season. This should give a more nearly accurate indication of the true genetic reaction.

**Literature Cited**


**Furrow Irrigation of Lettuce Resulting in Water and Nitrogen Loss**

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**Abstract.** Water and nitrogen loss from field soil cropped to head lettuce with furrow irrigation was measured during three seasons in a semi-arid region. Water applications were reduced during the latter 1/3 of the growth period in an attempt to conserve N and water in the root zone.

Approximately 5 acre feet of water was applied to grow the crop. One-fifth of the applied water drained off and one-half percolated below the root zone. Eighty-nine lb./acre of NO₃-N was leached. Two-thirds of the water and three-fourths of the N (soil and applied) which were lost below the root zone were lost during germination. Reducing the total volume of water applied by 1/5 acre feet did not reduce water or N loss appreciably and had a deleterious effect on the crop. Very little N was lost as a result of runoff, but much was moved to the bed tops after the first irrigation. Implications of these findings are discussed.

The major method of supplying water to lettuce in the West is by furrow irrigation. In some areas sprinklers are being used to a limited extent to germinate the crop. Reports from Arizona and California indicate that from 6 to 41 acre inches of water are applied by furrow irrigation for germination alone (8, 10, 13).

Lettuce removes little N (18) in relation to the large amount applied. It is well documented that a highly mobile anion such as nitrate would leach (1, 2, 16) during periods of heavy furrow irrigation and also move to the bed surface (7, 12) between irrigations. When one considers a shallow rooted crop such as head lettuce growing on porous soils in semi-arid regions, N leaching and movement become extremely important in the growth of the crop.

It was the purpose of this experiment to measure the volume of water applied, surface drainage (runoff), internal drainage (percolation), as well as the disposition of NO₃-N relative to this water during furrow irrigation of a head lettuce crop. It was also the purpose of this experiment to determine the extent of water conservation on the parameters above as well as the crop. Such quantitative information may be useful as an aid in decision making when contemplating a shift to sprinkler irrigation, at least for early growth.

**Materials and Methods**

Field experiments were conducted from June through August during 1965, 1966, and 1967 at Colorado State University’s San Luis Valley Experiment Station. Each year a half-acre site was selected. Soils from two of the sites were San Acacio. Soil from the third site belonged to the Del Norte soil series. The texture of these three calcareous soils is a sandy loam. Organic matter content averaged 0.8 percent. Permeability rate is classified as moderate to moderately rapid,4 and depth to a gravel horizon is 30-35 inches. Moisture and particle size characteristics are presented in Table 1. Slope of the sites ranged from 0.29-0.34 per cent. These soils are repre

**Table 1. Average moisture and particle size characteristics of the three experimental soils**

<table>
<thead>
<tr>
<th>Moisture tension</th>
<th>Plow layer 0-12 inches</th>
<th>Root zone 0-24 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bars</td>
<td>Moisture %</td>
<td>Moisture %</td>
</tr>
<tr>
<td>0.10</td>
<td>17.1</td>
<td>16.3</td>
</tr>
<tr>
<td>0.33</td>
<td>11.9</td>
<td>11.9</td>
</tr>
<tr>
<td>1.00</td>
<td>8.7</td>
<td>8.7</td>
</tr>
<tr>
<td>7.50</td>
<td>7.4</td>
<td>7.6</td>
</tr>
<tr>
<td>15.00</td>
<td>7.0</td>
<td>7.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Plow layer 0-12 inches</th>
<th>Root zone 0-24 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>Weight %</td>
<td>Weight %</td>
</tr>
<tr>
<td>Sand</td>
<td>74</td>
<td>63</td>
</tr>
<tr>
<td>Silt</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Clay</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>

4Average of 6 samples, 2 from Del Norte site and 2 from each San Acacio site.

sentative of approximately 70,000 acres cultivated in the San Luis Valley and much of the Southwest.

‘Great Lakes 659’ head lettuce cultivar was planted to give a rate of 26,000 plants/acre. Cultural practices and harvesting methods used have been described by Whitaker et al. (17). A total of 120 to 190 lb. of N/acre was banded at the furrow side of each row, 1/2 at planting, 1/2 after thinning, and 1/2 approximately 1 month prior to harvest. Eight per cent of the N applied was nitrate, the rest ammonium. Nitrate N in the soil profile down to 24 inches was estimated to average 90 lb./acre prior to planting and irrigation each season according to soil incubation data together with surface (0–8 inches) soil nitrate analyses employing the phenoldysulfonic acid method (4).

During 2 seasons, 2 irrigation regimes were used. The “normal” consisted of irrigating when soil moisture tension in the 8 to 10 inch zone beneath the lettuce seed row exceeded 0.15 bars. The variable, “conservative,” consisted of irrigating when the tension in this zone exceeded 0.40 bars. Volume of water applied was also reduced during the conservative irrigation regime. The irrigation regimes were imposed approximately 1 month prior to harvest when a vigorous stand had been well established. It is during this period that head lettuce makes most of its growth (18). Midrib tissue samples collected approximately 2 weeks prior to harvest and heads for yield and postharvest measurements were taken from each 4 row, 45 ft long plot per irrigation regime and replication, giving a total of 16 plots for each irrigation variable per season. Tissue N was determined by the modified semi-micro Kjeldahl procedure to include nitrate. The venadomolybdophosphoric yellow method was used for tissue phosphorus and flame photometric technique was used for potassium (4).

Approximately 2 days prior to the first irrigation and 2 days after each of the succeeding irrigations, soil core samples (0–2 inches, Fig. 3) were taken from the bed tops at a point halfway between the seed row and the bed center for nitrate analyses.

Estimating applied water, runoff, internal drainage, and the fate of nitrate nitrogen. A porous ceramic cup technique similar to Wagner’s (15) was used to extract soil water samples (Fig. 1) for nitrate analyses. This technique is relatively inexpensive, maintains desired field conditions and avoids some of the limitations ascribed to lysimeters (6). Equipment was constructed so that 80 ml samples could be drawn simultaneously under a suction of 0.68 bars. Eight ceramic cups measuring 21/2 inches by 3/4 inch and eight tensiometers were placed with their tips 24 inches below the seed row and at a point halfway between 2 lettuce plants. Tensiometers and sampling tubes were placed in a line approximately 100 ft from the head ditch and 100 ft from the waste ditch.

The following rationale was used to calculate leachate volume:

\[ L = A_{t1} - R_{t1} \]

with the symbol definitions: L, Leachate volume; A, Applied water volume; R, Runoff water volume; \( t_1 \), time when water front passed the 24-inch depth; \( t_2 \), time when irrigation ceased.

Small Parshall flumes (9) were placed in the head and waste ditches in order to measure applied water volume (A) and runoff water volume (R). Siphon tubes 15/16 inch in diameter were leveled with a transit in order that equal volumes of water could be delivered to each furrow. Leachate (L) volume was calculated during each irrigation. Water movement at \( t_1 \) was indicated by tensiometer deflection.

Assumptions and considerations. The soil received water from precipitation, irrigation, and condensation of water vapor (soil and air). Soil water is removed from cropped land with the tissue removed in harvest, surface drainage (runoff), percolation below the root zone, and free surface evaporation during application and by evapotranspiration.

1) Average precipitation during the experiments of 3.21 inches was approximately equal to moisture loss due to evaporation from the surface of the irrigation water during application (3). Condensate forming at the soil surface disappeared a few hours after sunrise and was not considered a significant contribution to soil moisture.

2) Soil water passing below the root zone (24 inches) is lost to the current lettuce crop.

3) Tensiometer response time is negligible at low soil moisture tensions (5) such as those at 24 inches (ca. 0.10–0.13 bars) during this experiment.

4) The water removed with the crop is negligible (0.16 acre inches with head lettuce).

5) Water movement upward or downward relative to the 24-inch profile, between observations, is negligible since the time period is relatively short and these soils are well drained. Appreciable drainage of the profile after irrigation would, however, result in an underestimate of leachate volume and, therefore, N loss as well.

RESULTS

Sixty-two inches of water per acre was applied to irrigate the lettuce crop (Table 2). Twenty-one percent of that drained off the surface, and 48 percent percolated below a depth of 24 inches. Very little N was lost in the surface drainage water, but approximately 89 lb./acre was lost due to leaching. A large volume of water (19 acre inches), containing a high concentration of nitrate N, carried 68 lb./acre of N below the root zone during the germination period alone (ca. 11 days, 3–4 irrigations;
Table 2. Volume (acre inches) of irrigation water applied, runoff, and percolated during furrow irrigation of head lettuce and N loss (lb. NO₃-N/acre).a

<table>
<thead>
<tr>
<th>Water volume per crop</th>
<th>Standard error</th>
<th>95% Confidence limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied ..............</td>
<td>62.0</td>
<td>± 2.0</td>
</tr>
<tr>
<td>Runoff ................</td>
<td>13.0</td>
<td>± 1.5</td>
</tr>
<tr>
<td>Percolatedb ..........</td>
<td>29.8</td>
<td>± 2.3</td>
</tr>
</tbody>
</table>

N lost per crop

<table>
<thead>
<tr>
<th>Standard error</th>
<th>95% Confidence limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff ..........</td>
<td>1.9</td>
</tr>
<tr>
<td>Leachedb .......</td>
<td>89.4</td>
</tr>
</tbody>
</table>

aMeans presented are based on 27 irrigations applied to 3 lettuce crops grown during June through August, 1965, 1966, and 1967. Slope was 0.31% ± 95% Conf. 0.06%.

bPercolated and leached past a point 24 inches below the seed row.

Fig. 2). An increase in N in the leachate after germination and stand establishment occurs during irrigations 5 and 6 and again during irrigation 8. Less water percolated below the root zone as the season progressed.

Conserving water by reducing application by 18 acre inches after the lettuce had germinated and a stand was established saved only 5.4 lb. of N/acre, but reduced the yield and post-transit general quality with a concomitant reduction in the concentration of potassium in the mid-rib tissue (Table 3). Plants in plots which were conservatively irrigated wilted temporarily during days when air temperature was relatively high and dry air movement produced excessive transpiration.

The first irrigation moved nitrates into the bed tops where a relatively high concentration was maintained until rain occurred before observation number 7, Fig. 3.

Table 3. Conservative as compared with normal furrow irrigation and its influence on head lettuce and water and N loss.*

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>Water volume per crop</th>
<th>Normal</th>
<th>Conservative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied (acre inches)</td>
<td>61.5</td>
<td>43.5</td>
<td></td>
</tr>
<tr>
<td>Runoff (acre inches)</td>
<td>14.1</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>Percolatedb (acre inches)</td>
<td>29.6</td>
<td>20.9</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>N lost per crop</th>
<th>Normal</th>
<th>Conservative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff (lb. NO₃-N/acre)</td>
<td>2.7</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Leachedb (lb. NO₃-N/acre)</td>
<td>67.0</td>
<td>61.6</td>
<td></td>
</tr>
</tbody>
</table>

*Means presented are based on 18 irrigations applied to 2 lettuce crops grown during June through August, 1966 and 1967. Slope was 0.31% ± 95% Conf. 0.06%.

bPercolated and leached past a point 24 inches below the seed row.

cMean percent cut times mean head weight.

dGeneral quality is observed after a refrigerated transit and market period test. Ratings are based on a scale of 1 to 9: 9 = freshly cut, 7 = good (with minor defects), 5 = fair (with few defects removable by nominal trimming), 3 = unsalable.

NS Adjacent mean not significantly different.

** Adjacent mean significantly different at 1% P level.

* Adjacent mean significantly different at 5% P level.

Discussion

Since lettuce seed requires a continuously moist soil environment for germination, much water is applied.

In arid and semi-arid regions with high evaporative rates, it is reasonable to expect that the first furrow irrigation would move large amounts of nitrate N which had previously accumulated near the soil surface. During the growth of the lettuce crop these move down (Fig. 2) below the root zone and up (Fig. 3) into the bed tops. The N in the bed tops would temporarily be unavailable to the plants. Also, precipitation could put this N into the root zone when crop stimulation is not desired.

Sixty-four percent of the water which percolated below the root zone did so during the germination period. Seventy-six percent of the nitrate N which was leached, leached during the germination period. As the season progresses, irrigation is not as intense and the crop itself

Fig. 2. Water percolation and nitrate leaching during the growth of head lettuce under furrow irrigation.

Fig. 3. Changes in nitrate N in bed tops measured prior to first irrigation (number 1), after each irrigation, and after precipitation (number 7).

becomes more efficient and minimizes leaching loss of N both directly, by assimilation, and indirectly, by reducing the amount of leachate. The increase in N content of the leachate which is exhibited after the second N application (Fig. 2) during irrigations 5 and 6, is greater than after the third N application which is exhibited during irrigation 8. Although most of the applied N was in the immobile ammonium form, under conditions favorable for crop growth, ammonium is quickly oxidized to nitrate in the soil.

Twenty-one percent of the applied water was lost as runoff even on a medium coarse soil with only a slight grade. It is not surprising that very little of the total N was lost in runoff water. The concentration of nitrates in the runoff water was low due to limited contact between the irrigation water and the furrow surface where nitrates normally do not accumulate.

When an attempt was made to conserve water during the critical high-demand period of growth (18), little N was saved; and a deleterious effect on general quality, yield and K (14) accumulation was evident. The apparent waste of water by furrow irrigation is indicated by the run off even on a medium coarse soil with only a slight grade. It is not surprising that very little of the total N was lost in runoff water. The concentration of nitrates in the runoff water was low due to limited contact between the irrigation water and the furrow surface where nitrates normally do not accumulate.

The implication of the 89 lb./acre N 03-N leached is that time ground water pollution may occur (11) especially in a high water table, closed basin area such as that found in the San Luis Valley.

In the major crop producing areas of the world the movement of N with water down in the soil profile beyond the reach of plant roots is the largest single mechanism of loss (2). This investigation indicates that much water and N are being wasted especially during the germination period when furrow irrigation is used on lettuce growing on porous soil. If lower and firmer beds could be used together with a controlled release N source, the problem might be partially alleviated. Moisture barriers may also aid in reducing percolation and N leaching. Efficient sprinkler irrigation, at least during the germination period, should solve the problem of excessive N mobility. In the future high density planting on wide beds will necessitate sprinkler irrigation, and N and water efficiency should be greater.

**Literature Cited**