Lysimeter Measurements of Nitrate and Chloride Losses from Soil Under Conventional and No-tillage Corn[1]

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ABSTRACT

Salt and water movement was studied using steel pan lysimeters in the field under corn (*Zea mays* L.) grown in killed sod and with conventional tillage. The study was done to determine the actual leaching losses of nitrogen under the two tillage systems. Losses of nitrate nitrogen and chloride used as a tracer of nitrate ion were higher under the no-tillage system as measured in the leachate collected after rainfall. This loss could occur within 1 to 2 months after the application of the nitrogen. Concentrations of nitrate and chloride ions in the leachate indicated that these mobile, surface-applied anions could be washed into natural soil cracks and channels and flow much deeper into the soil than predicted by miscible displacement theory.

Additional Index Words: leaching, unstable water flow, mulch.

With the advent of proper equipment and herbicides, the planting of row crops, especially corn (*Zea mays* L.), in a killed sod has gained wide acceptance. This method of planting corn in a chemically killed sod without the conventional disking and plowing was used on more than 100,000 ha of corn grown in Kentucky in 1975.

Killed sod under no-tillage has been shown to affect corn yields, the soil water regime, the degree of salt movement, and the flow characteristics related to soil structure.

Corn yields generally have been higher under no-tillage, especially under climatic conditions where water deficits occur during the summer months (Blevins et al., 1971). These higher yields are related to higher soil water resulting from lower evaporation from a mulched surface (Jones et al., 1968, 1969; Blevins et al., 1971). This additional soil water, mainly in the upper 15 cm, has been found, to allow larger amounts of water and nitrate to move more deeply in the soil relative to conventional tillage practices (Thomas et al., 1973). The lower evaporation under the killed sod also resulted in less upward movement of nitrate nitrogen. This enhanced loss of N has also been shown to be related to the initially different flow paths that the water takes under the two systems. In the absence of tillage, a larger amount of more stable cracks and channels are present near the surface relative to the pore system of the disturbed plow layer (Quisenberry, 1974[3]; Thomas et al., 1973; Ehlers, 1973). When the surface soil aggregates are wet, the water has been shown to flow into these large flow channels and carry the dissolved surface-applied ions much more deeply than when the surface is drier and less well-defined channels are present.

A collection of soil water moving through the profile under both tillage systems would be very helpful in understanding the movement and potential loss of applied fertilizers. Therefore, a pan lysimeter study to collect and analyze the water leachate in conjunction with soil sampling was undertaken. The results reported here are for the years of 1973 and 1974.

MATERIALS AND METHODS

The soil used was a Maury silt loam located on the University of Kentucky farm at Lexington, Kentucky. Maury silt loam (Typic Paleudalfs, clayey, mixed, mesic) is a well-drained upland soil formed in material weathered from phosphatic limestone. The soil above the lysimeters is from 0 to 36 cm, a dark brown, very friable silt loam with moderate granular structure. From 36 to 106 cm, a reddish brown, friable silty clay loam that grades into silty clay in the lower part, with moderate blocky structure. The clay minerals are a mixture of interlayered vermiculite and kaolinite. The soil shrinks only moderately on drying so that any cracks formed are very small (on the order of 1 to 2 mm across). The particular site used was about 205 m to rock and before plot establishment the area had been under a bluegrass (*Poa pratensis* L.) sod for at least 50 years.

Lysimeters of the pan type (sometimes called Ebermayer lysimeters) were installed under four 3.66 by 3.66 m plots on 24 May 1972. The lysimeter pans were placed at a depth of 106 cm and were 0.91 by 1.22 m in size. Installation was accomplished by digging a trench alongside the four adjacent plots. A lysimeter pan was installed under each plot by digging a slit in the wall of a size that one edge of the pan was flush with the trench wall. Then, soil was packed tightly around the pan and the wall was braced with timber, to prevent movement of the soil or pans. Washed, coarse gravel was added to the pans before installation. No suction apparatus was employed in the lysimeters. This type of lysimeter installation was first used by Ebermayer (1879, 1897) and described again by Joffe (1932). Joffe believed that it was a much preferable system for percolation studies relative to systems where side walls or disturbing of the soil are necessary. Kardos (1948) also utilized similar pan lysimeters effectively in studying percolation on sloping land.

The four lysimeter plots were labeled L_1, L_2, L_3, and L_4; and were planted in no-tillage and conventional tillage corn, with L_1 and L_3 being no-tillage and L_2 and L_4 being conventional tillage each year. The bluegrass (first year) and rye (*Secale cereale* L.) (subsequent years) present on the no-tillage plots were killed with a mixture of 0.28 kg (active ingredient) of paraquat and 2.24 kg (active ingredient) of atrazine/ha 2 weeks prior to planting. The conventional tillage plots were hand spaded at that time and also treated with atrazine and paraquat at the above rates. This procedure was used in the two growing seasons considered in this study, 1973 and 1974. Corn was planted in mid-May both years. The corn was four rows wide with 90 cm between each row and a spacing between each plant of 15 cm giving an approximate plant population of 71,730 stalks/ha in both seasons. Pioneer 3369A corn was used. Nitrogen as NH_4NO_3 was broadcast at planting (middle of May) at a rate of 168 kg/ha in *both* years with chloride as KCl broadcast *only* in 1973 at 396 kg/ha.

Corn was harvested in late September in 1973 and early October in 1974. Leachate percolating into the lysimeter pans was collected in 20-liter plastic jugs. Volumes of leachates were measured after rains and a 1-liter sample was collected and stored under refrigeration. The leachate was analyzed for nitrate and chloride. Problems were encountered with the lysimeter pan L_4 under conventional tillage. It collected only very small amounts of leachate from November 1972 through July 1973. Therefore, it was not used during this first collection period in determining data for conventional tillage. In November 1973 pan L_4 began operating just as efficiently as the other three pans and was, therefore, used from November 1973 to

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[3]V. L. Quisenberry, Jr. 1974. Soil water percolation displacement relative to initial water content under field and laboratory conditions. Unpublished Doctoral Dissertation. Univ. of Kentucky, Lexington.

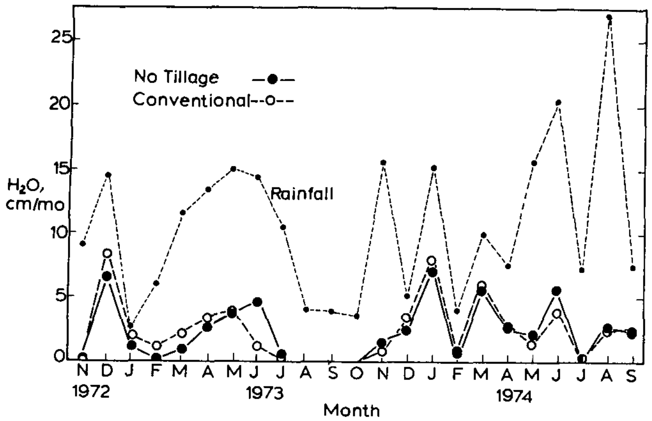

Fig. 1—Monthly water flow from no-tillage corn and conventional corn into lysimeter pans installed at 106-cm depth. Monthly rainfall also is shown.

September 1974 in conjunction with the L_2 lysimeter pan for average conventional tillage leachate volumes and anion losses. The data under no-tillage are averages of L_1 and L_3 pans in both collection periods.

Nitrate concentration was measured using a slightly revised method of Lowe and Hamilton (1967). The method uses *E. coli* to reduce the nitrate to nitrite, which then reacts with N-(1-Naphyl) ethylene diamine dihydrochloride. The leachate was analyzed for chloride ion using a Buchler-Cotlove Automatic Chloride Titrator.

The four corn plots were sampled with a soil tube at 15-cm intervals to various depths at 15 different times during the 2 years. Two 15-cm cores were taken at each depth from two locations on each plot. No samples were taken directly over the pans, but water content was compared over the pans and away from the pans by newton probe. No water buildup relative to the rest of the plot was ever measured in moisture access tubes installed to a depth of 75 cm directly above the center of the pans.

The soil was also analyzed for nitrate and chloride concentrations. The concentration of nitrate in the soil samples was determined using an Orion nitrate electrode in conjunction with a Orion calomel electrode as a reference. Millivolt readings were determined with a Beckman Research pH meter.

The analysis for chloride consisted of leaching 20-g samples of the soil with 100 ml of deionized water. An aliquot of 4 ml of this solution was analyzed using the Buchler-Cotlove Chloridometer by the procedure used for chloride in the lysimeter leachate, described previously.

RESULTS AND DISCUSSION

Figure 1 shows the monthly amounts of rainfall and leachate for the period of November 1972 to October 1974 under no-tillage and conventional tillage. Flow began in late November 1972, the amounts of leachate were highest in December and dropped considerably in January owing to very low rainfall. Amounts collected remained low in subsequent months relative to rainfall. The amounts collected under conventional tillage were slightly higher than under no-tillage, which may have been collection error. However, this general trend was reversed in May and June. As the temperature increased in June, the surface mulch conserved the soil water in the no-tillage plots, resulting in a greater volume of water flowing to the 106 cm depth. A leachate volume of 4.5 cm was collected under no-tillage with only 1.2 cm collected under conventional tillage. A large part of this difference came about on 27 June. The period from 1 June through 27 June was one of relatively low rainfall (7.1 cm) and high open pan evaporation (13.7 cm). After the intense

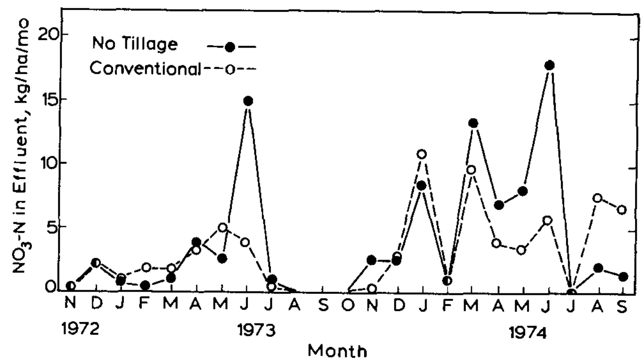

Fig. 2—Amounts of NO_3-N in lysimeter pan leachates on a monthly basis.

rainfall of 6.1 cm on 27 June, the no-tillage pans collected an average of 2.2 cm of water relative to only 0.1 cm collected under conventional tillage. This was indicative of the soil water differences that can arise between the two tillage systems (Blevins et al., 1971). In July leachate volumes were small under both systems with flow ending in mid-July owing to the high evapotranspiration rates.

Flow did not begin again until November 1973. Subsequent leachate collections were essentially equal under the two systems except in May and June when water flow under no-tillage was again considerably higher. In May 2.00 cm were collected under no-tillage relative to 1.42 cm under conventional tillage. In June even greater differences were evident with leachate volumes of 5.7 cm under no-tillage compared to 3.8 under conventional tillage. A more general agreement with rainfall patterns than in the previous year is also evident (Fig. 1). The period from May through August (except July) was one of higher-than-normal rainfall. In June, 20.4 cm of rain fell (10.9 cm, 30-year average) and in August 27 cm fell (8.6 cm, 30-year average). This high rainfall resulted in water flowing to the 106-cm depth in August and September. Flow into pans ended by mid-September.

Figure 2 shows the amounts of nitrate nitrogen in the leachate versus time from November 1972 to September 1974. In May 1972, ammonium nitrate had been applied to the plots, and when flow to 106 cm began in November 1972 very little nitrate was found in the leachate. Amounts remained low and were affected only by amounts of leachate until after May 1973. In mid-May the corn was planted and ammonium nitrate was reapplied to the plots. A large difference in amounts of N in the leachate water was found in June between the two systems. The monthly leachate under no-tillage contained a total of 14.7 kg/ha compared to only 4 kg/ha under conventional tillage. As seen in Fig. 3, soil sampling also showed these leaching differences. The concentrations in the leachate at the beginning of June were relatively low and ranged from 5 to 17 ppm in the leachate collected on 6 and 7 June. Between 17 June and 21 June, 3.3 cm of rainfall occurred; the leachates resulted from these rains ranged in concentrations from 24 to 81 ppm. These concentrations were too high to have been displaced from the lower part of the profile. It seems that at least a part of the nitrogen from near the surface was moved to the 106-cm depth.

Very high concentrations of nitrate nitrogen were also

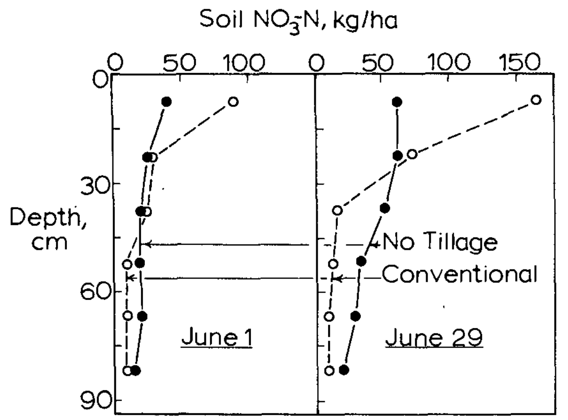

Fig. 3—NO_3-N in the soil above lysimeters on 1 June and 29 June 1973.

observed on 28 June after 6.1 cm rainfall on 27 June. Concentrations in the 2.2 cm of leachate under no-tillage collected on 28 and 30 June ranged from 35 to 75 ppm. On 29 and 30 June a small amount of 0.1 cm was collected under conventional tillage, and this water also had concentrations of 78 and 81 ppm. Surprisingly, on 5 July 1973 the water resulting from a 2.29-cm rainfall before flow ended showed much lower concentrations of nitrate ranging from 5 to 14 ppm. The final leachate collected on 16 July 1973 was approximately 1 liter under both systems and showed relatively very low concentrations of 5 to 6 ppm.

Lawes et al. (1882), in considering the Rothamsted monolith lysimeter data, concluded that the large fluctuations in chloride and nitrate concentration in leachate indicated that the drainage was through root holes, worm holes, and fissures in the soil. Cole et al. (1961) found nitrate concentrations in lysimeter leachates going from 90 ppm to 28 ppm after 3 days of intense precipitation. Then the first leachate collected after rainfall 7 days later again showed very high nitrate concentrations. Ehlers (1973) and Quisenberry (1974)[3] both observed that mobile ions such as nitrate and chloride could move with water that was channelized in large, naturally occurring soil cracks and channels especially after intense rainfall. In other words, the concentrations of these ions vary with time due to the initial flow being channelized near the surface with final leachate being drainage from smaller channels more directly involved with the soil mass.

With initial flow in late November only small amounts of nitrogen were lost. The leaching losses increased greatly in January, fell significantly in February, and increased again in March generally flowing the pattern of leachate volumes as seen in Fig. 1. The same trends were evident in April and May.

Corn was again planted in mid-May with ammonium nitrate applied to both the conventional and no-tillage lysimeter plots. Again, as in 1973, the amount of N lost in June under no-tillage was much greater than that under conventional tillage with 17.9 kg/ha lost relative to 6.1 kg/ha N. These large losses of N in June of both years demonstrate the critical nature of this leaching period.

Very little water flowed to the 106-cm depth in July and only small amounts of nitrate were recovered in the leachate. A reversal of the leaching trends occurred in the very wet month of August. More nitrate was lost in both August and September under conventional tillage relative to no-tillage indicating a residual amount of nitrate which had not been lost under the conventional plots.

Problems with nitrate-leaching studies include immobilization, mineralization, and plant uptake which result in different amounts of nitrogen available for leaching. Yields of corn for 1972 through 1974 averaged 11,100 kg/ha for no-tillage and 10,900 kg/ha for conventional tillage so that N removal by the grain alone was in the neighborhood of 160 kg/ha each year, about the quantity applied. Larger losses of N under no-tillage are even more damaging than under conventional tillage owing to higher mineralization under conventional tillage (McMahon and Thomas, 1976). Therefore, there is more N available in spring and summer under conventional tillage even without fertilization. Denitrification was thought to be a minor factor on this soil type since measurements of redox potential have shown that reducing conditions are rarely present on this well-drained soil (R. L. Blevins, unpublished data, University of Kentucky, 1969).

These factors do not affect the chloride ion, which moves in much the same way as nitrate (Corey et al., 1967). Therefore, chloride was applied in May of 1973 on an equivalent basis with nitrate to act as a tracer. Very small amounts of chloride, 3.6 kg/ha under no-tillage and 1.0 kg/ha under conventional tillage, were collected during the first leachate period since chloride was not applied till mid-May and water flow ended in July. Variations in chloride concentration occurred under the two systems in this short period of time. On 25 June the chloride concentrations were low, ranging from 3 to 5 ppm, under both systems, but on 28 June they had increased to between 12 and 16 ppm in leachate from no-tillage but were still low in the leachate under conventional tillage. The high concentrations of NO_3-N reported above may be rationalized with the chloride data in two ways. First, there was a high concentration of NO_3-N in the surface soil before fertilization and second, the entire profile was higher in NO_3-N than in chloride. Figure 4 shows the amounts of chloride found at various depths in the soil on analysis of soil samples. The chloride had moved deeper in the no-tillage plots on both dates, with significantly more chloride much deeper in the profile on 29 June 1973.

Figure 5 shows the chloride losses in the leachate from November 1973 to September 1974. Even though the

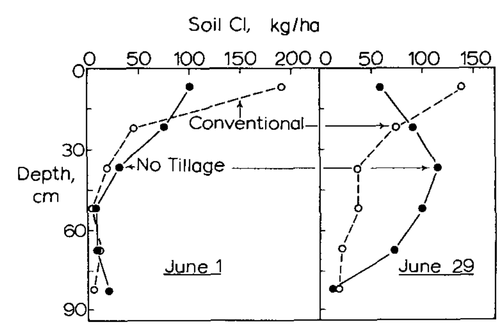

Fig. 4—Chloride in the soil above lysimeters on 1 June and 29 June 1973.

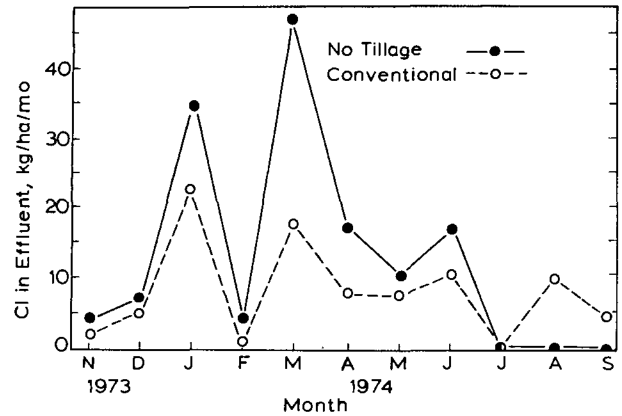

Fig. 5—Chloride flowing from lysimeter pans on a monthly basis.

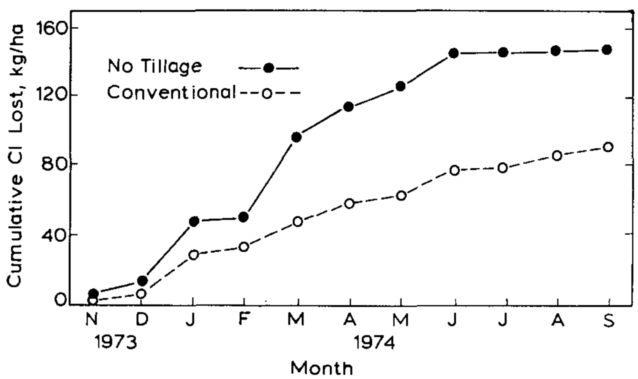

Fig. 6—Cumulative chloride loss from lysimeters (396 kg/ha applied) Black circles are no tillage; open circles are conventional tillage.

amounts of leachate were nearly equal for both tillage systems for all months of this period except May and June, the amounts of chloride collected were always higher under no-tillage until August and September. This difference was especially significant in March. The water under no-tillage contained 44 kg/ha chloride, whereas the conventional tillage pans collected leachate containing 17 kg/ha. The chloride concentrations under no-tillage averaged approximately 80 ppm during most of the month. Under conventional tillage they averaged 45 ppm or less.

The trend was reversed in August exactly as with nitrate (compare Fig. 2), with some of the residual chloride under conventional tillage reaching the 106-cm depth. Throughout the period, chloride leaching patterns show the significant differences in the leaching efficiency of water between the two systems.

Figure 6 shows cumulative chloride versus time for both systems. From May 1973 to September 1974, the total amount of chloride accounted for in the leachate water from no-tillage plots was only 145.5 kg/ha or 37% of that applied. Under the conventional system 90 kg/ha was found in the leachate accounting for only 23% of that applied. Therefore, a large percentage of chloride applied was still contained in the soil profile. It is apparent that chloride moved very nonuniformly with the soil water, and much larger amounts of water than a single pore volume were required to displace the chloride above the pans. The Maury soil does not significantly adsrob chloride or nitrate; therefore, this did not affect the ion movement (McMahon and Thomas, 1974). This again indicates that water was at times bypassing much of the soil holding the chloride and flowing through the cracks and channels present.

This possibility of large amounts of surface-applied nutrients being rapidly lost on well-structured soils such as the Maury silt loam is evident especially in May and June. Therefore, delayed application of N on corn from 4 to 6 weeks after planting would seem advisable, especially when using no-tillage. In this way the leaching losses can be minimized by avoiding this critical leaching period.

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