munster 1975). Consequently, green-sprouting can result in more rapid plant development, earlier tuber initiation, less foliage and earlier senescence than non-sprouted seed (O'Brien et al. 1983; Moll 1985). Thus, green-sprouting would have significant potential benefits for long-season cultivars produced in short growing seasons (Perennec and Madac 1980; O'Brien et al. 1983; Iritani and Thornton 1984; Knowles and Botar 1991). Although green-sprouting can increase yields at early harvest, yield can be reduced at later harvest owing to differences in physiological status in relation to prevailing moisture and light conditions (O'Brien et al.1983; Knowles and Botar 1991). Absence of moisture stress can minimize the effects of age on leaf area index and yield. Unfavorable weather conditions at emergence will increase the effect of physiological age on final yield, possibly causing "little potato" (stunting) in physiologically older seed tubers. However, despite favorable reports, green-sprouting is rarely practiced in North America (Collins 1977; Saunders 1979; Mikitzel and Wattie 2000).

Russet Burbank is widely grown in the northeastern U.S. The characteristic late maturity of this variety, coupled with the relatively short Northeast growing season, may often limit tuber yield. Hence, any treatment that accelerates the production cycle of potatoes may permit the crop to utilize a shorter growing season more efficiently. This present study was conducted (i) to determine if green-sprouted seed tubers planted in raised beds or ridges could promote early sprout emergence and increase total and marketable yields and (ii) to evaluate Russet Burbank tuber quality response to green-sprouted seed tubers planted in fall-formed raised beds and fall-formed ridges as compared to spring chisel plow, as conventionally practiced.

MATERIALS AND METHODS

Site Description

The experiment was conducted at the USDA-ARS experimental farm at Presque Isle, ME, (68° W, 46° 40' N, and 190-m altitude) during the 2000 and 2001 growing seasons, under non-irrigated conditions. Both trials were conducted on the same plot of land. Meteorological data for the periods of the experiment are shown in Figure 1. The soil is classified as a Caribou gravely loam (coarse-loamy, mixed, frigid, *Typic Haplorthod*) with 4.0% organic matter, pH 6.0 and 2%-8% slope. The site was previously under oats (*Avena sativa* L.) and barley (*Hordeum vulgare* L.).

Cultural Practices and Treatments

All plots were cleared of previous vegetation by chisel plow tillage in the fall of 1999. The experiment was conducted using a split-plot, randomized complete block design (RCBD) with four replications. Tillage treatments were the main plots, each measuring 3.6 m wide by 18 m long. The tillage treatments were (i) fall raised bed, (ii) fall ridge till, and (iii) spring chisel plow. Subplots, 3.6 m wide by 9 m long, consisted of preplant seed management within the main plots. The two subplot treatments were (i) green-sprouted seed and (ii) non-sprouted seed. Spacing between rows was 90 cm for all treatments.

Raised beds were constructed in chisel-plowed soil using a raised bed implement (Ferguson Manufacturing Co., Suffolk, Virginia)[1] that formed flat-topped beds approximately 22 cm high and 60 cm wide at the top. Ridges were made using a tractor-mounted cultivator (High Residue cultivator, SUKUP Manufacturing CO., Sheffield, Iowa)[1] that formed ridges 30-cm high, and about 25 cm wide at the base. Rows were made in the chisel plow treatment only at hilling (started 5 wk after planting). Hills were 30 cm high and 25 cm wide at the base, and were made using a tractor-mounted cultivator.

Russet Burbank certified seed tubers were divided into two lots. One lot was kept in storage in darkness at a temper-

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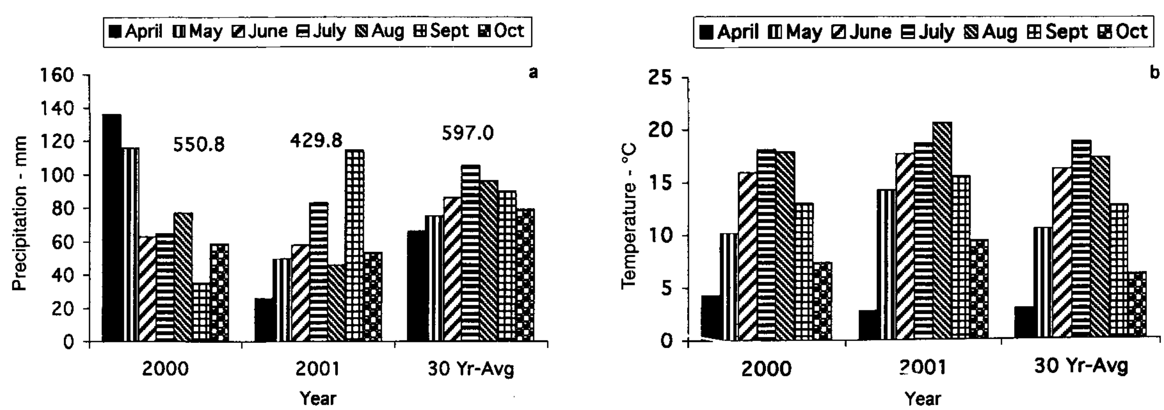

FIGURE 1.
Monthly (a) precipitation and (b) temperature in 2000, 2001 and their respective 30-yr average.

ature of 4 C and the other lot was green-sprouted by putting the seed tubers on flat benches one layer deep in a greenhouse equipped with cool white fluorescent lamps, for 3 wk before planting. Room temperature was controlled at 15 C with relative humidity of approximately 85%.

Volumetric water content at 5 and 15 cm depths beneath the ridge peak, raised bed surface, or chisel plow soil surface was measured continuously with reflectometers (Campbell Scientific Inc., Logan, Utah)[1]. Soil temperature was measured at 5, 10, 15, and 20 cm depths beneath the top of the ridge, raised bed, or chisel plow soil surface using thermocouples. The sensors were connected directly to a Campbell Scientific CR10X datalogger (Campbell Scientific Inc., Logan, Utah)[1], which collected and stored data points every hour.

Potato seedpieces (cv Russet Burbank) were hand cut to an average weight ranging from 70 to 80 g per seedpiece and planted one day later on 1 June 2000 and 17 May 2001. These planting dates are typical for northern Maine. Seedpieces were planted at 5 to 7 cm below the soil surface. The average seedpiece spacing within the row was 35 cm. Compound fertilizer N-P-K (10-10-10) at the rate of 2.2 T ha^{-1} was applied at planting approximately 3 cm below and 6 cm on each side of the seedpiece using a four-row fertilizer applicator that did not destroy the shape of the beds or ridges.

Pest control measures were selected from those typically recommended by The University of Maine Cooperative Extension. Metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylbio)-1,2,4-triazin-5(4H)-one] was broadcast sprayed at the rate of 1.1 kg a.i. ha^{-1} soon after planting for preemergence weed control. All plots were hilled three times during the growing season (5, 7, and 8 weeks after planting), with the same equipment used to form the hills initially. Vines were sprayed 10 days before harvest with Reglone[1] diquat desiccant [(6,7-dihydrodipyrido (1,2-a:2',1'-c) pyrazinediium dibromide] at a rate of 0.8 kg a.i. ha^{-1}. A 6-m section of the two center rows of each plot was harvested by hand on 26 October 2000 and 11 October 2001, for yield and quality determination.

Plant Stand, Yield and Tuber Quality

Plant stands were counted approximately every 2 days for 4 to 5 wk, beginning 19 June 2000 and 7 June 2001. All tubers harvested by hand after vine killing from a 6-m section of the two middle rows were weighed in the field. Tubers from each subplot were graded for external and internal defects (sunburn, misshapen, decay, growth cracks, hollow heart), tuber weight, length, and diameter. Tubers were separated into various distribution groups based on weight (<113.5 g, 113.5-227.0 g, 227.0-340.5 g, 340.5-454.0 g, >454.0 g), length (<7.5 cm, 7.5-8.7 cm, >8.7 cm), and diameter (<5 cm, >5 cm but <285 g, >5 cm and >285 g). Length and diameter were measured on all tubers harvested. Ten large (340.5-454.0 g) tubers per sample were taken for hollow heart evaluation. Specific gravity was measured with the weight-in-air/weight-in-water method.

Statistical Analysis

All data were subjected to analysis of variance to test for main effects and interactions between tillage and seed-sprouting treatments. When significant interaction effects were detected, the proc mixed procedure in SAS (1999:42-47) was used to analyze the data to estimate differences between treatment means.

RESULTS AND DISCUSSION

Weather Conditions

Precipitation during the growing season was 92% and 72% of the long term (30-yr) average in 2000 and 2001, respectively (Figure 1a). Rainfall distribution was distinctly different between the two years. Average precipitation in April, May, and August, was lower in 2001 than 2000. April and May of 2000 were unusually wet, as was September of 2001. Temperatures in 2000 were generally near average, while those in 2001 were warmer than average (Figure 1b). These data indicate that the tillage and seed-sprouting strategies used were evaluated across a considerable range in weather conditions.

Soil Water

Raised beds dried faster at the 5-cm depth than ridge and chisel treatments (Figure 2a) prior to planting in 2000 when rainfall was 46% above average (Figure 1a). From planting (June 1) to early plant establishment (June-July 2000), raised beds retained more water at the 5-cm depth (22% to 27%) than ridge and chisel plow treatments (10% to 15%). Raised beds also retained more water at the 15-cm depth during the spring of 2000 (Figure 2b). In the dry spring of 2001 (average rainfall in April and May was 51% below average), raised bed and chisel plow treatments retained more water in the upper 5 cm

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until planting (Figure 3a). At planting (17 May 2001) raised beds had slightly more water (20%) than ridge and chisel plow treatments (17%) at the 15-cm depth (Figure 3b). From tuber formation through tuber bulking (mid-July until vine kill), raised beds generally retained more water (13% to 23% at 5 cm and 10% to 23% at 15 cm) than ridge and chisel plow (5% to 15% at 5 cm and 10% to 15% at 15 cm) in the dry year of 2001 (Figure 3). These data show that raised beds drained more water during periods of high water supply (April 2000), but retained more water at the critical period of tuber bulking during the drought year of 2001. Similar observations have been made by Prestt and Carr (1984) and Fisher et al. (1995) who reported that flat-topped beds conserved more water than sharply sloped ridges, that water was more evenly distributed throughout flat-topped beds, and the soil surface of beds was more conducive to infiltration. The lack of soil water recharge with ridge and chisel plow resulted in a distinct soil water deficit at critical periods of crop growth and development, as observed by Robinson (1999). This was observed in the upper 5 cm of ridge and chisel plow during early plant growth and establishment in 2000, and during tuber bulking in 2001. The observed moisture deficits in ridge and chisel plow treatments suggest water ran off the ridges and into the lowest point of the furrow.

Robinson (1999) reported two causes for this: the first being the slope of the ridges and water repellent nature of the soil, and the second being the rate at which rain fell on the ridges. Saffigna et al. (1976) and Curwen and Massie (1984) felt that redirecting water into furrows is likely to be exacerbated as the crop grows. The crop canopy may act like an umbrella, causing rain to be distributed into the furrows. The flat, wide surface of raised beds allows more water to be captured and held on the soil surface, providing greater opportunity for infiltration (Prestt and Carr 1984). We considered that raised beds exerted the same influence in our study.

Differences in soil temperature within the growing season were not observed across the three tillage treatments and these data are not presented.

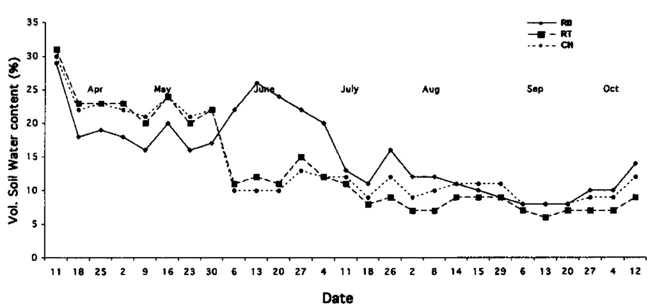

FIGURE 2a.
Volumetric soil water content (5 cm) for the raised bed (RB), ridge tillage (RT) and chisel plow (CH) tillage systems in 2000.

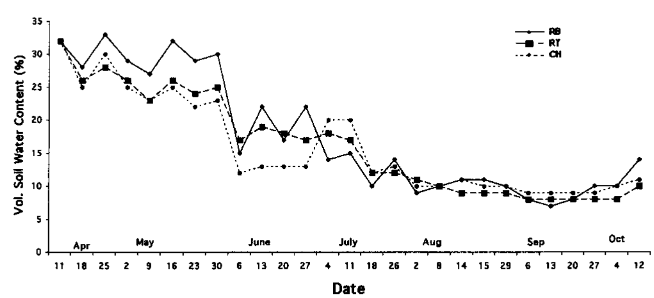

FIGURE 2b.
Volumetric soil water content (15 cm) for the raised bed (RB), ridge tillage (RT) and chisel plow (CH) tillage systems in 2000.

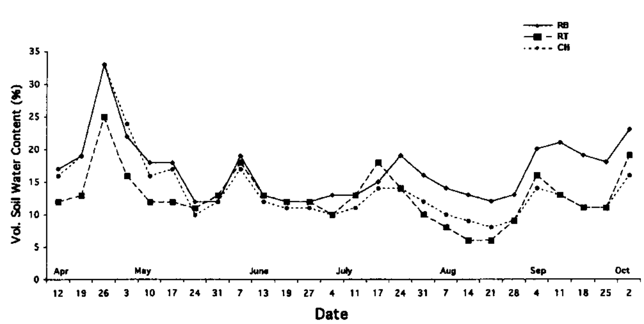

FIGURE 3a.
Volumetric soil water content at (5 cm) for the raised bed (RB), ridge tillage (RT) and chisel plow (CH) tillage systems in 2001.

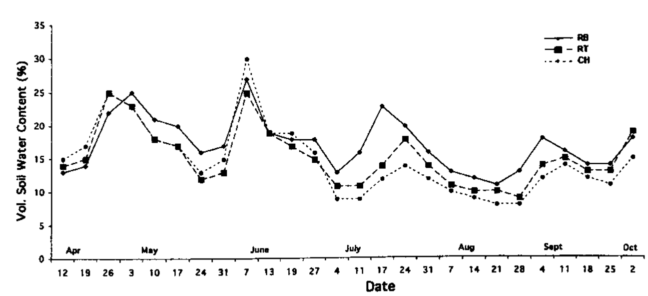

FIGURE 3b.
Volumetric soil water content at (15 cm) for the raised bed (RB), ridge tillage (RT) and chisel plow (CH) tillage systems in 2001.

Plant Emergence

Seed-sprouting affected plant emergence. Within tillage treatments in both study years, shoots from green-sprouted seed tubers emerged earlier than from non-sprouted seed tubers. At 18 days after planting (DAP), between 87% and 96% of all plants from green-sprouted seed had emerged, compared to 21% to 37% for non-sprouted seed in 2000, and it was not until 27 DAP that plant stands in non-sprouted treatments reached emergence equal to green-sprouted treatments (Figure 4a). In the drier year of 2001, between 73% and 88% of the green-sprouted treatments had emerged at 20 DAP, compared to 18% to 23% for non-sprouted treatments, and it was not until 24 DAP that non-sprouted treatments reached emergence equal to green-sprouted treatments (Figure 4b). Other researchers (Knowles and Botar 1991, 1992; Mckeown 1994; Mikitzel and Wattie 2000) have reported similar results.

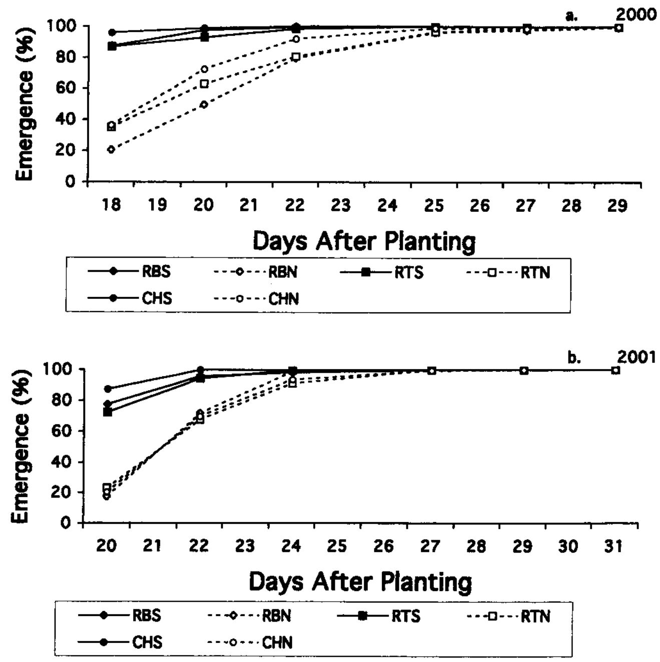

FIGURE 4.
Plant emergence vs days after planting, as influenced by tillage and seed sprouting in (a) 2000 and (b) 2001. RB = Raised Bed; RT = Ridge Tillage; CH = Chisel Plow Tillage; S = Green-sprouted; N = Non-sprouted.

Total and Marketable Yields

Tillage and seed-sprouting had significant interaction effects on total and marketable yield. In raised beds, green-sprouting increased total tuber yield over non-sprouted seed by 4.6 Mg ha^{-1} (14%) in 2000, and by 5.9 Mg ha^{-1} (24%) in 2001 (Table 1). However, highest yields in ridge and chisel treatments were observed with non-sprouted seed. Similarly, green-sprouting increased marketable yield (tubers >113.5 g) by 4.6 Mg ha^{-1} (23%) in 2000, but non-significantly in 2001 (Table1). Non-sprouted seed in ridge and chisel plow treatments increased marketable yield by 8% and 6%, respectively, in 2000, and by 32% and 26%, respectively, in 2001 compared to sprouted seed. Increased marketable yield with non-sprouted seed in ridge and chisel plow treatments was most expressed in the 113.5-340.5 g distribution class. In 2001 when average rainfall in April and May was 51% below average and total rainfall was 28% below average, no treatment produced tubers weighing >454.0 g. However, in 2000, when rainfall in April and May was 46% above average, green-sprouted seed in raised beds produced more tubers in the >454.0 g weight class.

Tuber Length

In raised beds, green-sprouted seed produced 4.1 Mg ha^{-1} (28%) more tubers >8.7 cm (3.5 in.) long in 2000, and 4.4 Mg ha^{-1} (45%) more in 2001, compared to non-sprouted seed (Table 2). No difference was observed between green- and non-sprouted seed in ridge and chisel plow treatments for tubers >8.7 cm long. For tubers >7.5-cm (3 in.) long, green-sprouted seed in raised beds produced 3.2 Mg ha^{-1} (14%) more in 2000, and 4.5 Mg ha^{-1} (26%) more in 2001, than non-sprouted seed in raised beds. Non-sprouted seed in ridge and chisel plow produced significantly more tubers >7.5 cm long than green-sprouted seed for the same tillage treatment in 2000. These data suggest that the greater water supply in raised beds during tuber bulking enabled green-sprouted seed tubers to produce longer tubers than non-sprouted treatments.

Tuber Diameter/Weight

Green-sprouted seed in raised beds produced tubers with a larger diameter (>5-cm and >284 g) than non-sprouted seed in 2000 and 2001 (Table 3). Non-sprouted seed in ridge and chisel plow treatments produced more tubers with diameters >5-cm than green-sprouted seed in the corresponding tillage treatment. This primarily arose from the production of larger diameter tubers that weighed <284 g (Table 3).

External and Internal Defects

Less sunburn was observed for green-sprouted than non-sprouted seed in raised beds in 2000, but not in 2001 (Figure 5). The percentage of sunburn was less in green-sprouted treat-

TABLE 1—*Total and marketable yield, and tuber size distribution of Russet Burbank planted in three tillage systems with green-sprouted and non-sprouted seed in 2000 and 2001.*

Treatment	Total Yield	Marketable Yield	< 113.5 g	113.5 - 227.0 g	227.0 - 340.5 g	340.5 - 454.0 g	> 454.0 g
			Mg ha^{-1}				
			2000				
Raised Bed/Green-sprout	38.6 *a*[1]	24.3 *a*	14.4 *b*	17.7 *a*	4.5 *b*	1.7 *a*	0.4 *a*
Raised Bed/Non-sprout	34.0 *d*	19.7 *d*	14.3 *b*	17.6 *a*	2.0 *d*	0.1 *d*	0.0 *d*
Ridge/Green-sprout	34.5 *d*	19.9 *d*	14.6 *b*	15.5 d	3.4 *c*	1.1 *b*	0.0 *d*
Ridge/Non-sprout	37.4 *b*	21.4 *c*	16.0 *a*	16.9 bc	3.3 *c*	1.1 *b*	0.1 *c*
Chisel Plow/Green-sprout	35.6 *c*	21.8 *c*	13.8 *b*	16.7 c	4.5 *b*	0.5 *c*	0.1 *c*
Chisel Plow/Non-sprout	36.7 *b*	23.1 *b*	13.7 *b*	17.4 ab	4.9 *a*	0.6 *c*	0.2 *b*
CV (%)	1.2	2.3	4.6	2.1	5.5	9.7	4.1
			2001				
Raised Bed/Green-sprout	30.9 *a*	14.8 *abc*	15.9 *a*	12.6 *bc*	1.9 *b*	0.3 *a*	0
Raised Bed/Non-sprout	25.0 *c*	11.7 *c*	12.6 *b*	11.0 *c*	0.7 *d*	0.1 *c*	0
Ridge/Green-sprout	26.4 *c*	12.5 *c*	13.5 *b*	10.7 *cd*	1.6 *c*	0.2 *b*	0
Ridge/Non-sprout	30.6 *ab*	16.5 *ab*	13.2 *b*	14.6 *a*	1.7 *bc*	0.3 *a*	0
Chisel Plow/Green-sprout	28.0 *bc*	13.6 *bc*	13.5 *b*	11.6 *cd*	1.8 *bc*	0.2 *b*	0
Chisel Plow/Non-sprout	32.1 *a*	17.2 *a*	13.7 *b*	14.0 *ab*	2.9 *a*	0.3 *a*	0
CV (%)	6.7	14.7	5.8	9.2	9.5	20	0

[1] Means in the same column bearing the same letters are not significantly different within a given year at the 0.05 level of probability.

ments for ridge and chisel plow in the wetter year of 2000, but higher in the drier year of 2001 (Figure 5). We speculate that the greater availability of soil water during tuber bulking in 2000 may have allowed the development of tubers deeper in the soil (Miller and Martin 1987), to protect against sunburn (Kouwenhover 1970). When averaged over seed-sprouting treatments, raised beds produced less sunburn than ridge till and chisel plow.

Green-sprouted seed in raised beds produced a higher percentage of misshapen tubers than non-sprouted seed in the same tillage treatment (Figure 6a and b), but fewer rotten tubers (Figure 7a and b). The interaction between seed-sprouting and tillage treatment was not consistent for misshaped and rotten tubers in ridge and chisel plow between the two growing seasons. Non-sprouted seed in ridge and chisel plow produced more misshaped tubers in the wetter year of 2000, but fewer in the drier year of 2001 (Figure 6a and b). Rotten tubers were virtually absent in ridges in 2000, and no differences were observed between seed-sprouting treatments in 2001 for ridge till (Figure 7). Non-sprouted seed in chisel plow produced more rotten tubers in 2000, but fewer rotten tubers in 2001, compared to green-sprouted seed.

Growth cracks and hollow heart were observed in the wetter year of 2000 when more tubers weighing more than

TABLE 2—*Tuber length distribution of Russet Burbank planted to three tillage systems with green-sprouted and non-sprouted seed in 2000 and 2001.*

Treatment	< 7.5 cm	> 7.5 cm	> 7.5 cm < 8.7 cm	> 8.7 cm
		Mg ha^{-1}		
		2000		
Raised Bed/Green-sprout	11.4 *b*[1]	26.9 *a*	8.3 *c*	18.7 *a*
Raised Bed/Non-sprout	10.1 *c*	23.7 *e*	9.1 *b*	14.6 *b*
Ridge/Green-sprout	11.0 *b*	23.0 *f*	8.3 *c*	14.7 *b*
Ridge/Non-sprout	12.9 *a*	24.2 *d*	10.1 *a*	14.1 *b*
Chisel Plow/Green-sprout	10.1 *c*	25.3 *c*	6.9 *e*	18.4 *a*
Chisel Plow/Non-sprout	10.1 *c*	26.2 *b*	7.5 *d*	18.6 *a*
CV (%)	4.8	1.2	4.2	3.8
		2001		
Raised Bed/Green-sprout	8.7 *a*	21.8 *a*	7.6 *a*	14.2 *a*
Raised Bed/Non-sprout	6.9 *c*	17.3 *b*	7.6 *a*	9.8 *b*
Ridge/Green-sprout	7.1 *c*	18.3 *b*	6.3 *bc*	12.1 *ab*
Ridge/Non-sprout	8.2 *ab*	21.3 *ab*	7.9 *a*	13.5 *a*
Chisel Plow/Green-sprout	7.6 *bc*	19.3 *ab*	5.8 *c*	13.4 *a*
Chisel Plow/Non-sprout	8.5 *a*	22.2 *a*	7.3 *ab*	14.9 *a*
CV (%)	6.2	9.9	9.4	13.6

[1] Means in the same year and column bearing the same letters are not significantly different at the 0.05 level of probability.

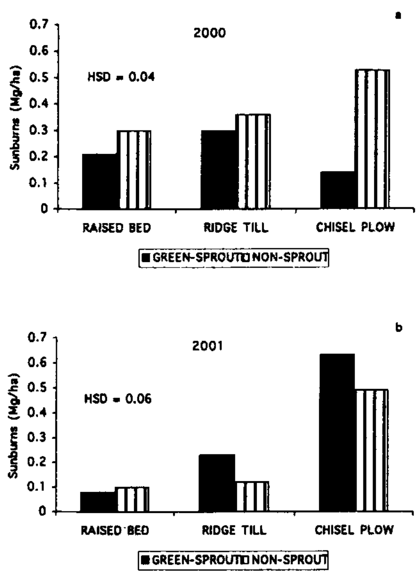

FIGURE 5.
Quantity of sunburned tubers as influenced by tillage and seed sprouting in (a) 2000 and (b) 2001.

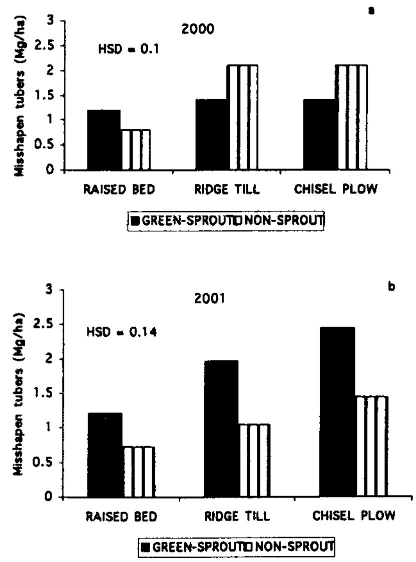

FIGURE 6.
Quantity of misshaped tubers as influenced by tillage and seed sprouting in (a) 2000 and (b) 2001.

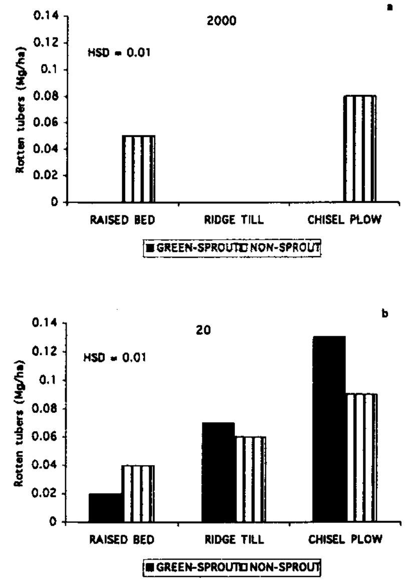

FIGURE 7.
Quantity of rotten tubers as influenced by tillage and seed sprouting in (a) 2000 and (b) 2001.

454.0 g were produced, but not in the drier year of 2001 when no tubers >454.0 g were produced (Figures 8 and 9). Weight of tubers exhibiting growth cracks in raised beds was less for non-sprouted than green-sprouted seed, but green-sprouted seed in ridge and chisel plow produced fewer growth cracks than non-sprouted seed (Figure 8). The observations made in this study indicate that misshapen tubers and growth cracks are associated with the production of very large tubers. Less hollow heart was observed for green-sprouted seed in raised bed and ridge till treatments (Figure 9).

No significant difference was observed among treatments for specific gravity, and these data are not presented.

SUMMARY AND CONCLUSIONS

In this study, raised beds retained more water during critical periods of crop growth and development. Higher tuber yield and quality of green-sprouted seed in raised beds observed in 2000 appear associated with this greater water availability, which helped to sustain the early vegetative growth due to early plant emergence. Optimizing initial emergence conditions allowed plants from green-

TABLE 3—*Tuber diameter distribution of Russet Burbank planted to three tillage systems with green-sprouted and non-sprouted seed in 2000 and 2001.*

Treatment	< 5 cm	> 5 cm	> 5 cm < 284 g	> 5 cm > 284 g
		Mg ha^{-1}		
		2000		
Raised Bed/Green-sprout	11.2 *bc*[1]	27.0 *a*	23.6 *a*	3.4 *a*
Raised Bed/Non-sprout	11.6 *ab*	22.2 *d*	21.6 *b*	0.6 *e*
Ridge/Green-sprout	12.1 *a*	21.9 *d*	20.0 *d*	1.9 *d*
Ridge/Non-sprout	11.6 *ab*	25.6 *b*	23.5 *a*	2.0 *c*
Chisel Plow/Green-sprout	12.1 *a*	23.2 *c*	21.0 *c*	2.3 *b*
Chisel Plow/Non-sprout	10.7 *c*	25.6 *b*	23.7 *a*	1.9 *d*
CV (%)	4.1	1.4	1.3	4.3
		2001		
Raised Bed/Green-sprout	16.4 *a*	15.5 *bc*	14.7 *bc*	0.9
Raised Bed/Non-sprout	13.2 *cd*	12.2 *d*	12.0 *d*	0.2 *c*
Ridge/Green-sprout	14.5 *b*	13.0 *d*	12.2 *d*	0.8 *b*
Ridge/Non-sprout	13.0 *d*	17.0 *ab*	16.3 *ab*	0.7 *b*
Chisel Plow/Green-sprout	14.7 *b*	13.5 *cd*	12.8 *cd*	0.7 *b*
Chisel Plow/Non-sprout	14.1 *bc*	18.2 *a*	16.8 *a*	1.4 *a*
CV (%)	4.8	9.4	8.3	16.8

[1] Means in the same year and column bearing the same letters are not significantly different at the 0.05 level of probability.

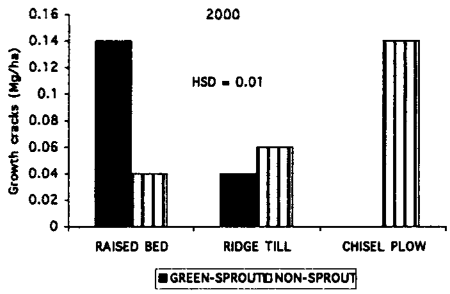

FIGURE 8. Quantity of tubers exhibiting growth cracks as influenced by tillage and seed sprouting in 2000.

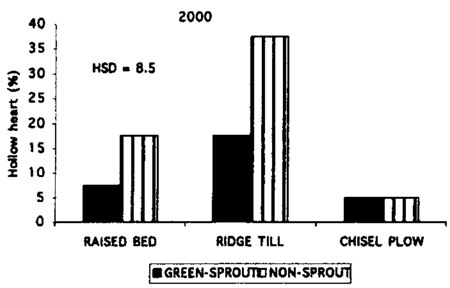

FIGURE 9. Percentage of large tubers (340.5-454.0 g) exhibiting hollow heart as influenced by tillage and seed sprouting in 2000.

sprouted seed tubers to utilize the short growing season more efficiently than plants from non-sprouted seed tubers. Although O'Brien et al. (1983) and Knowles and Botar (1991) observed green-sprouting to increase yields at early harvest, but decrease them later, they acknowledged that absence of water stress would minimize the effects of green-sprouting on final yield. The accelerated emergence from green-sprouted seed usually aids the plant's growth because the vegetative period is advanced, thereby allowing the plant to benefit from more favorable water supply and higher light intensity earlier in the season (O'Brien et al. 1983). We consider that the reduced soil water in ridge and chisel plow treatments early in the growing season (2000) or during tuber bulking (2001) may have caused green-sprouted seed to produce plants with lower maximum leaf areas that senesced earlier (data not shown). This resulted in lower total and marketable yields, and shorter and smaller tubers compared to the corresponding non-sprouted treatment. Similar findings were reported by Van Der Zaag and Van Loon (1987) and Moll (1985).

The technique of using raised beds planted to green-sprouted seed appears promising for early soil drying in the spring and retaining soil water during later critical periods of plant growth.

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