PERFORMANCE OF UNLINED AND LINED MOLE DRAINS IN A SALINE CLAY LOAM FIELD

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The performance of unlined and lined mole drains was studied in a saline, poorly drained, clay loam soil in southern Alberta. Both mole drains were operative throughout the 10-yr study and were effective in lowering the water table after each flooding. However, discharge from the unlined moles averaged 24% of that from the lined moles. Drain spacings (5.0 m for the unlined, 7.6 m for the lined moles) were satisfactory for effectively lowering the water table, and were in satisfactory agreement with the spacing calculated at 29 h, using hydraulic conductivity (K) from drain discharge. The K value obtained by the shallow well pump-in method (mainly horizontal flow) was 0.02 cm/h. By the drain discharge method (horizontal and vertical flow) K was 0.07 and 0.22 cm/h for the unlined and lined mole drain areas, respectively, and by the water table recession method (horizontal and vertical flow) it was 0.17 and 0.28 cm/h for the unlined and lined mole-drained areas. These data indicate vertical drainage was considerably greater than horizontal drainage, and that there was natural but slow internal horizontal drainage, possibly along the till-bedrock contact plane. The function of the drain after a flood was to aid the slow internal drainage in rapidly lowering the water table to a depth at which extended waterlogging was not a problem. Thereafter, internal drainage and plant use was sufficient for continued lowering of the water table.

Reclamation of waterlogged saline soils with mole drainage is uncommon. Yet, where conditions are suitable, mole drainage is less expensive to install than other kinds of subsurface drainage. One reason for not using mole drainage may be the uncertainty of its life expectancy. In Britain, where mole drains are used on wetlands, their durability varies from years to decades with an average of 10 to 15 yr (Nicholson 1946). Soil texture and soil moisture at time of installation are critical for stable mole drains (Childs 1942; Raadsmo 1974; Sommerfeldt 1983; Spoor et al. 1982a,b) and mole stability can be improved by the installation of plastic linings (Dyilla et al. 1963; Fouss and Donnan 1962).

A field experiment was conducted in a poorly drained, saline, clay loam soil to evaluate the use of mole drainage and to determine the relative performance of unlined and lined mole drains.

MATERIALS AND METHODS

Site Description and Preparation

The site, 100 × 200 m, was on a dominantly saline, poorly drained, Brown Regosolic fluvial soil over till near Taber, Alberta. Saline-sodic soil was also present at the site. Texture of the fluvial mantle, 0.6 m deep, and of the surface 0.6 m of till was generally clay loam. Texture of the till below this depth was medium fine, but varied from very fine sandy clay loam to silty clay loam and clay loam, with gypsum crystals throughout. A tongue of bedrock at 2-m depth extended under about 20% of the area (Fig. 1); elsewhere, there were fragments of weathered bedrock at 2.5 to 3.0-m depth, indicating bedrock was near 3-m depth throughout.

The area was formed to zero grade along the natural contours, with a 1% downslope for minimum soil disturbance. North of the site, an open drain (item a, Fig. 1) was constructed into which the mole drains discharged through galvanized tubing (90-mm diam). Mole drains (92-mm diam.) were installed in 1968 at 0.7-m depth, using materials and methods reported by Fouss and Donnan (1962). Perforated 20-mil PVC plastic, notched on the edges, was used in the lined drains. As the lining was fed through the mole plow, it folded to form a tube and the notches on the edges interlocked to retain the tube shape. Three drains of a kind were installed in a block which ran in a north-south direction from bottom to top of the slope. There were four blocks each of unlined (U) and lined (L) drains randomly paired across the site, and three check blocks (C) with no drains, one on each end and one in the center of the site. The C and U blocks were 15 m wide and the L blocks were 22.8 m wide. Between drains, spacing was 5 m for the U moles and 7.6 m for the L moles (spacings based on past experience, E. Rapp, pers. commun.). Border dykes were constructed perpendicular to the contours at 7.6-m intervals across the site, for gravity irrigation. A tailwater drain (item b, Fig. 1) was constructed at the north of the site to collect runoff. A supply ditch across the south of the site (item c, Fig. 1) provided the irrigation water. In the bank of the supply ditch, spiles (8 × 8 cm square with control gates) were installed, one to supply water to each border strip. The supply ditch provided sufficient capacity to irrigate the whole site in one setting. In both the supply and runoff catchment ditches, non-submerged Parshall flumes with water level recorders were installed to measure the water delivered to and lost as runoff from the site. Across the middle of the site, a row of 43 groundwater observation wells, of 2-cm perforated iron pipe, was installed (Fig. 1) to monitor groundwater depth at prescribed times, using a pneumatic sounder.

The site was developed in 1968, seeded to barley and flooded once in 1969. In 1970, after it was seeded to tall wheatgrass (Agropyron elongatum) with a barley (Hordeum vulgare) nurse crop, intensive reclamation began.

Reclamation Procedures and Drain Performance

The groundwater level was raised to ground surface by flooding; groundwater was then drained away while the drain discharge and water table recession were monitored. This procedure was carried out once in 1969, and at 2- to 3-wk intervals during the irrigation season (5-7 times) from 1970 to 1979. To saturate the profile, the site was flooded from 5 to 6 h on one day to raise the water table to ground surface and again for about 3 h on the second day. It was assumed that the soil was fully saturated after the second flooding. Flooding was terminated each day when the tailwater drain, which had limited capacity, became filled to near-capacity. The net
amount of water applied (total minus runoff) over the 2 days was 12–15 cm. The average annual net application was 77 cm
plus an annual average of 16.5 cm precipitation during the flooding season.

Drain discharge was measured with a calibrated vessel and stopwatch at termination of flooding on the second day and at 9, 18, 29, 46, 70, and 166 h later. Groundwater depths across the site were measured at the same times.

The grass growing on the site was cut with a flail mower periodically throughout the growing season and left to decompose on the soil surface.

In September 1976, soil samples to 2-m depth were collected along the row of observation wells. The electrical conductivity of the saturation extracts from these samples was determined, using methods of the U.S. Salinity Laboratory (Richards 1954). The sample sites within a drained block were at 1 m on either side of a drain and midway between the drains, and at three equally spaced distances across the check blocks.

At termination of the experiment in 1979, the hydraulic conductivity (K) of the leached soil near the edge of the plot area and of the unleached soil just outside the plot area (about 10 m apart) was determined by shallow well (1.2-m depth) pump-in method (Bouwer and Jackson 1974) at eight locations, two on each side of the area. These results were compared with K values determined with water table recession data (Dieleman 1974) and discharge data at 9 and 18 h (U.S. Bureau of Reclamation (USBR) 1978). Optimum drain spacings to achieve a specific drainage rate were calculated, using the transient flow method (USBR 1978) and K values from drain discharge data, and

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**Figure 1.** Site plan showing check (C), unlined (U), and lined (L) blocks with locations of the shallow bedrock, mole drains, observation wells, open drain (a), tailwater drain (b), and supply ditch (c).

**Figure 2.** Average annual peak discharge from the lined and unlined mole drains.
RESULTS

The mean annual rate of peak drain discharge increased from 1969 to a maximum in 1974 for both the unlined and lined moles, except in 1971 (Fig. 2). Thereafter, the rate decreased annually to time of termination of recording in 1979. Throughout the study, discharge from unlined moles was less than that from the lined, the overall average being 24% of that from the lined drains.

Drain discharge during a flooding-leaching cycle decreased exponentially with time until it stopped after about 70 h (Fig. 3). Initially, the rate at which the discharge approached zero was greater for the lined than for the unlined drains. But, after 46 h, the discharge from the unlined and lined drains was similar.

Water table recession rates, midway between drains, in the first 9-h interval were greatest in the blocks drained with lined moles (Table I). Because of this, the water table depths (y) in these blocks exceeded those in the unlined moles for the first 46 h. At that time, water table depths were within 4 cm of drain depths (70 cm). After the first 9-h interval, the rate of water table recession was greater from the unlined drains than from the lined, which is attributed to the differences in head and drain spacings. Noteworthy, though, is the rate of water table recession in the check blocks. Relief for this water was attributed to horizontal flow, especially along the plane of the weathered, fragmented bedrock at the till contact. The difference between water table recession rates of the check blocks and the blocks with unlined and lined mole drains is attributed to the drains.

If one assumes that drainage of this soil is primarily perpendicular to the restrictive layer (bedrock), K is a constant throughout, and the head (H) is measured from the bedrock (datum), then one can calculate K for the check blocks after the method of Klute (1965). The area of the standpipe and cross-sectional area of the core would be the same. Thus, Klute's equation reduces to

\[ K = \left( l / t \right) \ln \frac{H_1}{H_2} \]

where l is the length of saturated core (soil) which varies with time (t), as do \( H_1 \) and \( H_2 \) which are the hydraulic heads at time 1 and 2 (errors due to unsaturated flow and matric suction are recognized).

Using this approach, the internal K of this soil, as determined from the water table recession data of the check blocks and a specific yield of 0.038 (= lined mole drain discharge – unit area/water table recession), was 0.02 cm/h over the first four time intervals, i.e., to 46 h. (Evapotranspiration was not included since in the first few hours after flooding everything was saturated, including all the organic debris on the soil, and losses through evapotranspiration should have been minimal.)

The average K values of the soil as determined by water table recession in the drained plots, which measured vertical, radial, and horizontal (to bedrock) flows, were 0.17 and 0.28 cm/h for the unlined and lined mole drained blocks. By the drain discharge method at 9 h, which measured vertical, radial, and horizontal (to effective drain depth) flows, the K values were 0.07 and 0.22 cm/h for unlined and lined moles, respectively (0.05 and 0.12 cm/h at 18 h). By the shallow well pump-in method (inside and outside the plot area), which primarily measured horizontal flow, K was 0.02 cm/h, the same as that estimated from the water table recession in the check blocks.

The calculated hypothetical drain spacings for this soil using K values from lined

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<th>Time, t (h)</th>
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<th>Difference in depth, Δy (cm)</th>
<th>Recession rate, Δy/t (cm/h)</th>
<th>Unlined Depth to water, y (cm)</th>
<th>Difference in depth, Δy (cm)</th>
<th>Recession rate, Δy/t (cm/h)</th>
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Figure 3. Drain discharge for lined and unlined mole drains from after flooding stopped (0 time) to after drainage stopped, in the years 1970, 1974, and 1979.
mole drain discharge data (at 9 h) were 6.0 m, for a water table recession of 35 cm (half of drain depth) in 24 h, or 7.5 m for a recession of 41.45 cm in 29 h as observed (Table I). With K values from the unlined moles, the distance became 3.4 m for a water table recession of 35 cm in 24 h, or 4.0 m for a recession of 37.19 cm in 29 h as observed. Thus, at 29 h the calculated spacing for the lined drains was essentially the same as that of the installed drains, while that of the unlined drains was 0.8 times that of the installed.

The electrical conductivity results of 1976 for the surface 60 cm of soil (Fig. 4) show a decreasing salinity gradient from the center of C1 to the L1 block. Similar gradients are seen from mid C2 into both the U2 and U3 blocks. These results indicate that the radii of influence of the drains extended into the check plots in some cases, suggesting that the drain spacings could have been wider.

The cost of installing the drains in 1968 was about $0.10/m for the unlined and $0.70/m for the lined. Freight was a major portion of the additional $0.60/m cost for the plastic liner. Also, the liner was experimental, which inflated its cost. The cost of plastic was more than double that quoted by Fouss and Donnan (1962) of $0.24/m. These material costs exceed those for corrugated plastic drain tubing. But these costs could be reduced by manufacturing the liners near the place of use, as was done with the tubing.

**DISCUSSION**

Both the unlined and lined moles were effective for draining this land to satisfactory depth within 24 to 48 h, though the unlined moles seemed to have restricted capacity. The assumption is that the unlined drains were partially plugged by material falling from around the mole, possibly in the first year after installation, which caused the limited capacity. However, these partially collapsed drains provided sufficient drainage to be effective throughout the length of the experiment. The results may not have been as favorable on a large-scale field installation.

Because the soil was saturated to ground level on two successive days it is assumed that the profile was fully saturated when observations of groundwater recession commenced. Therefore, the observed recessions are attributed to internal and mole drainage. Lining the moles greatly increased their performance, namely in discharge, radius of influence, and apparent extended durability.

Flow among plots in the initial stages of leaching was assumed to be insignificant. All plots were saturated to ground level and the differences in groundwater depths between plots were small. Also, K values from the shallow well pump-in test indicated horizontal flow would be small.

The variable K values are not in as much disagreement with each other as their values suggest. The K values from the shallow well pump-in method are primarily for horizontal flow, assuming the bedrock is impermeable. The values from the drain discharge and water table recession (of the drained blocks) methods are for vertical, radial, and horizontal flow, and the difference between the results is attributed to the difference in depth of horizontal flow and experimental error. For the drain discharge method, depth is the effective depth of the drain whereas for the water table recession, it is the depth to bedrock.

Though the study was terminated after 10 yr of intensive leaching, the data suggest the drains would have functioned longer. How much longer is unknown.

The drain spacings, 5 m for the unlined and 7.6 for the lined drains, were narrow enough for the conditions of this study and are in satisfactory agreement with the calculated spacings. However, the electrical conductivity data indicate the spacings may have been a little too narrow.

The function of the drains was to aid the slow internal drainage by rapidly lowering the water table, after a flooding event, to a depth at which waterlogging was not a problem (> 0.5 m). Thereafter, internal drainage was sufficient and the water table continued to recede slowly.

The conclusion from this study is that mole drains were effective in draining this land which had become salinized and waterlogged because of poor natural drainage. Lined moles were most effective. Land conditions were suitable at time of drain installation, which is a requisite. If soil conditions are favorable, there are economic advantages to mole drainage, because of the low cost of installation relative to other kinds of subsurface drainage. If the cost of lining material were reduced, the benefits from lining the moles might be sufficient to justify the extra cost. Although lined moles might collapse over the years, they would probably continue to function, albeit at reduced capacity. Further research is required to determine the durability of mole drains, especially lined, and to determine the soil conditions under which they perform satisfactorily.

**ACKNOWLEDGMENT**

Professor Egon Rapp started this experiment before joining the Agricultural Engineering staff at the University of Alberta, Edmonton. Appreciation is extended to N. Paziuk for his diligent services in overseeing and carrying out the activities of this study.

**REFERENCES**


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