SOIL OXYGEN AND MOISTURE IN RELATION TO RUSSET BURBANK POTATO YIELD AND QUALITY[1]

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Abstract

On a Declo loam, rooting density, final yield and quality of potatoes (*Solanum tuberosum* cv. Russet Burbank) showed no significant differences among conventional planting, ripping along the row, or forced aeration 30 cm below the top of the row. There were significant relationships between oxygen diffusion rate (ODR) and soil moisture tension (matric potential) at the 30 and 40 cm depths, but these relationships were not significantly different among treatments.

In a complementary experiment, sprinkler irrigations at negative soil water matric potentials of 30-40 (wet), 40-50 (intermediate) and 50-60 kPa (dry, *i.e.,* 0.5-0.6 bar tension) produced no differences in total yield. However, the wet treatment gave significantly more knobby and undersized tubers < 113 g (4 oz.) and a lower percentage of U.S. #1 tubers than the intermediate and dry treatments. Premium sized tubers > 284 g (10 oz.) were significantly higher in the dry than in the wet treatment. Fertilizer N was applied periodically during the season and petiole NO_3-N levels indicated adequate levels with no differences among treatments in either experiment.

So much attention has been given to the effects of drought and high temperature stress on the quality of Idaho Russet Burbank potatoes, that some growers may now over-irrigate. Results of this research indicate that attention should also be directed to the effects of excess moisture on the size and quality of tubers.

Introduction

Profits from potato production are highly dependent on both the yield and quality of the tubers. There has been a considerable amount of work done on the effects of cultural factors on the quality of potato tubers. This has been reviewed by various authors (18, 21). In recent years interest has developed in the specific effects of the soil environment on plant production.

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Received for publication May 11, 1983.
Accepted for publication November 28, 1983.
KEY WORDS: Yield, quality, soil oxygen, soil water.

Soil aeration is notable in this respect. Studies have been done on aeration and root growth of various crops (12, 13, 14, 16). Particularly in the case of the potato, work has been done on the effects of various physical conditions on the rooting depth (1, 10). Some work has been done on the effects of soil conditions around the tubers, though most studies involved observations of air permeability or bulk density of the soil as a result of various methods of compaction or cultivation (6, 19, 20). Saini (1976) examined several soil physical properties and found that the oxygen diffusion rate (ODR) of subsoil was one single factor which highly correlated with marketable potato yield for several soils.

In potted plant experiments, Bushnell (4) showed that the underground parts of the potato plants are capable of absorbing oxygen at high rates compared to other plants discussed in the literature. In another study (5) he found low oxygen caused growth retardation and abnormal shapes of tubers. The weight of roots apparently was not affected. In a similar type of study (7), low oxygen around the seed piece caused stolons to continue growing without setting tubers and buds on the seed piece sprouted to form secondary stems. Root growth seemed unaffected by the low oxygen treatment. Naka (11) concluded that restricted aeration, by increased soil moisture or soil air replaced by hydrogen gas, caused a depressed respiration rate, increased reducing sugar content of the tuber and led to secondary growth. Jackson (8) found that ODR of 0.35 $\mu g\ cm^{-2}\ min^{-1}$ was insufficient but 0.63 $\mu g\ cm^{-2}\ min^{-1}$ was sufficient for emergence of potato sets. He quotes a personal communication by Erickson that 0.56 $\mu g\ cm^{-2}\ min^{-1}$ represents satisfactory air relations for potatoes. The above studies had the low oxygen treatments imposed for continuous, prolonged periods (7 days to 8 or 11 weeks). On the other hand, Burton and Wigginton (3) have found that mature tubers covered by a persistent film of water can be anaerobic after about 6.5 hours at 10°C or 2.5 hours at 21°C. This raises the question of the behavior of tubers under the fluctuating water and oxygen found under irrigated field conditions.

High temperatures and moisture stress have been clearly implicated as causes of knobby tubers, Kleinkopf (9). Periodic restricted aeration or high soil moisture has been associated with tuber malformations or an increased number of tubers (2, 4, 11, 20). In a preliminary greenhouse experiment in the present study, it was found that increased tuber set resulted from 8 to 16 hours of decreased aeration around the stolons. Differences of opinion still exist as to all the causes of knobby potatoes. Since the gaseous environment in any given soil structure is modified by its water relations, some of the past differences of opinion may have been due to insufficient attention to the moisture/aeration conditions around the tubers under field conditions. Saini (17) has shown that there is a direct, significant correlation between ODR at field capacity and marketable (and total) yield for several potato growing soils. The effect of non-uniform infiltration under the hills of sprinkler-irrigated potatoes has also been largely neglected. Saffigna *et al.*, (15) studying Russet Burbank potatoes showed that up to 46% of the irrigation or 23% of rainfall flowed down the stems from the plant canopy. The implications concerning nitrate leaching were discussed. Though not discussed, their data from the sandy soil showing more than twice as much water near the tubers than at other locations, suggest reduced aeration of the tubers relative to the roots, especially in slower draining soils.

The study reported here examines the feasibility of modifying the tuber environment and explores some effects on tuber quality.

Materials and Methods

Russet Burbank potatoes were grown on a Declo loam soil during 1980 and 1981. Two complementary experiments were conducted on adjacent plot areas in the same field in 1980. One experiment using 8 replicates examined the effects of aeration on the tubers by standard tillage methods versus a 30 cm tillage rip below the row or forced aeration through trickle irrigation tape 30 cm below the row. Air pressures of approximately 35 kPa (5 psi) and 7 kPa (1 psi) were respectively maintained throughout the season on the inlets and at the ends of the aeration tapes. This experiment was sprinkler irrigated when the matric potential of half the tensiometers at the 30 cm depth in the hill, decreased below -30 kPa (100 kPa = 1 bar). Standard tillage includes plowing, smoothing with a roller harrow, and later hilling with a herbicide application. The rip treatment also included moving a chisel through the soil ahead of the planter. The tape was laid with the chiseling for the forced aeration treatment.

The complementary experiment in 1980, using 6 replicates, examined the effects created by irrigation at various soil water matric potentials. The levels were 30-40 (wet), 40-50 (intermediate) and 50-60 negative kPa (dry). To increase treatment precision, the tensiometer readings at the 30 cm depth and the irrigations were made individually for each plot. Water was applied with sprinklers using 5 hour sets at a rate of 0.7 cm hr^{-1} in both of the 1980 experiments.

In 1981 the irrigation treatments (4 replicates) were initiated at the same 3 matric potential levels, but two sprinkling duration times were used, 3 and 5 hours. In all the experiments, plot size necessitated close spacing of irrigation lines to obtain uniform applications. The rates of water applied were about twice those of irrigations with normally spaced lines. However, the water did not pond on the soil surface and the total application was no more than commercial growers apply.

Oxygen diffusion rate (ODR) determinations were made in the hill at 30 and 40 cm depths using the platinum micro-electrode method over a range of matric potentials during the 1980 season in the forced aeration experiment. A specially designed meter with a capacity of 60 output terminals was obtained from Jensen, Inc.[3] This was connected to a printing recorder (Campbell Scientific) so that multiple electrodes in several replicates were scanned simultaneously. Potassium and phosphorus fertilizers were soil incorporated pre-plant according to soil test and University of Idaho recommendations. Nitrogen was applied before planting and with some irrigations during the season through the overhead sprinklers. Petiole samples were taken 4 times during the season to monitor NO_3-N levels. Root samples from 4 locations around a plant were washed from soil core samples from 0-45 cm in 3 equal increments. Root samples were dried for statistical analysis. Yield samples from 25 or 30 feet of row were taken with a single row plot harvester. Specific gravity, total yields, and weights of U.S. No. 1 as well as knobby and undersized potatoes were determined.

Results and Discussion

I. Comparison of conventional planting (control), ripping along the row (preplant ripping) and forced aeration using trickle irrigation tape (forced air) under sprinkler irrigation.

Sampling of root weights (63 days from planting) showed no significant differences among treatments at any depth from the surface to 45 cm. Potato roots did not usually penetrate beyond 45 cm because of a layer that restricted root growth but not water movement. Samples 87 days after planting, showed no significant differences among treatments in the numbers or fresh weight of tubers, or the percent solids. Sampling of the dryweight of tubers, vines, and easily recoverable roots showed no significant differences among treatments, but the dry matter was predominantly in the vines and tubers. Petiole samples during the season also showed no significant differences in NO_3-N levels among treatments for four sampling dates. Fifty-seven days after planting the average treatment levels were $14{,}500 \pm 1{,}000$ $\mu g\ g^{-1}$. This decreased gradually to $10{,}600 \pm 300$ $\mu g\ g^{-1}$ on day 102 after planting. At harvest there were no significant differences in the total yield or various size and grade categories of tubers, or in the specific gravity of tubers (Table 1). Although significant differences in ODR due to treatment were not observed, there was a significant linear relationship (1% level) between ODR and moisture tension over the range measured (Fig. 1).

II. Comparison of conventional planting under sprinkler irrigation at varying matric potentials.

For the wet, intermediate and dry treatments, the number of irrigations averaged 13, 11, and 10, and the water applied was 48.3, 38.1, and 35.6 cm (19, 15, 14 inches) respectively. Sampling 82 days from planting showed no

[3]Company and commercial names are shown for the benefit of the reader and do not imply endorsement or preferential treatment of the product noted by the U.S. Dept. of Agriculture.

TABLE 1. — *Final yield and tuber quality in 1980 for the three treatments shown.*

Treatment	Total Yield	U.S. No. 1		< 113 g	> 284 g	Knobby	Specific Gravity
	metric tons ha^{-1}		%	--- metric tons ha^{-1} ---			
Control	45.5	35.7	78	5.1	16.4	4.8	1.081
Preplant Ripping	43.9	34.6	79	5.3	15.5	4.0	1.082
Forced Air	43.1	34.4	80	4.7	16.0	4.0	1.081

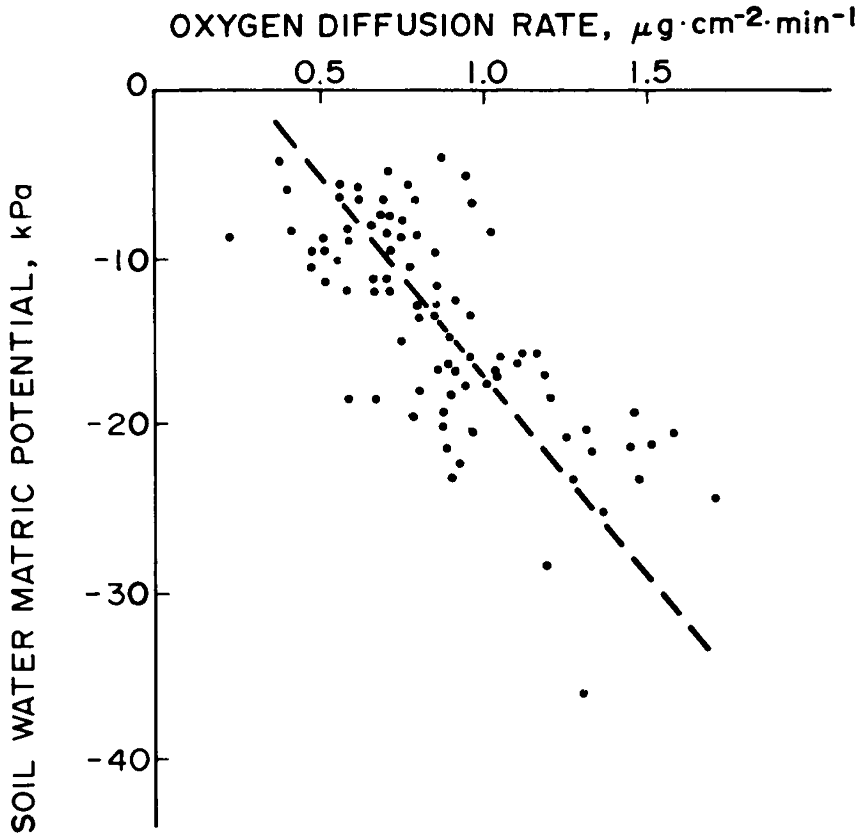

FIG. 1. The relation between soil oxygen diffusion rate and daily observations of soil water matric potential measured at the 30 and 40 cm depths in Declo loam soil during the field production of Russet Burbank potatoes under sprinkler irrigation. Field capacity is approximately −300 kPa (0.3 bar).

significant differences among treatments in the dry weights of tubers, vines and easily recoverable roots. Petiole NO_3-N levels showed no significant differences among treatments for four sampling dates during the season starting with 15,000 ± 600 μg g^{-1} 54 days after planting and decreasing to

7,800±300 μg g^{-1} 99 days after planting. At harvest, there was a trend toward higher total yields in the wetter treatment, but these differences were not significant at the 5% level (Table 2). However, there was a significantly higher percentage of U.S. No. 1 tubers in the intermediate and dry treatments than in the wet treatment. Also, the dry treatment yielded more premium sized tubers, >248 g (10 oz.) than the wet treatment. The wet treatment showed a significant increase over the dry and intermediate treatments for the knobby and undersized tubers, <113 g (4 oz.)

TABLE 2. — *Final yield and tuber quality in 1980 for three irrigation levels*#

Treatment	Total Yield	U.S. No. 1		<113 g	>284 g	Knobby	Specific Gravity
	metric tons ha^{-1}		%	--- metric tons ha^{-1} ---			
Wet	53.0 a	38.3 a	71 a	8.1 a	15.0 a	7.9 a	1.084 a
Intermediate	52.2 a	40.6 a	76 b	6.7 b	16.5 ab	5.9 b	1.082 a
Dry	50.0 a	39.4 a	78 b	6.1 b	18.5 b	5.3 b	1.082 a

#Numbers followed by the same letters in columns are not significantly different at the 5% level.

The daily observations of soil water potentials for the 30 cm depth are shown in Fig. 2 for two representative plots, one subject to the driest and the other to the wettest treatment. The soil water potential curve for the intermediate treatment fell closer to the dry than the wet treatment in Fig. 2. A striking difference was the number of days that the potential became less negative than −20 kPa on the wet treatment during June and July. Comparison with Fig. 1 shows matric potentials wetter than −20 kPa produce ODR values below 1 μg cm^{-2} min^{-1} in this particular soil. It is doubtful that ODR values above one would be detrimental, but the circumstantial evidence from these data suggest that the lower oxygen diffusion rates may well have been associated with the number and quality of tubers. Beginning Aug. 15 a rainy period kept all treatments intermittently wetter than −20 kPa matric potential until the 25th. Some tensiometers fell to 10 kPa or less for 1-2 days during this period, but the growing season was then near its end so the significant differences shown in Table 2 must have been established by early August. On the whole, during June and July, the number of days in which the soil matric potential was wetter than −20 kPa was 16, 8, and 8 for the wet, intermediate, and dry treatments at the 30 cm depth. They were 26, 3, and 0 days respectively at the 40 cm depth. As suggested by the data of Saffigna *et al.* (15) the number of days with high moisture potential and lower ODR around the tubers themselves may be underestimated by our data due to water running down the stems.

There were no significant differences in specific gravity of the tubers among treatments. The levels of 1.082 or above were good for this variety

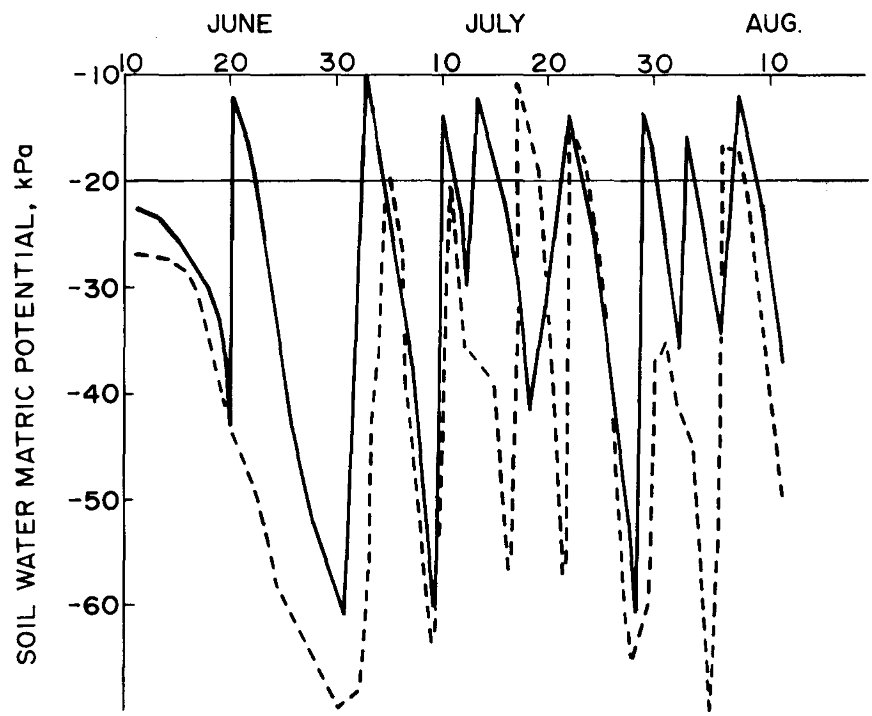

FIG. 2. Soil water matric potential records for the 30 cm depth on wet (solid line) and dry (dashed line) plots during the 1980 study (100 kPa = 1 bar).

and the yield of tubers was also high for the Russet Burbank in the area where grown.

Plants in all treatments in the forced aeration and rip experiment showed some irregular delays in time of emergence. Samples were examined in the field but it was concluded that *Rhizoctonia solani* (root fungus) was not the problem. Although the canopy eventually leveled out, it might be speculated that the erratic emergence contributed to the slightly lower yields in Table 1 compared to Table 2.

III. Comparison of conventional planting under sprinkler irrigation at varying moisture potentials and for different durations in 1981.

At harvest, differences among treatments in total yield and quality of tubers were not significant at the 5% level (Table 3). However, there was a trend toward higher total yields in the treatments with the shorter duration irrigation. This was also true with the drier treatments for the weight and percentage of U.S. No. 1's and the premium sized tubers. Knobby tubers tended to be less with the drier treatments as in the previous year. In 1981 freezing June temperatures caused foliar damage in the top of the potato plants. This, combined with other adverse weather conditions led to lower than average yields throughout the area. Had the growing season been more

TABLE 3. — *Final yield and tuber quality for six irrigation treatments in the 1981 experiment.*

Treatment	Irrigation Duration	Total Yield	U.S. No. 1		<113 g	>284 g	Knobby	Specific Gravity
		metric tons ha^{-1}		%	--- metric tons ha^{-1} ---			
Wet	5 hours	29.4	19.0	64	5.6	4.6	4.9	1.081
Intermediate		30.9	19.3	61	6.3	4.9	5.3	1.080
Dry		30.2	21.3	71	5.6	5.3	3.4	1.080
Wet	3 hours	35.0	23.5	67	6.2	5.7	5.3	1.083
Intermediate		33.9	23.1	68	6.6	6.2	4.2	1.083
Dry		31.7	22.7	72	5.7	5.6	3.3	1.080

favorable, the trends noted in 1981 might have become significantly different at the 5% level as they were in 1980 which was a good year for potato production.

Conclusions

1. The benefits from preplant ripping along the row, which are reported in the literature (Bishop and Grimes, 1978) were not observed in the Declo loam. Apparently rooting conditions were not limiting enough to benefit from the ripping. Furthermore, forced aeration as a means of improving the oxygen content around the tubers does not seem practical or necessary under the moisture/aeration conditions prevailing in a Declo loam. The more feasible way of controlling the oxygen environment around the tubers is by manipulating the relationship between the moisture potential and the oxygen diffusion rate in the soil.

2. The results reported here and the literature reviewed suggest that low ODR levels in the field may have more adverse effects on the tubers than on the potato roots. The roots can apparently tolerate short periods of reduced ODR without limiting total yield. Consequently, sprinkler irrigation and rainfall may compound aeration problems due to water running down the stems into the hills. Repeated cycles of low ODR cause increased tuber set leading to undersized tubers in short growing seasons. Periods of low ODR may also lead to knobby tubers. While questions of adequate aeration have been occasionally raised as a result of controlled laboratory studies, the data presented here are among the very few suggesting a field plot response under realistic management conditions. We cannot conclude definitely that the differences in Table 2 resulted from periods of tuber oxygen stress, but it is evident that excessive irrigation can cause problems, even when nitrate leaching is controlled.

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