CORN YIELD AND WATER USE AS INFLUENCED BY SPLIT APPLICATIONS OF NITROGEN FERTILIZER

by

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INTRODUCTION

The use of commercial fertilizers is very important in modern agriculture. Nelson (1972) stated that we can no longer provide sufficient food to meet the needs of a growing population without fertilization. Chemical fertilizers have become so necessary for man's well-being that to attempt to eliminate their use would meet with dire consequences. The developing nations of the earth must rely upon them strongly because their rapid population growth renders the food supply inadequate which results in starvation. In addition, their soils have become more depleted in plant nutrients than those in developed nations (Nelson, 1972). The production of high yield varieties of the "Green Revolution" would be impossible without high rates of fertilizer coupled with perticides, sufficient water, and proper management (Nelson, 1972).

Fifty percent of the yield increase per acre in the United States between 1940 and 1964 was due to the increased use of chemical fertilizers (Christensen et al., 1964). In 1964, corn (*Zea mays* L.) received 40% of all the fertilizer applied to crops in the United States (Ibach and Adams, 1967). Davide (1961) found that the quality of corn seed increased, in addition to increased ear girth and average ear weight, because of nitrogen fertilization. Kohnke and Vestal (1948) and Galvez et al. (1956) found that fertilization increased the protein content of corn grain. Viets and Domingo (1948) found yield increases in hybrid corn due to nitrogen fertilization and Galvez et al. (1956) found that this was true regardless of the hybrid or variety.

Of all chemical elements applied to crops, nitrogen is applied in the greatest amount, but the recovery of added nitrogen is seldom above 50-70% and is often less (Allison, 1966). Increased use of nitrogen fertilizers is often associated with increased ground water pollution. Large nitrate concentrations in drinking water is dangerous to human and livestock health. In 1945, it was suggested that well water containing greater than 10 ppm nitrate should not be used for infant feeding (Comley, 1945). Since that time, the U.S. Public Health Service has set 10 ppm nitrate-nitrogen as the maximum allowable concentration for drinking water (Stewart, 1970). There are differing opinions concerning the source of nitrate-nitrogen in ground water. Nelson (1972) stated that more must be learned about the potential pollution sources before standards are set and restrictions placed on certain areas.

Harmeson and Larson (1970) stated that differences between nitrate levels in streams flowing through agricultural areas and those flowing through nonagricultural areas are due to chemical fertilizer use. Ward (1970) claimed that large nitrate concentrations of ground water in agricultural areas of the United States are due to chemical fertilizer use, especially in the western United States. Bolton et al. (1970) found the average nitrogen loss due to leaching, mainly as nitrates, was greater under corn than under any other crop that he studied. This was true when corn was grown continuously or in rotation. Muir et al. (1973) reported that the extent of ground water pollution is governed by human and livestock densities and intensity of irrigation development. They stated that only under intensive irrigation on sandy soils, with a shallow water table, is there substantial ground water quality reduction.

Pratt et al. (1972) suggested that decreasing the pollution of ground water is possible by high production. Good irrigation management and wise fertilizer use are very important in reducing the pollution potential. A possible way of reducing the amount of nitrates moving downward to the ground water is to apply the nitrogen when the crop needs it most. Doing this will reduce the amount of nitrogen applied at any one time, limiting the nitrate build-up and reducing leaching (Nelson, 1972). Side-dressing of nitrogen fertilizers has been practiced for many years. Another method of supplying nitrogen for timely plant needs. is to apply nitrogen with irrigation water.

The literature indicates that chemical fertilization may lead to ground water pollution. A possible method of reducing the ground water pollution potential is to apply the fertilizer in smaller quantities, but more often. Supplying plant nutrients when they are needed most may help reduce pollution because of reduced leaching potential and because the total quantity of added chemicals may be reduced. Several factors, including crop yield and quality and efficiency of water used, may be influenced by method of nitrogen application.

We applied a nitrogen fertilizer solution in the irrigation water and broadcast applied urea in an attempt to answer the following questions:

1. How significant is nitrate leaching when nitrogen fertilizer is preplant, broadcast applied to a deep silt loam soil?

2. Is nitrate leaching altered by realistic nitrogen application rates or by method of fertilizer application (preplant broadcast as opposed to split, in-season applications with irrigation water?

3. Can the total nitrogen fertilizer applied to corn on this deep silt loam soil be reduced by supplying the nitrogen in split applications?

4. What influence does split applications of nitrogen fertilizer have upon corn yield, dry matter production, nitrogen content of leaves, and nitrogen content of grain?

5. Is corn water use efficiency altered by split applications of nitrogen fertilizer?

LITERATURE REVIEW

The use of chemical fertilizers, especially nitrogen, is essential for the production of large corn yields. The efficiency of corn in using applied nitrogen ranges from 30 to 70% (Larson and Hanway, 1977). The rate at which nitrogen is taken up is dependent upon: "1) kind of plant, 2) developmental stage, 3) nitrogen supply in the soil and factors affecting its availability, and 4) the total N uptake for the final dry weight produced" (Viets, 1965). The rate at which corn absorbs nitrogen is low early in the season, but the rate increases as the plant develops. Absorption continues at a rapid rate until the plant reaches maturity. As the grain develops, nitrogen is translocated from other plant tissues to the grain (Hanway, 1962). With low nitrogen absorption rates early in the season, the possibility of nitrate leaching is high, especially on coarse-textured soils.

The amount of nitrogen lost through leaching depends upon several variables, including: "a) form and amount of soluble and unadsorbed nitrogen present or added, b) amount and time of rainfall, c) infiltration and percolation rates, which are affected by soil composition, texture, structure, depth of profile, and surface treatment, d) water holding capacity of the soil and its moisture content throughout the profile at the time a rain occurs, e) the presence or absence of a crop and its growth characteristics, f) evapotranspiration, and g) rate of removal of the nitrogen in the soil during periods of drought" (Allison, 1965).

Pratt et al. (1972) listed three factors that they considered important in determining the amount of leaching: "i) the volume of drainage water, which is obtained if we know the leaching fraction and the evapotranspiration, ii) the yearly excess of nitrate available for leaching, which can be obtained from fertilizer rates minus removal in harvested crops, and iii) an estimate of denitrification."

Edwards et al. (1972) listed two important reasons for reducing the amount of nitrate leaching: 1) economics, the extra cost necessary to keep sufficient nitrogen present in the rooting zone and 2) leaching nitrates are a potential ground-water pollutant. Thomas (1970) stated that the irrigated soils of the western USA lose more of their nitrates to ground and surface waters than anywhere else in the country. In Wisconsin, Olsen et al. (1970) found that no more than 15 kg/ha nitrate-nitrogen can be allowed to leach in order to keep the nitrate-nitrogen concentration of the soil solution below 10 ppm.

Stout and Burau (1967) and Smith (1967) suggested that the soil fertility level is a more important factor in nitrate accumulation than is the source, leading to the assumption that soil fertility level is also an important leaching factor. Nightengale (1972) found in California that soil nitrate variability could be correlated with farming practices, cropping pattern, fertilization, etc. He said that larger rates of N fertilization do not necessarily mean higher soil nitrate levels, indicating that large soil nitrate content is related to the nitrogen use pattern of the crop. He emphasized the fact that excessive nitrate-nitrogen losses will result when crops are over-fertilized.

Ludwick et al. (1976) found in a clay loam soil in Colorado that the nitrate concentration at a depth of 300 cm increased with increasing nitrogen fertilizer application rates. They also found soil nitrate accumulation began before nitrogen rates necessary for maximum yields had been applied. Nitrates will not move appreciably below the root zone of a properly fertilized crop unless rainfall and irrigation are in excess of crop needs (Stanford, 1969; Schuman et al., 1975).

Research done by Smika et al. (1977) on sandy soils in Colorado found a direct correlation between the amount of nitrate-nitrogen leached and the amount of water moving through the soil. They reported that 1 cm of water percolating to a depth of 150 cm moved 10.2 kg/ha nitrate to that depth.

The depth to which nitrates leach is dependent upon the amount of water entering the soil. The amount of rainfall in each storm is an important factor in determining the effect on leaching as is the total rainfall during periods of high evapotranspiration. During low evapotranspiration periods, a low-intensity, long-duration rainfall is probably more important for leaching because of the low runoff rate (Thomas, 1970; Schuman, 1975). Terry and McCants (1974) reported results in North Carolina that indicated frequent small showers are more effective for leaching nitrates than are infrequent large ones. With small showers there is more water infiltration and as a result more water percolates down through the soil. Persistent rains of long duration are necessary to leach nitrates from both coarse and fine soils (Gasser, 1959; Cunningham and Cooke, 1958). Fiskell and Locasio (1975) found that the rainfall intensity and duration were major factors influencing leaching losses on their soils.

Several workers (Stauffer, 1942; Bates and Teasdale, 1957; Stewart, 1970; Thomas, 1970; Terry and McCants, 1974) have found nitrate leaching to be closely associated with the amount of percolating water. Stewart (1970) stated that the nitrate concentration of percolating water is dependent upon the amount of water moving through the soil and the amount of nitrate lost from the soil. The amount of water moving through the soil determines the leaching rate.

Krause and Batsch (1968) found that fall applications of ammonium nitrate resulted in losses as high as 88% of added nitrate when the applications were made to the Tioga fine sand in Ontario, Canada. Graetz et al. (1973) found on a Eustis fine sand in Florida planted to millet (*Pennisetum typhoides* [Burm.] Stapf and Hubbard), when nitrates were not incorporated into the plant system, 45% of all the fertilizer added was leached below 150 cm. A significant part of the 45% was found at 120 cm following a 5.9 cm rain which occurred six days after planting. Endleman et al. (1974) found that nitrates could be leached 15 to 20 cm with 2.5 cm of water on the plain field loamy sand in Wisconsin. On soils planted to potatoes (*Solanum tuberosum* L.), a 7.5 to 10 cm rain could effectively remove nitrates from the 45 to 60 cm rooting depth.

Nelson (1953) found that corn planted on the Ephrata fine sandy loam overlying gravel, must be irrigated carefully in order to keep the nitrates from leaching into the gravel. He found no difference in movement between side-placing, side-dressing, split applications, and broadcast of 134 kg N/ha as ammonium nitrate.

The data of Ludwick et al. (1976) suggest that most absorption of nitrogen by corn occurs between 0 and 120 cm. In addition, they also found that 50-75% of the profile nitrates accumulated between 120 and 300 cm. The need to minimize leaching is obvious, and they suggested that an irrigation program be formed that will help increase yield and yet decrease leaching.

Leaching is high when the added water, rainfall plus irrigation, exceeds evapotranspiration. This is especially true on soils with low water holding capacity, growing shallow rooted crops, and where the fertilizer is applied in a manner conducive to producing high nitrate concentrations in the soil (Nelson, 1972).

In California, Nightengale (1972) found that soils planted to certain crops allow more nitrate leaching than other soils with similar physical properties planted to the same crops. The high nitrate requirement of orchard and truck crops results in greater leaching because of high nitrogen application rates.

A growing crop can minimize the downward movement of nitrates by direct assimilation of the nitrogen and by evapotranspiration reductions of leachate (Nightengale, 1972). There are instances where a crop may enhance nitrate leaching. Rapid infiltration due to the fibrous root system of grain sorghum (*Sorgham bicolor* L.) on the Harlingen clay was found to increase nitrate leaching (Hipp and Gerard, 1973).

Several methods have been tried to reduce the extent of nitrate leaching. Among them is the use of a nitrification inhibitor in anhydrous ammonia (Cochran et al., 1973). Kemper et al. (1975) found that a siliconate material applied over a fertilizer band was effective in reducing leaching from the band. Nelson (1972) suggested the development of slow-release fertilizers to minimize periods of high nitrate concentration. Stauffer (1942) suggested the use of a cover crop to reduce leaching. He also recommended that straw mulches not be used in humid areas because they increase infiltration.

In many areas the leaching problem has been increased through the use of irrigation. Irrigation provides more water to move through the profile, increasing the leaching potential. There are many benefits that can come from irrigation in spite of the leaching problem. Holt and Timmons (1968) reported that yield of fertilized corn is influenced by the amount of water stored in the soil and the annual rainfall distribution, indicating that the amount of available water has a great effect on the use of plant nutrients.

The major purpose of irrigation is for the "improvement of the plants' moisture environment." There are two things governing the water needed per irrigation: 1) amount of usable water stored and 2) the depletion rate (Robins et al., 1967). They also cited results of several workers indicating that moisture stress on corn is most critical between tassel emergence and completion of pollination. Moderate stress during this time may result in considerable yield reduction. In addition, delayed silking due to low soil fertility may result in low yields because of poor pollination. Larson and Hanway (1977) reported that maximum corn yield reduction caused by deficient water occurs when the deficiency occurs at anthesis (flowering). They reported corn grain yield reductions of as much as 53%.

The use of irrigation puts more demands on the soil nutrients. In order to make irrigation profitable, crop yields must increase and as a result, crop nutrient needs also increase (Viets et al., 1967).

Soluble nutrient movement in the soil is largely dependent upon "the method and frequency of irrigation." Proper irrigation management should include some knowledge of the soil nitrate status (Viets et al., 1967). Applying irrigation water in excess of that needed to recharge the root zone generally causes leaching of soluble nutrients, especially nitrates. The amount lost depends upon the amount of nitrates present in the soil (Robins et al., 1967). Nelson (1972) suggested that one must be careful to avoid overirrigation, especially when large quantities of nitrate are present in the soil.

Stanford (1973) suggested several variables that need consideration when determining the rate of nitrogen fertilizer application. He listed the primary factors as "attainable yield of dry matter and the associated quantity of N in the crop."

Stanford (1973) cited the findings of several authors indicating that recovery of added N depends upon the following factors: "1) rate of N application, 2) time of N application, and 3) growing conditions affecting yield potential, e.g., soil properties, other essential nutrients, soil, management, climate, rainfall, and irrigation practices."

Lund et al. (1974) stressed the importance of soil profile characteristics when large nitrogen applications are recommended. Herron et al. (1971) found that residual N increased with moderate to heavy fertilizer application on fine textured soils, even though high crop yields were being obtained.

The use of nitrogen fertilizer has been shown to increase the nitrogen content of corn grain and leaves (Smith, 1952; Carlson et al., 1961; Kurtz and Smith, 1966; Reichman et al., 1959; Jordan et al., 1950). Viets and Domingo (1948) and Lang et al. (1956) found this to be true regardless of the corn hybrid or variety.

Earley and deTurk (1948) found that fertilization for maximum yields of corn was sufficient to produce adequate grain protein content.

They also found on nitrogen deficient soils smaller application rates resulted in low corn grain protein content, even though the grain yield increased. Boswell (1959) found corn grain protein content to decrease at a given rate of nitrogen fertilizer application when irrigated as opposed to dryland. He also found grain protein content decreased with increased yield at the same nitrogen application rate.

In North Dakota, Carlson et al. (1961) found that late June nitrogen side-dressing of corn did not increase leaf nitrogen content. They found nitrogen fertilization increased the total grain and forage protein content of corn. Stevenson and Baldwin (1969) found corn grain nitrogen percentages to be smaller when the fertilizer was fall applied than when spring pre-plant or side-dress applied. The results of Prabhakaran Nair and Singh (1974) indicate that nitrogen applications made at tasseling tend to increase the nitrogen content of the grain.

Bauer and Young (1966), studying fertilizer effects on consumptive water use, found an increased wheat (*Triticum aestivum*) yield of 808 kg/ha with a 1.5 cm increase in water use. Olson et al. (1960) were able to increase wheat yields with little increase in water use and Viets (1962) and Hanway (1966) stated that consumptive water use of corn is increased very little by fertilization. Musick et al. (1963) found seasonal consumptive water use for irrigated grain sorghum to be increased only slightly by fertilization. Barber and Olson (1968) reported increases in consumptive water use of corn with fertilization, but Carlson et al. (1959) found no difference in evapotranspiration between fertilized/nonfertilized corn. Rhoades and Nelson (1955) stated that the amount of water used by a corn crop is increased by irrigation, plant population, and fertilization because all these factors lead to increased crop growth.

Henderson et al. (1963) have defined water use efficiency as "crop yield per unit of water actually used by the crop plus unavoidable evaporation losses from the soil." Pendleton (1966) stated several reasons for fertilization, with two of them being important in increasing water use efficiency. They are: 1) the creation of a large plant canopy which helps reduce soil surface evaporation and 2) the yield increase obtained per unit of water added. Ferguson (1963) found wheat yield increased with fertilization and the yield increase was greater than the increased evapotranspiration.

Timing of irrigation is important in increasing the water use efficiency of corn. Howe and Rhoades (1955) found two well timed irrigations were as efficient as 3 to 6 poorly timed irrigations for increasing corn yield. They found high soil water content just prior to tasseling through maturity to be essential for high grain production.

Viets (1962) stated that the water use efficiency of a crop under irrigation generally decreases for a given fertilizer amount as compared to dryland. He also stated that water use efficiency may be very high, and yet yields be extremely low. In most cases, though, fertilization increases water use efficiency of irrigated crops because of increased growth.

Brown (1971) working with dryland winter wheat and Musick et al. (1973) working with irrigated grain sorghum, found water use efficiency increased by as much as 50% when nitrogen fertilizer was applied. Stanberry and Lowrey (1965) found tremendous increases in water use efficiency of irrigated barley because of fertilization. They found grain yield increases as 3930 kg/ha with essentially no difference in consumptive water use.

Olson et al. (1964) found average water use efficiency increases of 29% because of proper fertilization of several crops including corn. Carlson et al. (1959) stated that adequate fertilization is essential in making the most efficient use of water.

The timing of fertilization seems to be an important factor in efficient use of nitrogen fertilizer. Several workers have determined that fall fertilizer applications are not as efficient as spring applications in producing increased yield and crop quality (Krause and Batsch, 1968; Stevenson and Baldwin, 1969; Miller et al., 1975). The problem being due in part to the chemical formulation of the fertilizer at the time of application. Losses are greater when nitrates are used in areas with high winter precipitation. Thomas (1970) suggested that late fall applications of nitrogen fertilizer may be made in cold climates and they may be as effective as spring applications. Neither are very good though, if there are heavy rains in the late spring. Boswell (1971), in Georgia, found that time and method of nitrogen fertilizer application had no effect on corn yield on the Cecil sandy loam. He also found that fall applications were not as good as winter or spring on the Norfolk loamy sand. As a result, he suggested that soil texture should be an important factor in timing of nitrogen fertilizer applications.

On nitrogen deficient soils, yields are often greater when an application of nitrogen fertilizer is made when the plants are half grown. This increase may be due to decreased leaching, decreased denitrification, or the increase of grain yield being greater than straw yield increase (Viets, 1965). In Wisconsin, Jung et al. (1972) found that the most effective time for in-season application of nitrogen fertilizer to corn was between the 7th and 8th weeks after planting. When applied later than eight weeks the grain and tissue yields decreased. Inadequate morphological development, and consequently, decreased nitrogen assimilation efficiency were given as the reasons for this decrease.

Herron et al. (1971) found that residual N in a 180-cm profile was higher when a corn crop was summer side-dressed than when preplant applications were made. They felt this difference was due to denitrification and leaching losses in early spring prior to crop utilization of the fertilizer.

Increasing the efficiency of nitrogen used as a fertilizer in tropical countries is especially critical. High temperatures and large amounts of rainfall increase the nitrate leaching rate. Splitting the nitrogen applied to corn into five equal parts; planting, 20, 30, 40 days following planting, and at tasseling gave high yields regardless of the rainfall amounts. This indicates that when rainfall is high, nitrogen should be applied in several small applications (Prabhakaran Nair and Singh, 1974).

Rice (*Oryza sativa*) also responds well, in tropical countries, to delayed nitrogen fertilizer applications. Chandraratna (1962) found significantly higher rice grain yields with application of ammonium sulfate 30 days before heading. He also found that splitting the application with 1/3 on each of 3 dates was as effective as all of the nitrogen being applied at ear initiation.

Schreiber and Stanberry (1965) found split application of nitrogen fertilizer increased yields of barley (*Hordeum vulgare*) over the control. They found their greatest yields to come from planting and pollination applications. In addition, they found the planting application to be essential for high yields even though nitrogen applications were made later in the season. The single nitrogen application at pollination yielded 1123 kg/ha less than the single planting application.

Herron et. al. (1968) found that nitrogen summer side-dressed was a better method for increasing corn yields then either fall or spring applications.

Application of nitrogen fertilizers in irrigation water is receiving considerable attention. This fertilizer application method was tried as early as 1936. The first use of anhydrous ammonia as a fertilizer was when it was placed in irrigation water (Rosenstein, 1936). Warnock (1966) listed four advantages of nitrogen fertilizer applications in irrigation water. These are as follows: "1) Less labor and equipment are required for application. The need for equipment and power to 'knife' the ammonia into the soil is avoided. 2) Nutrient supply can be regulated to coincide with the demand by the growing crop. 3) Soil compaction by heavy application equipment is eliminated. 4) Nutrients may be applied when crop or soil conditions would prohibit fertilization by other conventional means."

One primary purpose in applying nitrogen fertilizers with irrigation water is to help the plant be a more efficient user of applied nitrogen by placing the nitrogen where and when it can be used most effectively. This is especially true in late season when the crop may run short. Under certain conditions this application method may be the only possible way of supplying needed nutrients (Viets, 1967). There are at least two criterion that must be met by the fertilizer material for application with irrigation water. 1) It must be completely soluble and enter solution rapidly, and 2) it must not react with materials in the water (Viets et al., 1967).

Rehm and Wiese (1975) found significant corn grain yield increases on sandy soils when nitrogen fertilizer was side-dressed 30 days after planting and with additional nitrogen applied with the irrigation water. They also found silage yields to be significantly greater for this treatment than when all nitrogen was applied pre-plant. The nitrogen content of the ear leaf was found to be greater in this treatment than when all nitrogen was applied pre-plant.

Smika et al. (1977), found in Colorado, that the amount of nitrate-nitrogen content in soils was lower when applications to corn were made through the irrigation system on seven different occasions. The small amounts of nitrogen applied were absorbed quickly by the plants and did not accumulate in the soil. Therefore, there was not an appreciable amount of nitrate present to be leached.

Application of fertilizer in the irrigation water increases the need for more efficient and more accurate irrigation. When furrow or flood irrigation is used, water percolation is higher at the beginning of a run than at the end. The use of ammonia instead of nitrates or urea may result in reduced leaching because of its adsorption on the soil exchange complex (Warnock, 1966). Application of nitrates in irrigation water creates a potential for pollution of surface waters because of high nitrate content of the runoff water, but with proper timing, nitrate application in the irrigation water places the fertilizer in the crop root zone (Edwards et al., 1972).

Fischback (1964) has given some suggestions for application of fertilizer in the irrigation water. He suggested runs be no longer than

183 m for sandy soils and 396 m for clay soils when surface applications are made. When the run is too long, excessive leaching may occur on the upper end and the lower end may receive inadequate water.

After ammonia is applied in irrigation water it is adsorbed in the top 5 to 8 cm of soil. On row crops this may be above the rooting zone, and during part of the dry period between irrigations, the nitrogen is not available for efficient plant use. When the ammonia is converted to nitrate it is moved downward into the root zone with the next irrigation (Warnock, 1966).

A major problem with the use of ammonia in irrigation water is volatilization, both during application and during solid drying following the irrigation. Warnock (1966) cited other workers who recommend that up to 10 kg of ammonia nitrogen per 105 kiloliters of water may be successfully applied in surface irrigation water before volatilization becomes a major loss factor. Mulliner and Frank (1975) stated that application of anhydrous ammonia in irrigation water is not affected by high soil moisture immediately following application. Other work indicates that as water temperature increases, volatilization losses from the water also increase (Warnock, 1966). Fischbach (1964) and Warnock (1966) discourage the use of anhydrous ammonia for application in irrigation water, and state that volatilization losses was the major drawback. They also stated that precipitation of insoluble materials in the water is a major problem. Warnock (1966) and Mulliner and Frank (1975) indicate that the latter problem may be alleviated through the use of an inhibitor.

Warnock (1966) cited Chapman's findings of decreases in ammonia concentration as high as 50% in irrigation water under furrow irrigation, due to volatilization and/or soil fixation. Henderson et al. (1955) studied the ammonia loss from irrigation water when applied through sprinkler jets. They found volatilization losses to be very high, especially at low ammonia concentrations and solution pH greater than 8.0. The loss percentage decreased as the concentration increased. They also found increasing water temperature increased ammonia loss. They suggested that when applying any ammonia salt in water with a pH greater than 7.5 the smallest amount of water possible should be used that will not harm the crop or irrigation system (Henderson et al., 1955). Leavitt (1966) reported that even when ammonia fertilizer is applied in the irrigation water, some dry fertilizer should be applied early to supply the needs of the young crop.

Uneven application because of wind distortion of the water pattern may result when sprinkler applications of ammonia are made (Warnock, 1966). Bryant and Thomas (1958) found that dissolved nitrates and urea applied through sprinkler systems have a more uniform distribution over the irrigated area.

Injection of urea into irrigation waters for citrus is a regular practice by some farmers in southern California. It has been found that about 67 kg N/ha leached per year from these citrus orchards, this being about 45% of the applied N. For citrus, it is felt that a single small application of fertilizer made at early bloom stage would be more effective in reducing nitrogen leaching losses than split application (Bingham et al., 1971).

MATERIALS AND METHODS

SOIL DESCRIPTION

The study soil is mapped a Eudora silt loam located on unit II of the Ashland Agronomy farm near Manhattan, Kansas (Jantz et al., 1975). The Eudora series is a coarse-silty, mixed, mesic, Fluventic Hapludoll. This soil has developed in coarse silty alluvium on a high flood plain along the Kansas River. It is a nearly level soil, 0-1% slope, and is well drained with moderate permeability. The soil has a high available water holding capacity and releases this water readily for plant use (Jantz et al., 1975).

SITE PREPARATION

The soil was fall plowed and spring disked each year. For weed control, 4.7 liters of Lasso plus 4.7 liters of Bladex were applied per hectare each year. The research area was 76 m north-south by 111 m east-west. This area included 30 research plots plus 12.2 m of border corn on the south, north, and west. The plots were 9.1 m wide and 12.8 m long (an area of 0.012 ha). Each plot contained 12 rows 12.8 m long with a spacing between rows of 76.2 cm. The border corn was included to achieve uniform atmospheric conditions within the research plot area. The research area had been cropped to soybeans for 10 years prior to this study. In April 1977, triple super phosphate was added to the entire area at a rate of 106 kg P_2O_5/ha.

CROPPING

The corn variety used in this study was Prairie Valley 82S. The corn was planted on 10 May 1976 and on 29 April 1977. The corn was thinned to approximately 59,000 plants/ha in 1976 and 56,000 plants/ha in 1977.

Alleyways were disked and the field furrowed for irrigation approximately four weeks after emergence each year. We then plowed a ridge on the west and east ends of each plot with a moldboard plow. This was done to contain the water during irrigation of the plots. Each plot was 12 rows wide but only the inner 10 rows received irrigation. The two rows of nonirrigated corn between each plot were a buffer zone protecting against water containing added nitrates breaking over into another plot.

Table 1 summarizes the corn growth development during 1976 and 1977.

TREATMENTS

Treatments consisted of various nitrogen fertilizer amounts applied pre-plant broadcast (dry) or applied with irrigation water (liquid). Nitrogen was applied with irrigation water at pre-tassel (14-leaf stage) and at early silking. Different amounts were applied pre-plant and different combinations of in-season amounts were used. We applied 180, 135, and 101 kg N/ha pre-plant broadcast using urea (44-0-0).

Split applications of 101 kg N/ha were also studied. Various amounts of the 101 kg N/ha were split applied at pre-plant, pre-tassel (14-leaf stage), and silking. Pre-plant broadcast applications of 0,

Table 1. Corn growth stage development with date of observance (according to Hanway, 1971).

Growth stage		Date	
Number	Description	1976	1977
0	Emergence	19 May	6 May
0.5	2 leaf	25 May	10 May
1	4 leaf	4 June	19 May
1.5	6 leaf	12 June	29 May
2	8 leaf	22 June	6 June
2.5	10 leaf	28 June	13 June
3	12 leaf	2 July	19 June
3.5	14 leaf	8 July	24 June
4	16 leaf	15 July	30 June*
5	Silk emergence	19 July	5 July*
6	Blister	29 July	14 July
7	Dough	10 Aug.	26 July
8	Beginning dent	20 Aug.	5 Aug.
9	Dent	1 Sept.	17 Aug.
10	Physiologic maturity	13 Sept.	29 Aug.

* The treatment plots in 1977 were not uniform in their development. Corn in plots which had received pre-plant nitrogen tasseled on 27 June, but the corn receiving no nitrogen fertilizer to that date was delayed in tasseling. A similar situation existed for silking: some corn was silking, but the corn receiving little or no nitrogen to that date was delayed in silking.

101, 51, and 34 kg N/ha were made using urea, 44-0-0. The in-season applications with irrigation water were made using a 28% nitrogen solution. It was composed of 7% N from combined ammonia, 7% N from nitrate, and 14% N from urea (Tisdale and Nelson, 1966). For 101 kg N/ha, we used 1792 ml of solution per plot (plot = 117 m^2). For 51 kg N/ha, we used 1396 ml of the solution per plot. For 34 kg N/ha, we used 931 ml of the solution per plot. Table 2 gives a summary of the ten treatments with their application rates and the times of nitrogen application.

The nitrogen solution was placed in an ordinary funnel on a stand that stood approximately 1.8 m above the ground. The nitrogen

Table 2. List of nitrogen fertilizer treatments and their respective times of application.

Treatment No.	Treatment	Time of nitrogen application		
		Pre-plant	Pre-tassel	Silking
		----- Nitrogen applied (kg/ha) ----		
1	0, 0, 0	0	0	0
2	180, 0, 0	180	0	0
3	135, 0, 0	135	0	0
4	101, 0, 0	101	0	0
5	0,101, 0	0	101	0
6	0, 0,101	0	0	101
7	51, 51, 0	51	51	0
8	51, 0, 51	51	0	51
9	0, 51, 51	0	51	51
10	34, 34, 34	34	34	34

solution was applied individually to each plot as the treatments dictated. Water was added to the solution to bring all funnels to approximately the same volume. This was done to equalize the solution flow rate from the funnels. Each funnel was connected to the irrigation pipe by means of tygon tubing. The nitrogen solution was allowed to flow into the irrigation stream at a T-intersection, to ensure mixing of the solution with the irrigation water. Viets et al. (1967) stressed the need for a turbulence point just after injection to ensure adequate mixing. A pinch clamp was placed in the tubing to hold the fertilizer solution until the irrigation water was flowing at a constant rate.

Figure 1 illustrates the research plot layout for the two-year study. Plot number, treatment number, and nitrogen fertilizer amount and time of application are indicated. Within the parentheses the first

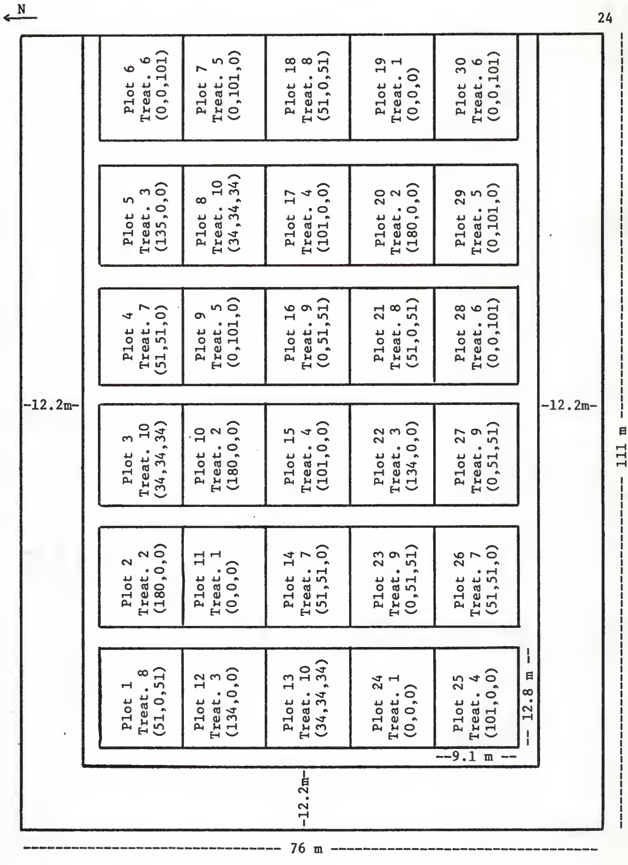

Figure 1. Diagram of plot area with associated treatment numbers. The nitrogen fertilizer amounts and times of application are also indicated.

number is the nitrogen added in kg N/ha at pre-plant, the second number is the amount added at pre-tassel, and the third number is the amount added at silking. Treatments were replicated three times and distributed in a completely randomized design.

IRRIGATION

The corn was irrigated at the pre-tassel (14-leaf) growth stage and a 28% nitrogen solution applied as required. Another irrigation and nitrogen application was made at silking. The corn received an additional irrigation at the dough stage without nitrogen application.

Each plot had its individual gated pipe connected to a main distribution system. The gated pipe at each plot was connected using flexible tubing to the main line. This made possible the in-season application of fertilizer to each individual plot. The amount of water applied at each irrigation varied. Enough water was applied to get even nitrate distribution over the plots and to bring the surface meter of soil to the upper limit of available soil water. The amount of water applied was determined by hand measurement of the flow rate through the constant-flow valves. The ridge at each end of the furrowed plots prevented runoff.

Table 3 lists the irrigation dates, the amounts of water applied, and the nitrogen fertilization dates. Table 4 summarizes the monthly rainfall at the study site for the growing season of both years.

SOIL SAMPLING FOR NITRATE ANALYSIS

The plots were sampled for nitrate nitrogen determination to a depth of 180 cm. Soil samples were taken in 15-cm increments to a depth

Table 3. Dates of irrigation with quantity of water applied.

1976		1977	
Date	Amount Applied (cm)	Date	Amount Applied (cm)
6 July*	3.6	27 June*	2.2
21 July*	7.1	5 July*	2.4
10 Aug.	7.6	29 July	6.5

* Indicates the dates of irrigation with nitrogen fertilizer applied.

Table 4. Monthly summary of rainfall amounts at the Ashland Agronomy farm, near Manhattan, Kansas.

Month	1976	1977
	Rainfall, cm	
Apr.	14.12	9.19
May	10.79	22.35
June	13.96	25.17
July	3.95	2.65
Aug.	1.91	20.06
Sept.	6.91	17.46

of 90 cm and in 30-cm increments to a depth of 180 cm. We used an Oakfield probe, available from the Oakfield Apparatus Co., Oakfield, Wisconsin. The plots were sampled for nitrate analysis prior to the pre-plant application of nitrogen fertilizer. They were also sampled prior to the first in-season application, between the first and second in-season applications, after the second in-season application, and in October. Table 5 gives the soil sampling dates.

Table 5. Dates of soil sampling for determination of nitrate-nitrogen concentration.

1976	1977
13 Apr.	18 Mar.
27 May	16 May
16 June	4 July
14 July	14 July
30 July	8 Sept.
16 Oct.	27 Oct.

SOIL NITRATE ANALYSIS

We analyzed the soils for nitrate-nitrogen using an Orion 801-A digital pH-MV meter and an Orion series 93-07 solid state specific ion electrode. The reference electrode was an Orion 90-02 double junction electrode. All these items were obtained from Orion Research Inc., Cambridge, Massachusetts.

We prepared a set of comparison nitrate samples and had them analyzed on the Technicon Autoanalyzer in the Soil Testing Laboratory, Kansas State University. The results from the Autoanalyzer were used as a "standard" by which we calculated a regression equation for the nitrate electrode. Using this regression equation we calculated the "actual" nitrate-nitrogen concentration in our field samples.

Table 6 presents the results of the regression analysis. Each of the 41 samples was analyzed using each specific ion module and the Autoanalyzer.

The soils were extracted using a special solution. There were 16.66 grams of aluminum sulfate per liter to produce a constant ionic strength. It required 1.24 grams of boric acid per liter as a preservative to prevent denitrification, especially in the standard solutions.

Table 6. Linear regression equations for the Technicon Autoanalyzer and the Orion specific-ion electrode comparison.

Module Number	Linear regression equation *	Number of observations (n)	Coefficient of correlation (r)	Standard error of estimate ($s_{y \cdot x}$)
1	Y = 0.335 + 1.019x	41	0.921	9.91
2	Y = -2.431 + 1.012x	41	0.952	7.82
3	Y = 4.559 + 1.031x	41	0.921	9.89
4	Y = 2.371 + 0.973x	41	0.951	7.84
5	Y = -2.927 + 1.187x	41	0.942	8.55

*Y is the ppm nitrate-nitrogen concentration using the Technicon Autoanalyzer. x is the ppm nitrate-nitrogen concentration using the Orion specific-ion electrode.

We used 2.335 grams of silver sulfate per liter to remove the chloride interference. We used 2.43 grams of sulfamic acid to reduce any nitrites to nitrates, but assumed nitrite concentration to be negligible. The solution was stored in a dark bottle to prevent any photodecomposition of the silver sulfate. It was also recommended by the manufacturer that fresh solution be prepared each week. With continuous operation, discarding old extracting solution was not necessary.

Standard solutions were prepared by serial dilution of a 5000 ppm nitrate-nitrogen stock solution, with extracting solution. The 5000 ppm stock solution was prepared by dissolving 3.611 grams of potassium nitrate in the extracting solution in a 100 ml volumetric flask, and filling to the mark with extracting solution. The standard concentrations were 200, 20, 10, 5 and 2 ppm NO_3^- - N and were used to create a calibration curve from which the nitrate-nitrogen concentration of the field samples was determined. The concentration of the standard was plotted on the log axis against the MV reading on the regular axis of semilog paper. To determine the parts per million nitrate-nitrogen, concentration of a soil sample the MV reading for the sample was read and the concentration determined using the calibration curve and then the appropriate linear regression equation from Table 6.

Soil samples were ground to pass through a 2 mm sieve using a mortar and pestal. Twenty-five milliliters of the extracting solution were added to 10 grams of soil in small mixing bottles for stirring. The samples were then placed on a multiple stirring machine and stirred for 20 minutes. The stirred samples were removed and analyzed. The stirring machine was purchased from the Custom Laboratory Equipment Co., Raleigh, North Carolina.

The nitrate concentration of the soil samples was lower than the manufactured recommended for accurate determinations. Therefore, 5 ppm nitrate-nitrogen was added to each sample. This was accomplished by adding 1 ml of the 5000 ppm stock solution to 1 l of the solution used for extracting the soil.

PLANT TISSUE ANALYSES

The total nitrogen content of the leaves at various times during the season as well as the total nitrogen content of the grain was determined each year of the study. In 1976, the 10th leaf was sampled on 28 June. Six to eight leaves were taken from each plot. On 20 July 1976 the ear leaf of the upper most ear and the upper-most fully developed leaf were collected. In 1977, the upper-most fully developed leaf was taken on 30 June. Approximately six leaves were collected per plot. The leaves were dried at 49° C for 2 days. They were then ground in a Wylie mill to pass a 2 mm screen. The samples were then analyzed for total nitrogen content using a Technicon Autoanalyzer by the Soil Testing Laboratory, Kansas State University.

The grain was also sampled and analyzed for total nitrogen content. The grain was harvested 21 Sept. 1976 and 8 Sept. 1977. The corn was dried, shelled, and ground to pass a 2 mm screen. The total nitrogen was determined as above.

Corn grain yield was determined by sampling a 4-m strip of each of the three center rows of each plot. It was then dried at 50° C for approximately 5 days. The corn was shelled, weighed, and adjusted to 15.5% water content to determine the yield.

Total dry matter production was determined at various times during the growing season. In 1976 the entire plant was collected on 23 July and 16 August. Entire plants were collected from one meter of one row per plot, chopped to facilitate drying, dried at 49-60° C for several days, and then weighed.

SOIL WATER DETERMINATION

We determined the water content of the soil by neutron thermalization outlined by Gardner (1965) and by gravimetric sampling. The neutron probe and scaler used were purchased from Troxler Laboratories, Raleigh, North Carolina.

An aluminum access tube of outside diameter 4.13 cm was placed in the center row of each plot midway down the row. Standardization of the instrument was made at each tube by taking counts while the probe remained in the shield. The count time for the standard reading was 30 sec. After the standard reading, the probe was lowered into the tube. Readings were taken in 15 cm increments, beginning at a depth of 15 cm and proceeding to a depth of 152 cm. The count-ratio was found by dividing the reading at each depth by the standard reading for that tube. This count-ratio was then compared with a calibration curve. This procedure yielded the water content of the soil on a volume basis.

The 0 to 15 cm water content was determined by using the gravimetric method on each water content sampling date. The soil was sampled using an Oakfield probe. The moist soil sample was placed in a sample can and weighed. The sample was oven-dried at 108° C for 48 hours, and weighed. The soil was removed from the can and the can weight determined. The water content by weight was calculated using formula (1):

$$w = \frac{M_w - M_d}{M_d} \qquad (1)$$

w the water content by weight
M_w the wet mass of the soil - the can weight
M_d the dry mass of the soil - the can weight

Conversion of water content on a dry weight basis to water content on a volume basis was according to formula (2) (Hillel, 1971):

$$\theta = w \frac{\rho_b}{\rho_w} \qquad (2)$$

w the water content on a weight basis
θ the volumetric water content
ρ_b the soil bulk density
ρ_w the density of water

Profile soil water depletion for any time interval is the difference in cm of water in the profile between the two reading dates. Profile depletion plus rainfall and irrigation during the time period is the total evapotranspiration for that period. The total evapotranspiration divided by the number of days in the period yields the average daily evapotranspiration rate.

The consumptive water use was computed by taking the total ET for each time period and summing it for the several reading intervals from the first reading to physiological maturity. To get the ET value from the next to the last reading date to physiological maturity, the average daily ET rate was calculated and multiplied by the number of days from the next to the last reading to physiological maturity. This was necessary because physiological maturity occurred between the last two reading dates.

The water use efficiency of the corn in kg of grain at 15.5% water content/ha/cm of water, was calculated by dividing the grain yield (kg/ha) by the cumulative ET (cm of water).

SOIL WATER RETENTION

We determined water release curves using the method described by Richards (1965). We used disturbed soil samples for determination of the water content at 0.1, 0.2, 0.33, 0.5, 1.0, 5, 10, and 15 bars of pressure. The soil had been ground with a mortar and pestal to pass a 2 mm sieve.

We used a ceramic plate for determining water retention in the 0.1 to 1.0 bar pressure range. For the 5 to 15 bar pressures, a cellulose acetate membrane and a pressure chamber were used. The membrane was placed on a screen base and rubber rings 5.4 cm in diameter and 1 cm in height were placed on the membrane. The rings were filled with soil (approximately 25 grams). Water was placed on the membrane in excess of that needed to wet the samples and allowed to stand with the samples for at least 16 hours. The chamber was then closed and pressurized and the water outflow observed. When water outflow ceased, the samples were removed and the moist weight determined immediately. The moist soil was then place in an oven to dry at 105° C for 24 hours. After drying, the oven dry soil weight was determined. Water content of the soil on a dry weight basis was computed by using formula (1). Equipment for this procedure is available from Soilmoisture Equipment Company, Santa Barbara, California.

MECHANICAL ANALYSIS

We used the hydrometer method for particle size analysis outlined by Day (1965). The materials required are: a standard hydrometer with Bouyoucos scale in grams/liter, an electrically driven mixer, a bouyoucos cylinder with a 1000 ml graduation mark, and a constant temperature room. Reagents were prepared by dissolving 50 grams of sodium hexametaphosphate in water and diluting to 1 liter, creating a 0.5 normal solution.

The hydrometer was calibrated in the following manner: 100 ml of the 0.5 N sodium hexametaphosphate solution were added to the sedimentation cylinder, water was then added until the level reached the 1000 ml mark, the solution was mixed thoroughly and allowed to come to room temperature. The temperature was recorded and the hydrometer lowered carefully into the solution and the scale reading (R_L) determined at the upper edge of the meniscus.

We weighed 40 grams of soil for particle size analysis and an equal amount for water content analysis. The sample for particle size analysis was placed in a dispersing cup, 100 ml of the sodium hexametaphosphate solution and 400 ml of distilled water were added. The sample was allowed to set for at least 10 minutes. The sample suspension was mixed for 5 minutes with a motor mixer and transferred to the sedimentation cylinder using a stream of water from a wash bottle. Distilled water was then added to complete filling to the 100 ml mark.

The suspension temperature was recorded after it became constant. The stopper was inserted and the suspension shaken to mix the contents thoroughly. The time was recorded when the mixing was completed.

The hydrometer was lowered into the suspension and after 30 seconds the first reading was taken. After the second reading had been taken at 1 minute, the hydrometer was removed, washed, and dried with a soft towel.

The hydrometer was lowered into the suspension without remixing, about 10 seconds before each measurement and readings were taken at 3, 10, 30, 90, and 480 minutes.

The hydrometer readings (R) were recorded at the various times. The concentration of suspension (c) in grams/liter, was obtained from the following equation: $c = R - R_L$. The summation percentage was determined from: $P = 100\ (c/c_o)$, c_o being the oven-dry weight of the soil in grams per liter of suspension.

The particle sizes were calculated using the following formula: $X_{(microns)} = \theta/(t)^{\frac{1}{2}}$ where (t) is the sedimentation time in minutes. θ is the sedimentation parameter from Table 43-7 on page 564 of Day (1965), determined by using the observed (uncorrected) R value.

P was plotted versus X on semilog paper as in Fig. 43-4 of Day (1965), using the log scale for X. Interpolation from the curve gave the summation percentages at particular values of X such as 2, 5, 20, and 50 microns.

The organic matter content, pH, and cation exchange capacity (CEC) of this soil were determined by the Kansas State University Soil Testing Laboratory.

BULK DENSITY ANALYSIS

The bulk density of the field soil was determined by taking six soil cores to a depth of 180 cm with a tractor mounted hydraulic probe. The core was sectioned into depth intervals corresponding to those used for nitrate sampling. The core sections were placed in sample cans and oven-dried at 105° C. The oven dry soil samples were then weighed. The volume of each core was determined by multiplying the inside cross-sectional area of the probe tip (8.04 cm^2) by the section length. The oven-dry mass of the sample was divided by the volume to give the bulk density in g/cm^3.

STATISTICAL ANALYSIS

The experimental plots were arranged in a completely randomized design. A one way analysis of variance was used to test for significant differences in consumptive water use, water use efficiency, nitrate-nitrogen concentrations, corn grain yield, total dry matter accumulation, and total nitrogen content of the leaf and grain tissue between the treatments. If differences were significant by use of analysis of variance at the 0.05 and/or the 0.10 level, the least significant difference (L.S.D.) was calculated. Steel and Torrie (1960) was used as the statistical reference.

RESULTS AND DISCUSSION

Some selected properties of the Eudora silt loam soil are presented in Table 6. The water retention data for the sampling layers of the soil profile are listed in Table 7.

Table 7. Selected properties of the Eudora silt loam soil.

Soil layer	Sand* (.05-2.0mm)	Silt* (.02-.05mm)	Silt* (.05-002mm)	Clay* (.002mm)	Organic matter	pH	CEC	Bulk density
-- cm --	%				-- % --		meq/100g	g/cm^3
0- 15	36.0	28.5	18.5	17.0	1.9	6.8	16.5	1.38
15- 30	35.0	36.5	12.5	16.0	1.6	6.5	17.2	1.38
30- 45	29.0	32.7	24.3	14.0	1.3	6.5	16.6	1.42
45- 60	33.0	43.4	15.1	8.5	0.6		11.3	1.35
60- 75	37.5	44.2	12.4	6.0	0.6		9.8	1.41
75- 90	51.8	32.9	11.8	3.5	0.5		7.8	1.34
90-120	53.2	33.0	10.3	3.5	0.5		9.0	1.42
120-150	47.5	28.7	20.3	3.5	0.5		8.1	1.37
150-180	53.5	36.2	10.3	3.5	0.4		8.0	1.46

* Diameter ranges for sand, silt and clay soil separates are according to the USDA classification system.

The clay content decreases and the sand content tends to increase with depth. With the soil becoming coarser, the potential for nitrate movement in the deeper layers is greater than in the upper layers. In Table 8 the effect of the decrease in clay content is evidenced by the decrease in the ability of the soil to retain water in the deeper layers at comparable pressures.

Table 8. Water retention values for various layers of the Eudora silt loam soil.

Soil layer	Soil-water pressure — bars 0.10	0.20	0.33	0.50	1.0	5.0	10	15
-- cm --	Soil-water content, cm^3/cm^3							
0- 15	0.511	0.373	0.288	0.253	0.199	0.137	0.126	0.115
15- 30	0.537	0.395	0.308	0.275	0.217	0.152	0.136	0.121
30- 45	0.513	0.338	0.265	0.236	0.189	0.142	0.123	0.113
45- 60	0.474	0.247	0.171	0.157	0.127	0.097	0.088	0.080
60- 75	0.460	0.220	0.137	0.128	0.100	0.079	0.072	0.065
75- 90	0.421	0.169	0.118	0.099	0.080	0.066	0.054	0.052
90-120	0.447	0.190	0.128	0.112	0.091	0.065	0.061	0.057
120-150	0.434	0.204	0.124	0.115	0.086	0.064	0.058	0.054
150-180	0.431	0.226	0.145	0.128	0.100	0.069	0.063	0.060

DRY MATTER PRODUCTION

Table 9 presents the corn dry matter production for 1976 and 1977. The value reported is the mean of the three replications per treatment.

The total dry matter production in 1976 contained no significant difference at either the 0.05 or 0.10 level between treatments on either sampling date. A possible reason is the influence of residual nitrogen from soybeans grown on this site for the previous 10 years.

For 1977, the analysis of variance indicated significant treatment differences at the 0.05 level on the last two sampling dates. On 16 June, several treatments that included a pre-plant application had significantly greater dry matter production than those without at the 0.10 level, but they were not significantly greater at the 0.05 level.

Table 9. Average total dry matter production for various dates of 1976 and 1977.

Treatment number	Treatment	Dry matter yield 1976 23 July	1976 16 Aug.	1977 16 June	1977 12 July	1977 19 Aug.
		kg/ha				
1	0, 0, 0	8,927	12,600	1,970	6,653	8,753
2	180, 0, 0	11,453	17,547	3,670	14,273	23,607
3	135, 0, 0	10,574	17,130	3,043	14,427	21,207
4	101, 0, 0	11,987	19,027	4,137	12,787	23,813
5	0,101, 0	10,500	18,850	1,960	10,363	15,440
6	0, 0,101	9,980	17,077	1,843	8,457	15,530
7	51, 51, 0	9,900	18,847	2,887	12,597	17,077
8	51, 0, 51	9,417	14,000	4,007	10,857	16,897
9	0, 51, 51	8,160	15,863	2,133	7,770	15,497
10	34, 34, 34	11,223	19,733	2,830	11,470	18,827
L.S.D. (0.05)		NS	NS	NS	3,074	4,696
L.S.D. (0.10)		NS	NS	1,401	2,542	3,884

On 12 July, all treatments except 6 and 9 had significantly greater dry matter accumulations than treatment 1. Those plots receiving a pre-plant nitrogen application had accumulated the greatest dry matter by this date. Treatment 5 was only slightly less than the treatments that included a pre-plant application.

On 19 August, all treatments had significantly greater amounts of dry matter than treatment 1. The greatest yield coming from those treatments receiving all nitrogen pre-plant. The pre-plant only treatments were significantly greater than all other treatments except 7 and 10. The results indicate that the greatest corn dry matter accumulations on this soil occur when the nitrogen is applied pre-plant.

The importance of pre-plant nitrogen application for dry matter production can be readily seen from the 1977 data. The pre-plant nitrogen application treatments consistently produced the greatest amounts of dry matter. The 1976 results do not indicate this same trend as strongly as the 1977 results, possibly because of residual nitrogen from soybeans.

TISSUE NITROGEN CONTENT

Table 10 contains the results of the tissue nitrogen determinations. The value reported is the mean percentage for the three replications per treatment.

Table 10. Average tissue nitrogen content for 1976 and 1977.

Treatment number	Treatment	Tissue nitrogen content				
		1976			1977	
		28 June	23 July	Grain	30 June	Grain
		%				
1	0, 0, 0	2.17	1.86	1.23	1.77	1.12
2	180, 0, 0	3.48	2.74	1.60	2.96	1.60
3	135, 0, 0	3.41	2.46	1.51	2.87	1.51
4	101, 0, 0	3.30	2.44	1.48	2.71	1.34
5	0,101, 0	2.83	2.60	1.47	2.18	1.50
6	0, 0,101	2.82	1.79	1.62	1.80	1.61
7	51, 51, 0	3.16	2.32	1.37	2.19	1.30
8	51, 0, 51	2.96	1.95	1.43	2.08	1.40
9	0, 51, 51	2.88	1.89	1.44	2.05	1.49
10	34, 34, 34	3.27	2.27	1.43	2.39	1.51
L.S.D. (0.05)		0.24	0.45	0.17	0.24	0.17
L.S.D. (0.10)		0.20	0.37	0.14	0.20	0.14

On 28 June 1976 the tissue nitrogen content was greatest in those plots receiving pre-plant nitrogen fertilizer. On 23 July the tissue from the pre-plant nitrogen treatments still contained large amounts of nitrogen, as did those that had received a pre-tassel nitrogen application (6 July). All treatments except 7 were significantly greater at the 0.05 level in grain nitrogen content than the control (treatment 1), indicating that applications of nitrogen fertilizer increased grain nitrogen content in 1976. In 1977, all treatments receiving nitrogen were significantly greater (0.05 level) in total grain nitrogen content than the no nitrogen treatment.

The results from this study agree with the findings of Jung et al. (1972). They found that increased nitrogen application rates and delayed application time resulted in greater grain nitrogen content. In both 1976 and 1977, the treatments greatest in grain nitrogen were the 180 kg N/ha pre-plant and the 101 kg N/ha silking treatment (Table 10).

Treatment 10 had large tissue nitrogen contents in both leaf and grain at all sampling dates, probably because fertilizer was readily available throughout the season.

GRAIN YIELD

Table 11 shows the 1976 and 1977 grain yield and the two year mean plus the ranking of two year means. The values reported are the means for the three replications per treatment.

The pattern of grain yield is similar to that of total dry matter production. In 1976, plots receiving no nitrogen (treatment 1) and those receiving nitrogen only at silking (treatment 6) had considerably lower grain yield than all other treatments.

Table 11. Corn grain yield for 1976 and 1977. Each value is the mean yield of three plots.

Treatment number	Treatment	Corn grain yield* 1976	1977	Two-year mean	Rank
		kg/ha			
1	0, 0, 0	6,017	3,330	4,674	10
2	180, 0, 0	8,329	10,030	9,178	1
3	135, 0, 0	8,562	9,311	8,937	3
4	101, 0, 0	8,960	8,928	8,944	2
5	0,101, 0	8,370	8,313	8,341	6
6	0, 0,101	6,419	6,347	6,383	9
7	51, 51, 0	8,220	8,471	8,346	5
8	51, 0, 51	7,633	7,594	7,614	8
9	0, 51, 51	8,049	7,990	8,020	7
10	34, 34, 34	8,558	8,885	8,722	4
L.S.D. (0.05)		NS	1,850	1,851	
L.S.D. (0.10)		NS	1,530	1,530	

* Reported at 15.5% water content.

The 1976 results agree with the findings of Mulliner and Frank (1975) and indicate that previous cropping systems can leave considerable residual nitrogen in the soil. Soybeans had been grown on this soil for 10 years previous to this study. The relatively high yield of the 0 nitrogen treatment in 1976 indicates the possible presence of a considerable amount of residual nitrogen, especially when comparing the 1976 and 1977 yields. Larson and Hanway (1977) also cited evidence of residual nitrogen effects on corn yield.

In 1977, the grain yield trends were similar to those of 1976 with the treatments receiving all nitrogen at pre-plant producing the greatest yields. Treatment 6 (all nitrogen at silking) was the second lowest yielding treatment in both 1976 and 1977. Also, treatments receiving 1/2 their nitrogen at silking were the next in line with low yield rankings. These data indicate that fertilizer applications at silking are less effective than earlier applications in increasing corn grain yield.

These data indicate that split applications of nitrogen fertilizer on the Eudora silt loam soil are not effective in increasing yields compared to all nitrogen applied pre-plant.

WATER USE AND WATER USE EFFICIENCY

The total water used by the corn is reported in Table 12. The reported value is the mean of the three replications per treatment.

The water used by the corn was essentially the same for all treatments. No significant difference existed at the 0.05 or 0.10 levels between any of the treatments for 1976 or 1977. Several authors (Viets, 1962; Hanway, 1966; Carlson et al., 1959) have found that fertilization did not increase consumptive water use. Splitting the fertilizer into two or three applications did not alter water use in our study. The amount of available water did influence water use. In 1976, 39 cm of water from rainfall and irrigation was available during the growing season and in 1977, 80 cm was available. The difference in the two amounts influenced the consumptive water use as reported in Table 12.

The water use efficiency of corn is reported in Table 13. Each value listed is the mean of the three replications per treatment.

Table 12. Consumptive water use by corn for 1976 and 1977. Each value is the mean of three replications.

Treatment number	Treatment	Consumptive water use 1976	1977
		---------- cm	----------
1	0, 0, 0	55.2	77.9
2	180, 0, 0	57.0	75.8
3	135, 0, 0	56.2	77.3
4	101, 0, 0	59.3	76.7
5	0,101, 0	58.1	74.9
6	0, 0,101	56.6	78.4
7	51, 51, 0	58.6	78.1
8	51, 0, 51	55.4	80.4
9	0, 51, 51	57.6	76.2
10	34, 34, 34	55.4	75.2
L.S.D. (0.05)		NS	NS
L.S.D. (0.10)		NS	NS

The two year mean is also reported with the treatments ranked according to their efficiency with 1 being the most efficient and 10 being the least efficient.

The water use efficiency of corn increased with increased fertilization. In 1976, there was no significant difference between treatments at the 0.05 level. The plots receiving no nitrogen and those receiving none until silking were significantly less efficient at the 0.10 level than all treatments except treatment 8. When nitrogen is not applied until silking adequate growth and development has not occurred resulting in low grain yield. The decreased yield decreases water use efficiency.

Table 13. Water use efficiency of corn grown on the Eudora silt loam for two years.

Treatment number	Treatment	Water use efficiency 1976	1977	Two-year mean	Rank
		---------- kg/ha/cm	----------		
1	0, 0, 0	109	43	76	10
2	180, 0, 0	146	133	139	1
3	135, 0, 0	152	121	137	2
4	101, 0, 0	151	116	134	4
5	0,101, 0	144	112	128	5
6	0, 0,101	113	81	97	9
7	51, 51, 0	140	109	125	6
8	51, 0, 51	137	95	116	8
9	0, 51, 51	140	106	123	7
10	34, 34, 34	154	118	136	3
L.S.D. (0.05)		NS	29	28	
L.S.D. (0.10)		26	24	24	

In 1977, trends were similar to those of 1976, the no nitrogen treatment had the lowest water use efficiency. Treatment 6 was approximately twice the value for treatment 1,indicating that the nitrogen applied at silking increased the plants' water use efficiency. Those treatments receiving large pre-plant applications and those with applications made at pre-plant, at pre-tassel, and at silking, were the most efficient users of water.

In comparing the results of the two years we see a decrease in the water use efficiency of corn in 1977. The probable reason for this is the larger amount of rainfall and irrigation during the 1977 growing season (80 cm) than the 1976 growing season (39 cm). The seasonal ET in 1977 was greater than in 1976 (Table 12).

In this two-year study increased nitrogen fertilizer application increased water use efficiency of corn for a given amount of water. Also, the increased amount of water available for plant use decreased water use efficiency (Table 13).

LEACHING

Table 14 presents the nitrate-nitrogen concentration for the nine soil layers on three dates in each year. The value reported is the mean concentration for the three replications of each treatment.

Table 14. Nitrate-nitrogen concentrations for the various soil layers and six dates.

13 April 1976												
Soil layer	Treatment 1	2	3	4	5	6	7	8	9	10	L.S.D. (0.05)	L.S.D. (0.10)
-- cm --	ppm											
0- 15	9	14	14	13	7	15	15	15	8	14	NS	5
15- 30	13	13	12	12	10	10	11	13	13	13	NS	NS
30- 45	7	12	10	8	4	10	9	10	7	10	NS	NS
45- 60	11	6	7	12	12	10	11	12	9	9	NS	NS
60- 75	7	12	7	7	8	11	8	3	8	8	NS	NS
75- 90	9	8	10	2	7	7	8	8	8	6	NS	NS
90-120	7	3	4	7	4	5	4	4	4	3	NS	NS
120-150	6	2	2	6	7	4	7	2	4	4	NS	NS
150-180	4	4	6	7	4	1	5	3	5	3	NS	NS

Table 14. Cont.

14 July 1976												
Soil layer	Treatment 1	2	3	4	5	6	7	8	9	10	L.S.D. (0.05)	L.S.D. (0.10)
-- cm --	ppm											
0- 15	2	5	3	3	28	1	12	4	4	7	14	12
15- 30	3	10	3	2	13	1	8	2	5	4	NS	NS
30- 45	3	7	2	3	7	3	6	5	5	4	NS	NS
45- 60	4	7	3	3	7	3	5	6	3	4	NS	NS
60- 75	4	6	5	5	9	3	4	5	4	4	NS	NS
75- 90	5	5	4	5	5	1	5	3	4	7	NS	NS
90-120	4	2	5	3	4	2	7	1	3	3	NS	NS
120-150	1	1	2	2	2	2	5	2	3	2	NS	NS
150-180	1	2	4	1	2	1	3	3	3	4	NS	NS
16 October 1976												
Soil layer	Treatment 1	2	3	4	5	6	7	8	9	10	L.S.D. (0.05)	L.S.D. (0.10)
-- cm --	ppm											
0- 15	9	14	10	8	7	8	11	8	7	12	NS	NS
15- 30	3	13	4	9	3	9	6	6	4	7	5	5
30- 45	4	7	4	7	3	6	6	2	3	3	NS	NS
45- 60	5	4	9	5	3	8	2	6	3	4	4	3
60- 75	5	5	5	5	3	6	3	3	2	5	NS	NS
75- 90	3	7	2	1	3	4	4	2	4	3	NS	2
90-120	2	6	1	3	3	1	6	2	2	3	NS	NS
120-150	1	4	1	1	5	4	4	2	3	4	NS	NS
150-180	3	3	1	1	6	4	3	2	3	5	NS	NS
18 March 1977												
Soil layer	Treatment 1	2	3	4	5	6	7	8	9	10	L.S.D. (0.05)	L.S.D. (0.10)
-- cm --	ppm											
0- 15	8	15	9	11	6	10	7	9	9	12	NS	NS
15- 30	5	11	8	8	5	7	8	7	4	10	NS	NS
30- 45	8	6	5	6	6	8	7	6	6	6	NS	NS
45- 60	6	6	7	7	6	7	4	7	7	5	NS	NS
60- 75	7	7	4	7	7	4	5	6	5	6	NS	NS
75- 90	7	8	4	5	5	5	3	3	3	6	NS	NS
90-120	5	5	5	5	3	2	4	4	5	5	NS	NS
120-150	5	5	4	5	5	4	3	5	2	5	NS	NS
150-180	5	4	2	4	1	5	6	2	4	4	NS	NS

Table 14. Cont.

4 July 1977												
Soil layer	Treatment 1	2	3	4	5	6	7	8	9	10	L.S.D. (0.05)	L.S.D. (0.10)
-- cm --	ppm											
0- 15	6	7	7	6	7	5	5	4	5	7	NS	NS
15- 30	4	7	4	4	6	6	5	5	5	4	NS	NS
30- 45	5	8	5	5	6	4	6	6	7	5	NS	NS
45- 60	8	12	6	7	6	4	7	7	7	5	4	3
60- 75	7	11	6	8	7	4	3	3	8	6	4	3
75- 90	6	11	5	8	4	4	3	3	6	6	NS	4
90-120	3	10	4	3	4	5	3	3	2	9	5	4
120-150	2	10	9	6	6	4	5	5	2	9	NS	5
150-180	3	5	7	10	6	3	3	3	5	7	NS	NS

27 October 1977												
Soil layer	Treatment 1	2	3	4	5	6	7	8	9	10	L.S.D. (0.05)	L.S.D. (0.10)
-- cm --	ppm											
0- 15	6	9	6	7	8	7	5	8	6	5	NS	NS
15- 30	6	10	9	9	7	9	9	6	5	7	3	3
30- 45	7	8	7	7	7	7	13	7	5	4	NS	NS
45- 60	7	7	7	7	6	5	4	6	6	7	NS	NS
60- 75	6	10	4	5	5	7	7	6	7	7	NS	NS
75- 90	3	8	7	5	5	4	3	2	3	5	NS	NS
90-120	8	7	6	4	4	4	2	2	2	3	4	3
120-150	6	8	4	4	5	5	8	5	4	6	NS	NS
150-180	6	8	3	3	4	6	5	7	4	5	NS	NS

Table 14 shows that there was no significant difference at the 0.05 level between treatments in any soil layer before the spring fertilizer application of either year. On 14 July 1976 the treatment receiving 101 kg N/ha (treatment 5) at pre-tassel (6 July) was significantly greater (0.05 level) in nitrate-nitrogen concentration in the surface 15 cm than all other treatments. The treatments receiving 51 kg N/ha at pre-tassel (treatments 7 and 9) were also greater than the others but the difference was not statistically greater at the 0.05 level or the 0.10 level.

On 16 October 1976 the plots receiving 135 kg N/ha pre-plant (treatment 3) and those receiving 101 kg N/ha at silking (treatment 6) had the greatest nitrate-nitrogen concentration in the 45 to 60 cm layer. The 180 kg N/ha at pre-plant (treatment 2), the 101 kg N/ha at pre-plant (treatment 4), and the 101 kg N/ha at silking (treatment 6) were the greatest in nitrate-nitrogen concentration in the 15 to 30 cm layer.

On 4 July 1977 there is evidence that leaching may have occurred. The 180 kg N/ha pre-plant (treatment 2) had the greatest nitrate-nitrogen concentration than all other treatments. Treatment 2 and treatment 10 also had large nitrate-nitrogen concentrations in the 90 to 120 cm layer. Treatment 2 also had large nitrate-nitrogen concentrations in the 45 to 60 cm and 60 to 75 cm layer.

On 27 October 1977, treatments 1, 2, and 3 were greatest in nitrate-nitrogen concentration in the 90 to 120 cm soil layer. Treatments 7, 8, and 9 were significantly less in nitrate-nitrogen than treatments 1, 2, and 3 in the 90 to 120 cm soil layer.

The results of this study indicate that nitrate leaching is not a problem on the Eudora silt loam soil. Even with the large amount of water received in 1977 (80 cm), movement and accumulation of nitrate-nitrogen in the deeper layers of the 180 cm profile was not great.

SUMMARY AND CONCLUSIONS

Interest in application of fertilizers with irrigation water has been increasing in recent years. In this study, there were several things concerning split applications of nitrogen fertilizer with irrigation water that we wanted to examine. The specific thesis objectives were: 1) to examine leaching when fertilizer was applied in irrigation water; 2) to evaluate the use of split application of nitrogen fertilizer during the growing season as a method of reducing the total amount of nitrogen fertilizer applied to corn; 3) to examine the influence of split fertilizer applications upon grain yield, dry matter production, and nitrogen content of corn leaves and grain; and 4) to examine water use efficiency as influenced by split applications of nitrogen fertilizer.

We did corn tissue analysis to determine the nitrogen content of leaves and grain. Grain nitrogen contents were greatest where large amounts of nitrogen were applied pre-plant or where the application of nitrogen was delayed until silking.

Corn grain yield was not increased by split applications of nitrogen; 101 kg N/ha applied pre-plant was as effective as the treatments where the same amount of nitrogen was split and applied with the irrigation water.

The results of dry matter production and grain yield, indicate the total amount of nitrogen fertilizer applied to corn on the Eudora silk loam soil cannot be reduced by split applying nitrogen with irrigation water. Dry matter and grain yield were not increased by split applications as opposed to pre-plant only applications.

We also found that leaching of nitrates, on this particular soil, was not significant, even when all the nitrogen fertilizer was applied pre-plant. The data for 1976 and 1977 indicate that leaching on the Eudora silt loam is not significant. For medium to fine-textured soils this method may be useful for reducing leaching when large amounts of water move through the soil.

In this two-year study we found no advantage to split applications of nitrogen fertilizer as opposed to all pre-plant applications. The split applications did not have dry matter production, grain yield, water use efficiency or tissue nitrogen contents when compared to the all pre-plant treatments. Consumptive water use was not influenced by either method of nitrogen application. Split applications of nitrogen fertilizer are not effective in reducing leaching on the Eudora silt loam. The results of the leaching study indicate that nitrate leaching is not significant on this soil.

We need to be looking for methods by which we can reduce the amount of energy expended in the production of food. Application of fertilizer in irrigation water is one possible method.

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APPENDIX

Table 1A. Daily rainfall amounts for the two study years at the Ashland Agronomy farm near Manhattan, Kansas.

Day	Apr.		May		June		July		Aug.		Sept.	
	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977
	cm											
1	0	0	0	0.91	0	0.79	0	0	0	0	0	9.14
2	0	0	0	0.05	0	0	0	0.08	0.08	0.20	0	0.10
3	0	0	0	0	0	0	0	0	0	0.25	0	0
4	0	3.43	0	0	0	0	0	0	0	3.05	0	0
5	0	0	0	0	0	0	0	0	0.13	0.30	0	0
6	0	0	3.30	0	0	0	0	0	0	1.65	0	0
7	0.76	0	0	0	0	0	0	0.03	0	0	0	0
8	1.37	0	0	0	0	0	0	0	0	0	0.33	0.36
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0.56	0
11	0	0	0	0	0.20	0	0	2.54	0	1.57	0	0
12	0	0	0.58	0	0	1.42	0	0	1.57	0	0	1.88
13	0	0.43	0	0	0	0.10	0	0	0	0	0	4.34
14	0	0	0.05	0	0	0	0	0	0.13	0	0	0
15	0	0	2.54	0.08	0	0	0	0	0	1.40	2.29	0
16	0.13	0	0	0	0	0	0.13	0	0	1.52	0	0.13
17	3.43	0	0	0.58	0	0.84	1.91	0	0	0.38	0	0
18	0	0.66	0	0	3.43	10.54	0	0	0	0	0	0.03
19	0	1.14	0	0	0	2.03	0	0	0	0	0	0
20	5.33	0.43	0	6.48	0	0.25	0	0	0	0	0.30	0
21	0.51	1.63	0	3.81	0	0.71	0	0	0	0	0	0.15
22	1.14	1.47	0	2.67	0	3.89	0	0	0	0.05	0	0
23	0	0	0	0	3.68	2.36	0	0	0	3.84	0.51	0.20
24	0	0	3.43	0	4.06	0	0	0	0	0.13	0	0.64
25	0	0	0	0	0	2.24	0	0	0	0	0	0

Table 1A. Cont.

Day	Apr.		May		June		July		Aug.		Sept.	
	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977
	cm											
26	0	0	0.38	0	0	0	0	0	0	0	0	0
27	1.02	0	0.51	0	0	0	0	0	0	0	2.92	0
28	0.18	0	0	0.81	1.07	0	1.91	0	0	5.72	0	0
29	0	0	0	2.64	1.52	0	0	0	0	0	0	0.46
30	0.25	0	0	4.32	0	0	0	0	0	0	0	0.03
31	0	0	0	0			0	0	0	0		
Total	14.12	9.19	10.79	22.35	13.96	25.17	3.95	2.65	1.91	20.06	6.91	17.46

Table 2A. Analysis of variance of total dry matter production for both study years.

Source of Variation	SS	DF	MS	F	L.S.D. (0.05)	L.S.D. (0.10)
			23 July 1976			
Treatments	37,663,586	9	4,184,843	1.64	NS	NS
Error	50,972,601	20	2,548,630			
Total	88,636,187	29				
			16 August 1976			
Treatments	145,018,385	9	16,113,154	1.59	NS	NS
Error	202,794,602	20	10,139,730			
Total	347,812,987	29				
			16 June 1977			
Treatments	20,395,080	9	2,266,120	2.29	NS	1401
Error	19,775,600	20	988,780			
Total	40,170,680	29				
			12 July 1977			
Treatments	193,884,012	9	21,542,688	6.61	3074	2542
Error	65,162,935	20	3,258,147			
Total	259,046,947	29				
			19 August 1977			
Treatments	541,502,401	9	60,166,933	7.91	4696	3884
Error	152,059,136	20	7,602,957			
Total	693,561,537	29				

Table 3A. Analysis of variance of tissue nitrogen content (%).

Source of Variation	SS	DF	MS	F	L.S.D. (0.05)	L.S.D. (0.10)
	Leaf, 28 June 1976					
Treatments	2.04	9	0.23	10.76	0.24	0.20
Error	0.42	20	0.02			
Total	2.46	29				
	Leaf, 23 July 1976					
Treatments	3.10	9	0.34	4.96	0.45	0.37
Error	1.39	20	0.07			
Total	4.49	29				
	Grain, 1976					
Treatments	0.33	9	0.04	2.86	0.17	0.14
Error	0.26	20	0.01			
Total	0.59	29				
	Leaf, 30 June 1977					
Treatments	4.82	9	0.54	30.04	0.24	0.20
Error	0.36	20	0.02			
Total	5.18	29				
	Grain, 1977					
Treatments	0.61	9	0.07	8.55	0.17	0.14
Error	0.16	20	0.01			
Total	0.77	29				

Table 4A. Analysis of variance of corn grain yield for the two study years plus the two-year mean.

Source of Variation	SS	DF	MS	F	L.S.D. (0.05)	L.S.D. (0.10)
			1976			
Treatments	24,998,988	9	2,777,665	1.78	NS	NS
Error	31,161,547	20	1,558,077			
Total	56,160,535	29				
			1977			
Treatments	97,336,208	9	10,815,134	9.17	1850	1530
Error	23,588,083	20	1,179,404			
Total	120,924,291	29				
			Two year mean			
Treatments	53,011,315	9	5,890,146	4.99	1851	1530
Error	23,614,580	20	1,180,729			
Total	76,625,895	29				

Table 5A. Analysis of variance of consumptive water use data.

Source of Variation	SS	DF	MS	F	L.S.D. (0.05)	L.S.D. (0.10)
			1976			
Treatments	55.87	9	6.21	0.72	NS	NS
Error	171.75	20	8.59			
Total	227.62	29				
			1977			
Treatments	75.33	9	8.37	0.48	NS	NS
Error	351.42	20	17.57			
Total	426.75	29				
			Two-year mean			
Treatments	22.92	9	2.55	6.70	NS	NS
Error	73.11	20	3.66			
Total	96.02	29				

Table 6A. Analysis of variance of water use efficiency for the two study years plus the two-year mean.

Source of Variation	SS	DF	MS	F	L.S.D. (0.05)	L.S.D. (0.10)
			1976			
Treatments	6,575.12	9	730.57	2.09	NS	
Error	6,991.69	20	349.58			
Total	13,566.81	29				
			1977			
Treatments	17,708.69	9	1,967.63	7.02	28.52	
Error	5,609.15	20	280.46			
Total	23,317.84	29				
			Two year mean			
Treatments	10,977.78	9	1,219.75	4.36	28.48	
Error	5,593.97	20	279.70			
Total	15,571.75	29				

Table 7A. Comparison samples analyzed with nitrate electrode and compared with technicon autoanalyzer.

Sample number	Technicon	Module number 1	2	3	4	5
	ppm					
1	6.0	8.3	8.7	10.1	3.2	3.9
2	60.0	64.5	68.5	69.3	61.3	60.0
3	64.5	78.4	76.0	69.1	74.0	62.5
4	119.3	118.0	99.0	93.0	111.0	78.0
5	45.0	51.0	50.5	33.0	46.2	31.6
6	33.0	12.7	28.4	18.7	20.4	26.0
7	79.5	61.5	85.0	69.2	80.0	75.3
8	32.5	25.9	31.6	20.3	23.5	29.0
9	71.3	66.5	68.5	66.0	76.0	71.0
10	88.5	64.5	81.0	62.5	71.5	68.2
11	48.0	33.0	46.7	48.5	37.4	38.6
12	65.3	61.5	73.0	58.0	58.6	60.0
13	48.5	47.5	55.7	69.3	50.0	49.4
14	16.8	16.0	14.0	14.8	14.0	12.3
15	66.0	60.0	66.5	47.8	72.0	51.4
16	72.8	62.0	75.0	62.0	65.8	62.5
17	37.8	36.7	35.5	28.0	34.2	33.2
18	66.0	47.0	60.0	40.7	56.0	54.5
19	46.5	38.8	44.0	32.3	37.3	35.5
20	26.0	18.0	21.5	14.3	15.1	19.9
21	25.0	24.0	26.5	17.3	17.7	22.9
22	9.5	12.2	8.6	4.7	8.7	6.4
23	47.0	55.7	52.0	40.7	59.5	45.5
24	10.0	9.4	13.2	0.9	9.5	10.8
25	20.0	28.2	24.4	20.2	27.5	22.9
26	20.5	22.8	17.7	23.8	18.7	16.7
27	10.0	9.4	14.3	8.2	9.4	11.3
28	24.5	23.7	24.5	19.1	19.2	21.3
29	45.5	38.0	37.5	50.3	38.5	38.2
30	28.0	50.2	39.3	36.7	47.0	37.0
31	15.5	18.9	26.6	22.5	15.0	20.3
32	30.0	27.3	31.6	26.0	23.7	27.0
33	24.3	30.0	25.0	22.2	25.5	22.5
34	11.5	14.8	8.2	12.6	12.9	15.5
35	10.5	20.5	13.6	8.1	11.9	10.7
36	24.0	25.1	29.9	17.8	20.9	22.2
37	24.3	37.2	50.5	27.8	38.5	42.8
38	36.0	48.3	45.7	34.8	42.8	35.5
39	49.0	37.2	38.3	29.4	38.0	38.2
40	31.8	35.5	44.0	21.4	34.0	36.8
41	22.5	28.0	31.2	16.0	30.4	32.5

Table 8A. Total nitrate-nitrogen for the 180 cm profile of the Eudora silt loam soil.

Treatment number	Treatment	1976					
		13 Apr.	27 May	16 June	14 July	30 July	16 Oct.
		kg/ha					
1	0, 0, 0	181	217	116	64	133	81
2	180, 0, 0	164	357	286	104	206	159
3	135, 0, 0	151	285	192	82	141	72
4	101, 0, 0	195	283	165	64	126	90
5	0,101, 0	155	202	140	177	186	97
6	0, 0,101	161	188	98	36	184	115
7	51, 51, 0	188	274	115	143	165	116
8	51, 0, 51	155	237	166	72	141	80
9	0, 51, 51	163	191	113	85	139	81
10	34, 34, 34	162	241	154	104	189	118

Treatment number	Treatment	1977					
		18 Mar.	16 May	4 July	14 July	8 Sept.	27 Oct.
		kg/ha					
1	0, 0, 0	143	94	104	262	47	152
2	180, 0, 0	164	378	217	375	141	206
3	135, 0, 0	118	266	137	383	68	142
4	101, 0, 0	145	195	158	280	68	132
5	0,101, 0	111	143	145	254	75	135
6	0, 0,101	125	111	109	292	65	145
7	51, 51, 0	118	240	155	258	90	146
8	51, 0, 51	117	134	107	310	77	129
9	0, 51, 51	112	116	113	336	79	111
10	34, 34, 34	145	202	171	275	97	131

Table 9A. Nitrate-nitrogen concentration in the 150 to 180 cm soil layer for the various soil sampling dates.

Treatment number	Treatment	1976					
		13 Apr.	27 May	16 June	14 July	30 July	16 Oct.
		ppm					
1	0, 0, 0	3.1	7.4	3.5	0.1	5.0	3.1
2	180, 0, 0	3.1	5.8	5.2	1.5	4.1	2.5
3	135, 0, 0	6.2	4.9	0.7	3.6	4.0	0
4	101, 0, 0	6.2	4.1	2.2	0.8	4.4	0.8
5	0,101, 0	3.1	4.8	2.5	2.0	5.9	5.3
6	0, 0,101	0	4.5	2.7	0.8	5.7	3.5
7	51, 51, 0	4.2	6.2	1.4	3.4	7.5	2.6
8	51, 0, 51	2.3	6.3	6.9	2.8	6.0	1.5
9	0, 51, 51	4.8	4.5	3.0	3.0	6.9	2.8
10	34, 34, 34	2.7	5.9	1.8	3.3	6.7	4.2

Treatment number	Treatment	1977					
		18 Mar.	16 May	4 July	14 July	8 Sept.	27 Oct.
		ppm					
1	0, 0, 0	4.6	1.0	2.9	14.1	0	5.9
2	180, 0, 0	3.8	3.6	5.4	19.2	5.4	8.3
3	135, 0, 0	1.9	1.6	6.5	21.0	2.6	3.6
4	101, 0, 0	4.1	3.6	9.9	15.5	1.9	3.3
5	0,101, 0	0.9	2.6	6.0	8.0	1.3	4.7
6	0, 0,101	4.6	2.5	3.5	19.4	0.4	6.3
7	51, 51, 0	5.5	5.0	7.8	9.1	2.8	5.3
8	51, 0, 51	1.7	0.3	3.1	19.0	1.0	6.4
9	0, 51, 51	3.4	2.5	4.7	19.1	2.9	3.8
10	34, 34, 34	3.0	3.8	7.4	17.6	3.5	5.1

Table 10A. Analysis of variance of nitrate-nitrogen concentration in the 150 to 180 cm soil depth layer.

Source of Variation	SS	DF	MS	F	L.S.D. (0.05)	L.S.D. (0.10)
			13 April 1976			
Treatments	95.1	9	10.6	0.84	NS	NS
Error	252.9	20	12.6			
Total	348.0	29				
			26 May 1976			
Treatments	28.6	9	3.2	0.71	NS	NS
Error	89.3	20	4.5			
Total	117.9	29				
			16 June 1976			
Treatments	91.6	9	10.2	1.34	NS	NS
Error	152.2	20	7.6			
Total	243.8	29				
			14 July 1976			
Treatments	431.1	9	4.8	1.85	NS	NS
Error	51.8	20	2.6			
Total	94.9	29				
			30 July 1976			
Treatments	39.9	9	4.4	0.50	NS	NS
Error	176.0	20	8.8			
Total	215.8	29				
			16 October 1976			
Treatments	66.4	9	7.4	0.82	NS	NS
Error	180.1	20	9.0			
Total	246.6	29				
			18 March 1977			
Treatments	58.4	9	6.5	1.15	NS	NS
Error	112.8	20	5.6			
Total	171.2	29				

Table 10A. Cont.

Source of Variation	SS	DF	MS	F	L.S.D. (0.05)	L.S.D. (0.10)
			16 May 1977			
Treatments	55.6	9	6.2	1.14	NS	NS
Error	107.8	20	5.4			
Total	163.4	29				
			4 July 1977			
Treatments	138.3	9	15.4	1.72	NS	NS
Error	179.2	20	9.0			
Total	317.5	29				
			14 July 1977			
Treatments	548.2	9	60.9	4.14	6.55	
Error	295.3	20	14.8			
Total	843.5	29				
			8 September 1977			
Treatments	70.5	9	7.8	0.72	NS	NS
Error	218.2	20	10.9			
Total	288.7	29				
			27 October 1977			
Treatments	64.3	9	7.1	1.16	NS	NS
Error	122.8	20	6.1			
Total	187.1	29				

CORN YIELD AND WATER USE AS INFLUENCED BY SPLIT APPLICATIONS OF NITROGEN FERTILIZER

by

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ABSTRACT

We studied the influence of split application of nitrogen fertilizer on the grain yield and water use by corn. This study was done on the Eudora silt loam soil on the Ashland Agronomy farm near Manhattan, Kansas in 1976 and 1977. The treatments were assigned to the plots in a completely randomized experimental design with three replications per treatment. The fertilizer was applied at pre-plant, at pre-tassel, and at silking. The pre-tassel and silking applications were made with irrigation water. The corn plants were sampled for grain yield, dry matter yield, leaf tissue and grain nitrogen content, and the soil was sampled for nitrate-nitrogen content.

Results of the dry matter yield showed that pre-plant applications were superior to split applications. The grain yields were not significantly different at the 0.05 level in 1976. In 1977 the yields were significantly different at the 0.05 level, but showed no yield advantage to split applications. Delaying the nitrogen fertilizer application resulted in large grain nitrogen contents as did large, pre-plant applications.

Total water use was unchanged by split applications. No significant difference existed between treatments at the 0.05 level. Water use efficiency was greatest for those treatments that received all nitrogen pre-plant.

The leaching data showed that nitrate movement in the Eudora silt loam soil was not significant for the two years of this study.