Response of spring wheat and barley to simulated application of N through irrigation sprinklers in Montana
by Randy Jay Killorn

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soil Science
Montana State University

Abstract:
During the summer of 1977, three experiments were established at two locations in Montana to determine the yield response of spring wheat and barley to applying a portion of the total N fertilizer in irrigation water. Various proportions of the total N fertiliser were applied at planting. The remainder of the N fertilizer was applied in simulated fertigation treatments during the growing season. Treatments receiving less than 100% of the total applied M fertilizer at planting had lower grain yields and higher grain protein than treatments receiving 100% of the N fertilizer at planting. There seems to be no advantage in Montana to applying part of the total N fertilizer at planting followed by growing season applications of the remainder in irrigation water.

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Randy Jay Killen

Date 2-9-79

RESPONSE OF SPRING WHEAT AND BARLEY TO SIMULATED APPLICATION OF N THROUGH IRRIGATION SPRINKLERS IN MONTANA

by

RANDY JAY KILLORN

A thesis submitted in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science

Approved:

Earl O. Skogley
Chairman, Graduate Committee

Hayden Ferguson
Head, Major Department

Henry L Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana
February 1979

ACKNOWLEDGEMENT

The author wishes to express sincere gratitude to Dr. Neil W. Christensen without whose patience and guidance this project would not have been completed.

The author would also like to thank his wife Kathy and daughter Kelly whose understanding and moral support during this project were the key to its completion.

TABLE OF CONTENTS

LIST OF TABLES

page

LIST OF FIGURES

page

ABSTRACT

During the summer of 1977, three experiments were established at two locations in Montana to determine the yield response of spring wheat and barley to applying a portion of the total N fertilizer in irrigation water. Various proportions of the total N fertilizer were applied at planting. The remainder of the N fertilizer was applied in simulated fertigation treatments during the growing season. Treatments receiving less than 100% of the total applied N fertilizer at planting had lower grain yields and higher grain protein than treatments receiving 100% of the N fertilizer at planting. There seems to be no advantage in Montana to applying part of the total N fertilizer at planting followed by growing season applications of the remainder in irrigation water.

INTRODUCTION

In recent years the number of irrigated acres in Montana has increased. Small grains are produced on much of the newly developed sprinkler irrigated acreage. To obtain the high yields necessary to offset the cost of irrigation development, crops must be properly fertilized. Hence, an interest in applying fertilizers through sprinkler systems is developing.

Fertigation, applying fertilizers with irrigation water, is a common practice in some parts of the United States. It is used extensively to apply nitrogen fertilizers to crops grown on coarse textured soils in low rainfall areas along the Columbia River in Oregon and Washington as well as in other areas.

In order to maximize crop production and minimize costs, nitrogen (N) losses, and possible pollution of ground and surface waters, fertilizer must be applied at the proper rate and the proper time. Precipitation distribution influences when irrigation is initiated and may limit the utility of fertigation in Montana. Fifty percent or more of the total annual precipitation in Montana falls during the months of April, May and June, thus delaying the time of irrigation and fertigation initiation, and restricting the timing of fertilizer applications. Consequently, extrapolation of data from areas where irrigation begins earlier in the spring may not be valid. In order to ensure proper fertilizer utilization, guidelines for fertigation in Montana need to be developed.

LITERATURE REVIEW

In order to maximize quantity and quality of spring grains grown under irrigation, proper use of fertilizer is essential. The efficiency of applied N for grain production is altered by the method of application, timing of the application, and possibly by the N source used.

Fertigation

The practice of applying fertilizer in irrigation water probably started when an irrigator ran his irrigation canal through a pit filled with barnyard manure (Fischbach, 1976). When anhydrous ammonia became plentiful in the 1950's, irrigators started applying it in their irrigation water. Anhydrous ammonia use in sprinkler systems was severely limited because ammonia displaced other cations such as calcium and magnesium, in solution. These ions form precipitates that plug nozzles. Salts such as calcium carbonates and calcium bicarbonates are also displaced by the ammonia ion, forming precipitates that plug sprinkler nozzles. In the late 1950's and early 1960's, non-pressure solutions of ammonium nitrate (AN) and urea (UR) were introduced to the market. Unlike anhydrous and aqua ammonia, AN and UR are non-volatile and do not cause precipitates to form in irrigation water and thus can be used in sprinkler irrigation systems.

Nitrogen is not the only nutrient that can be applied in irrigation water. Murphy (1970) showed that iron can successfully be applied through sprinkler irrigation systems. In fact, iron chelate compounds applied through sprinklers to grain sorghum produced higher average yields and iron contents than iron applied to the soil. Schneider, et al. (1968) found that iron solutions can be used to correct deficiencies during the critical period of crop growth 2 to 4 weeks following emergence of the crop.

Beaton and Bixby (1974) found that sulfur, magnesium and calcium can all be applied in solutions. Suspensions of limestone and gypsum can be used to rapidly correct the soil pH of acid or sodic soils respectively.

In many cases polyphosphates can be applied through sprinkler systems. If calcium is present in the irrigation water, however, a calcium ammonium pyrophosphate precipitate will form, clogging the sprinkler system. Duis and Burman (1969) developed a rapid test procedure for predicting precipitate formation, allowing immediate knowledge about the feasibility of phosphate fertigation on an individual basis.

Fertigation also provides a way in which to utilize nitrate contaminated ground water. Fischbach, et al. (1973) irrigated corn using ground water known to be contaminated with nitrate. If the water contained 27 parts per million nitrate-nitrogen, no fertilizer nitrogen was required.

Since N is the nutrient used in the largest quantities, and because most N sources are more soluble than other fertilizers, most producers are interested in the aspects of applying N fertilizer through sprinkler systems.

Fischbach (1970, 1964) compared sprinkler application of N with ground application. Both Fischbach (1976) and Morton (1976) demonstrated that on shallow sandy soils, applying N through an irrigation system is more effective than ground application. Fischbach (1970) found N fertigation of crops on fine textured soils to be just as effective as ground application.

In five field trials comparing N fertigation with ground application in central and western Nebraska, fertigation produced a yield increase of eight bushels of corn per acre over ground application, plus eliminated one field operation (Fischbach, 1964). Ground applying the recommended amount of N, and then applying 20 to 30 pounds additional N in the first irrigation produced an average of fifteen bushels per acre of corn more than applying the recommended amount of N alone.

When urea or ammonium containing fertilizers are applied to warm, moist, well-aerated soils, the N is rapidly converted to NO_3 by nitrosomonas and nitrobacter bacteria. Because nitrate is an anion, and therefore not adsorbed to soil and organic colloids, it moves freely in the soil solution. Nitrate can be expected to leach through sandy soils if too much water is applied when irrigating (Thorup, 1977). Therefore, in sandy soils, efficient management of water and fertilizer can result in a favorable cost/benefit ratio for fertigation. Watts (1975) was able to demonstrate greater efficiency of use from sprinkler applied N than from preplant broadcast N on sandy soils. The yield resulting from 150 pounds of N injected into the irrigation system was nearly double that of 150 pounds of N broadcast preplant. The N loss due to leaching was far less for the injected treatment than for the preplant broadcast treatment.

Caldwell (1972) demonstrated that split application of N increased yields of Kitt and Era spring wheats. Fischbach (1972) and MacGregor (1972) have shown that applying at least one-third of the total N requirement through the irrigation system can increase corn yields as much as 26 bushels per acre on deep sandy soils.

Time of Application

Timing of fertilizer application is important. Morton (1976) points out that the total amounts of N and water applied are not as important as the ability to place them on the crop when they are needed. On sandy soils, yields can be maximized by "spoon feeding" N to the crop at critical times in the life cycle. Using fertigation, fertilizer can be applied to a crop at times when ground application could damage the crop and severely reduce yields. This is particularly true of late applications of fertilizer (i.e. in the boot stage of small grains).

Rankin (1946) showed that applying only a portion of the N requirement at seeding, followed by later N applications increased both yield and quality of wheat over applying the total N requirement at seeding.

Due simply to the size of the root system after germination, seedlings are able to use only a small fraction of any N applied at seeding. Fenn and Escarzaga (1977) and Hargrove, Kissel and Fenn (1977) found that significant amounts of N applied at seeding can be lost through volatilization, especially if the soil is wet when the N fertilizer is applied. They found that when 100 kg N/ha was added to moistened soil in pots, up to 68% was lost via volatilization, while up to 45% of the added N was lost from oven dried soil. Russell (1973) points out that N applied at seeding can also be lost through leaching. Therefore, a considerably reduced amount of N may be available for tillering and growth when the entire N requirement is applied at seeding.

The availability of N to wheat at and during tillering is critical (Khalifa, 1973; Balba, et al. 1972; Jain, Maurya, and Singh, 1971). Mehrotra et al. (1967) have shown that N uptake increases dramatically from the seedling to the tillering and jointing stages. They found that 45% of total N uptake occurred following seeding through tillering. From jointing to ear initiation 25% of total N uptake occurred, while 30% of total N uptake occurred from jointing to grain formation.

Van Dobben (1966) found that early N applications stimulate tillering as well as straw length in cereal grain. This response decreases with delay of application and disappears completely after stem elongation begins. Khalifa (1973) and Balba et al. (1972) found that application of nitrogen fertilizers in the early phases of crop growth gave the greatest yield response. Yield response to N application at ear emergence was much less.

Data of Balba et al. (1972) show 13% utilization of N applied at ear emergence compared to 31.4% utilization of N applied at tillering. Khalifa (1973) found that 44 kg N/ha applied to irrigated wheat at planting, tillering and ear emergence produced grain yields of 1787, 1690, and 932 kg/ha respectively.

Khalifa (1973) found that applying half the N to wheat at planting and half at tillering or ear emergence produced no significant difference in yields from applying all the N at planting. He found that differences in grain yield were a reflection of the effect of the treatments on leaf area duration (LAD) after ear emergence. Leaf area duration describes the length of time the leaf area is functional. Grain yield of cereals is related to LAD after the ears emerge (Mitchell, 1970a). Early N application increases LAD at the time of ear emergence (Khalifa, 1973).

Ayoub (1974) found that time of fertilizer application affected wheat grain yield mainly by increasing the number of ears per unit area.

A maximum of about 800 ears/m^2 was obtained by application at the jointing stage.

These research results have shown that split applications of N fertilizer affect grain yield per unit land area. The amount of grain produced per unit land area is only one parameter used to evaluate fertilizer response, however. The quality of wheat measured by protein content, is another important aspect to consider.

McNeal et al. (1966) found that even though most (up to 61.6%) of stem nitrogen is translocated to the kernel, wheat plants continued to take up N from the soil during the filling of the kernels. McNeal et al. report results which indicate that N applied when the kernels are filling could increase the protein content of the grain.

Hunter, et al. (1973), Hucklesby et al. (1971), and MacLeod (1975) showed that late (spring) applications of N to winter wheat consistently gave higher protein contents than fall applications.

Spratt (1974) suggested applying N at sowing to increase leaf and stem growth and applying N at the boot stage to increase grain protein levels. Hamid and Sarwar (1976) found that applying N in six equal applications at seeding, tillering, boot, heading, flowering, and the milky stage significantly increased protein content compared with a single application at planting or two split (seeding and tillering) applications.

Nitrogen Source

Nitrogen fertilizer may be applied as nitrate or ammonium salts, urea, anhydrous ammonia, or a combination of these materials. There are also many organic sources of N including animal manures, animal by-products (i.e. dried blood and fish meal), and plant materials such as alfalfa. Generally speaking, the N present in all these compounds is supplied as ammonium-N, nitrate-N, or both. Nitrate-N is the form most used by plants and therefore before NH^+_4-N is taken up by plants it is generally transformed to NO^-_3-N (Meyer et al. 1973). The N present in organic compounds and urea is generally in an amine group ($-NH_2$). In order for organic N to become available to plants, it must undergo the process of mineralization. This normally takes place in essentially three steps: aminization, ammonification, and nitrification. The first two are accomplished through the medium of heterotrophic microorganisms and the third is brought about largely by autotrophic soil bacteria (Tisdale and Nelson, 1975). Aminization is the process of hydrolytic decomposition of proteins and the release of amino acids as accomplished by one group of heterotrophs:

$$\text{proteins} \longrightarrow R\text{-}NH_2 + CO_2 + \text{other products.}$$

These amines and amino acids are utilized by another group of heterotrophs, resulting in the release of ammonia:

$$R\text{-}NH_2 + H_2O \longrightarrow NH_3 + R\text{-}OH + \text{energy.}$$

Some of the NH_3 released is dissolved in water to form ammonium (NH_4^+) and this is converted into nitrate via two steps by autotrophic bacteria. N supplied as NH_4^+ enters the mineralization process at this point.

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+$$

$$NO_2^- + O_2 \longrightarrow 2NO_3^-$$

Tisdale and Nelson (1975) say that in well drained neutral to slightly acidic soils, the rate of oxidation of NO_2^- to NO_3^- is usually higher than that of NH_4^+ to NO_2^-. The rate of NO_2^- formation is usually equal to or greater than the rate of NH_4^+ formation. Therefore, NO_3^- is the form that tends to accumulate in soils or, if plants are growing on that soil, will be the form most used by them.

Plants are not capable of distinguishing from what source N is originating. Of note, however, is the fact that at different phenological stages wheat plants may use one form of N preferentially over another (Spratt, 1974). The ammonium form is used in early stages of plant growth, and nitrate-N is used in later stages. Spratt found that applying ammonium-N to wheat at planting promoted more stem and leaf growth than nitrate-N. Conversely, nitrate-N applied during the boot stage increased grain protein more than did ammonium-N.

Spratt and Gasser (1970) found that with adequate moisture, wheat produces more dry matter (and grain) containing more N when provided with a nitrate source as opposed to an ammonium source of fertilizer N.

When moisture is lacking, ammonium N is as good or better than nitrate-N for increasing dry matter production and N uptake.

The difference in efficiency of crop production (as measured by yields) between sources of N fertilizers, lies in the factors influencing N transformations once the fertilizers contact the soil. Researchers consistently find N x year interactions (Alessi and Power, 1972; Spratt 1974; Hamid and Sarwar, 1976; and Ayoub 1974) are significant, indicating that N fertilizer interactions with components of the environment are what determines the efficiency of a nitrogen source.

Christensen, et al. (1975) have shown that if N fertilizer is applied properly, under proper conditions, different N sources produce comparable crop response. Caldwell, Murphy, Tucker, Wiese and Zubriski (1977) concur, that if used properly, there is no difference in efficiency of the various nitrogen sources.

^{15}N Use in Agricultural Experimentation

There are six known isotopes of N. Of these six only two, ^{14}N and ^{15}N, are stable and occur naturally. Since these isotopes occur naturally in an almost constant ratio (0.366 atom % ^{15}N), they can be used as tracers in biological systems by using three basic assumptions (Hauck and Bremner, 1976). Those assumptions are:

1. Elements containing two or more isotopes have a constant isotope concentration in the natural state.

2. Living systems cannot distinguish one isotope from the other.

3. The chemical identity of the isotopes is maintained in biological systems.

Hauck and Bremner (1976) have found 1500 papers published since 1943 relating to the use of ^{15}N tracers in agronomic related research.

In their 1976 review paper, Hauck and Bremner conclude that tracer methods have distinct advantages over nontracer methods for studying the recovery of applied fertilizer-N by plants. Even though the use of labeled N is confounded by possible biological interchange of labeled N with unlabeled soil N, N tracer methodology is still a convenient procedure for studying N uptake. No control plots are required, so more treatments or replications can be used. Uptake is calculated directly from total plant N and isotope ratio analysis. Users of non-tracer techniques calculate N uptake from fertilizer by taking the difference between total N uptake from fertilized and unfertilized plots. This technique is based on the erroneous assumption that addition of N to the soil does not alter the amount of soil N taken up by the plant (Hauck and Bremner, 1976).

During mass spectrometer analyses of N_2, the nitrogen ions $(^{14}N_2)^+$, $(^{14}N^{15}N)^+$ and $(^{15}N_2)^+$ are found to occur in the mass spectrum. The relative number of ions of each species approaches the ideal statistical values given by the equation

$$(a + b)^2 = a^2 + 2ab + b^2$$

where a is the atom fraction of ^{14}N, b is the atom fraction of ^{15}N, and a + b = 1 (Hauck and Bremner, 1976). The mass spectrometer can measure the ion currents at M/e[1]28, M/e29 and M/e30, which are proportional to the respective molecular ions (Bremner, 1965). It is usually not necessary to measure the ion current at M/e30 to determine the atom percent ^{15}N because of the random distribution of isotopes in the N_2 molecules. Hauck and Bremner (1976) show that from the ratio (R) of the ion current at M/e28 and M/e29, atom % $^{15}N = 100/(2R + 1)$.

---

[1]/M/e = Mass/charge of the ions

OBJECTIVES

This review of the literature reveals that, when used properly, fertigation may be a highly efficient manner in which to apply fertilizers. The literature also points out that the timing of fertilizer application and other management decisions are important factors to consider under any fertility management scheme.

Due to the extended period of spring rains in Montana, the first application of fertilizer through sprinkler systems is normally later, in terms of the stage of crop development, than in other areas where fertigation is commonly practiced. Consequently, little data exist that will predict the effect of late application of N fertilizers to small grains. The major objective of this study was to gather such information.

Specifically, the objectives of this study were:

1. To determine the effect on spring wheat and barley grain yield and quality of applying various proportions of the total N-requirement through sprinkler systems.

2. To determine the optimum timing, measured phenologically, for applications of N fertilizers through sprinkler systems.

3. To compare crop response to new N fertilizers with response to ammonium nitrate.

4. To obtain information to correlate soil test values for P and K to crop yield response in the field.

MATERIALS AND METHODS

Site Selection

Three criteria were used in selecting sites for this experiment. The area had to be under sprinkler irrigation, have low residual NO_3-N levels to 1.8 meters, and, due to the management required, be close to Bozeman, Montana. Parameters including slope, apparent texture and surface soil color were subjectively examined to evaluate soil uniformity at prospective sites. Soil samples were collected at each site to determine soil nutrient levels.

Six random samples were taken at each prospective site to 1.8 meters in 30.5 cm increments with a Veihmeyer tube. These samples were oven dried at 65^{o}C, ground in a Robert Hewitt stainless steel hammermill to pass a 20 mesh screen and analyzed for SO_4-S using the $BaSO_4$ method of Bardsley and Lancaster (1960), and for NO_3-N using the Phenoldisulfonic procedure of Bremner (1965). Results for the two sites selected for the experiments are reported in Table 1.

Appproximately 35 samples were taken randomly from the 0-15 cm soil depth at each site using an Oakfield probe. The samples were composited, dried and ground as previously described and analyzed for pH, electrical conductivity (E.C.), P, K, organic matter (O.M.) and Na. The results are recorded in Table 2.

Table 1. Initial NO_3-N and SO_4-S concentrations at experimental sites

	Depth in cm						
Location	0-30	30-60	60-90	90-125	125-155	155-185	total (kg/ha)
577	ppm						
NO_3-N	10.7	3.6	3.0	2.0	2.0	3.0	109
SO_4-S	31.0	70.4	90.8	96	5	56.9	1547
777 & 876							
NO_3-N	1.4	0.9	0.9	0.9	1.4	1.4	31
SO_4-S	8.6	5	18.3	34.1	35.2	28.9	560

Table 2. Initial soil test results at experimental sites

Location	pH	E.C. (mmhos/cm)	P (ppm)	K (ppm)	O.M. (%)	Na (meq/100g)
577	8.1	1.1	41	509	1.9	0.2
777 & 876	8.2	0.5	45	429	2.7	trace

Electrical conductivity and pH were determined using a 2:1 water:soil dilution (USDA Handbook 60, 1969). Concentrations of K and Na were determined with a Perkin Elmer 290B atomic absorption spectrophotometer following extraction with one normal ammonium acetate using methods described by Rich (1965). Phosphorous concentrations were determined using the Bray procedure as modified by Smith, et al. (1957). Percent organic matter was determined using the procedure of Sims and Haby (1971). All analyses were performed by the Soil Testing Lab at Montana State University.

Location and Design

Site 577 was located near Toston, Montana. Sites 777 and 876 were located adjacent to one another ten miles north of Bozeman, Montana. All three sites were irrigated with side-wheel-roll type sprinkler systems. Soil series descriptions are listed in Appendix 1.

The field design at each location consisted of three replications of 16 treatments arranged in a randomized complete block design. All three locations were planted using a modified Minneapolis-Moline deep furrow press wheel drill with a row spacing of 30.5 cm. Locations 577 and 777 were seeded with spring wheat (Triticum aestivum L.) var. Newana at a rate of 100 kg/ha. Location 876 was seeded with malting barley (Hordeum vulgare L.) var. Shabet at a rate of 100 kg/ha.

Plots were 4.3 m wide (14 rows) and 12.2 m long. Since the width of the plots was twice the drill width, plots were seeded by making two passes in the same direction. Rows were planted parallel to the long dimension of the plot which in turn was aligned parallel to the length of the sprinkler system. Plots were divided into halves with each half containing seven rows 12.2 m long. One-half of each plot was used for subsampling during the growing season while the other half was harvested at the end of the growing season for determination of grain yield and quality.

Treatments

The treatments at each location were designed to include a number of variables (see Table 3). Phosphorous (P) was drilled with the seed as Triple Super Phosphate (0-45-0) at rates of 0, 11 and 22.5 kg P/ha (tmts. 2, 3, 7). Potassium (K) as Muriate of Potash (0-0-60) was topdressed immediately following seeding at rates of 0 or 45 kg K/ha (tmts. 4 and 7). Treatments used to evaluate response to P and K fertilizer were topdressed with Ammonium Nitrate (AN, 34-0-0) at a rate of 100 kg N/ha immediately after seeding.

There were three distinct sets of N variables at each location (all received 22.5 kg P/ha and 45 kg K/ha applied as previously described). Response to N fertilizer was determined using rates of 0, 50, 100 and 150 kg N/ha as AN topdressed immediately following seeding (tmts. 5-8). A series of treatments were included to compare grain response to Urea (UR, 46-0-0), Ammonium Nitrate Sulfate (ANS, 30-0-0-6.5S), Urea Ammonium Sulfate (UAS, 40-0-0-6 S) and AN (tmts. 7, 9, 10, 11). These four treatments were topdressed immediately following seeding at a rate of 100 kg N/ha. The third set of N treatments (tmts. 12-16) was designed to measure response to simulated sprinkler application of N fertilizer. Nitrogen (as AN) was applied at a total rate of 100 kg/ha (treatment 16 at location 577 and 777 received 125 kg N/ha). These treatments received either 25, 50, 75 or 100 kg N/ha topdressed immediately after seeding. The remainder of the 100 kg N/ha total was applied at rates of from 25 to 50 kg N/ha at various times later in the growing season. The later applications were timed to