Irrigation and nitrogen effects on Wampum spring wheat
by John Craig Wallace

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
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Abstract:
Current recommendations for scheduling irrigations of wheat in Montana call for allowing depletion of 50% of the soil's available water holding capacity before starting irrigation. The objectives of this investigation were to measure the response of 'Wampum' spring wheat to nitrogen and irrigation variables, and to determine if the 50% depletion recommendation should be modified for varying nitrogen fertility levels.

A field plot experiment was established near Fairfield, Montana in 1981, to investigate the response of 'Wampum' spring wheat to varying nitrogen and irrigation levels. The study employed a line source sprinkler system in a continuous variable design. Irrigation treatments consisted of successively decreasing amounts of water with all treatments irrigated with equal frequency.

Wampum grain yields increased with increasing applications of both nitrogen and water, and an interaction between these factors was indicated.

A greenhouse pot study was initiated in the fall of 1981, to further study Wampum's response to irrigation and nitrogen, by varying both the timing and amount of irrigation. A randomized complete block design was used, in which irrigation treatments consisted of allowing 25, 50, or 75% of the plant available water to be depleted before irrigation.

The interaction between nitrogen fertility and maximum allowed depletion was not significant over the treatment range used. Therefore, the maximum allowable depletion concept, and the currently recommended values, should be applicable to fields having a broad range in nitrogen fertility status without requiring modification.

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Date November 5, 1982

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ON WAMPUM SPRING WHEAT

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ABSTRACT

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CHAPTER 1

INTRODUCTION

Irrigation allows the farmer to control the soil water status which, under dryland conditions, is the most limiting and least controllable crop production factor. Water should be provided in the correct amount for the prevailing soil, crop, and climatic conditions to maximize the benefit of irrigation. In addition, the crop demand for water is modified by the amount of nitrogen (N), and other essential plant nutrients available to the crop.

Many researchers have reported the yield of wheat in relation to the amount of water used by the crop. It is impractical for a farmer to apply a particular amount of water to reach a specific yield goal. Rather, he can only observe the degree of plant water stress and the amount of depletion of the soil water to estimate the optimum timing and application amount of irrigation water. The net amount of water applied during the growing season will be determined by the weather conditions for that season, and the physiological nature of the crop. Current recommendations for the amount of maximum allowable soil water depletion (MAD) for spring wheat, are typically 50 to 70% (Bauder et al., 1982; Eisenhauer, et al., 1980; Thompson and Fischbach, 1980, Trimmer, 1980.). These recommendations are based on a 'well fertilized' field and do not consider the actual N status of the field to arrive at the MAD value. Interaction between N status and cumulative water use has been reported by some researchers under both dryland (Brown, 1971), and irrigated conditions (Ehlig and LeMert, 1976). The objective of this research was to evaluate the potential interaction between N status and an optimum value of MAD.

In 1981 a field experiment was established with 'Wampum' spring wheat (Triticum aestivum L.), using a line source irrigation system, developed by Hanks (1976), in a continuous variable design (CVD). The yield of wheat was strongly affected by both N status and irrigation amount. The response surface indicated an interaction between these two factors.

A greenhouse experiment was initiated to evaluate the desirability of modifying the MAD value for differing levels of N fertility. Three irrigaton strategies were used corresponding to MAD values of 25%, 50%, and 75%. These treatments were applied in factorial combination with five N rates. The experiment was conducted with six replications in a randomized, complete block design. This experiment indicated that the interaction between N status and MAD was not significant over the treatment range used. The MAD concept, and values derived from experimental plots, should be applicable to production systems having a wide range in N status, without requiring modification. An analysis of yield components revealed no significant effects of the water treatments on heads per plant, seeds per head, or mass per seed.

CHAPTER 2

REVIEW OF LITERATURE

Observations of the relation of crop yields to the amount of water used by the crop have been reported since the early 1700's, when Langley Batty reported that fruit drop of peaches and other tree fruits could be reduced by shading and watering during late May and June (Salter and Goode, 1962). Statistical studies were begun in the late 1800's to relate annual rainfall records to crop yield records. Lawes and Gilbert (1880) reported a correlation between wheat yields and rainfall over the period 1832-1878. These early correlative techniques were hampered by using seasonal time frames. At the turn of the century, Russian researchers began to relate periodic rainfall to the crop phenologic stage, with dramatically improved results. Brounov (1899) reported a close correlation between the yield of oats and amount of rain falling in the ten day period preceeding heading. Brounov coined the term 'critical period', to refer to a period of crop sensitivity to any meteorological factor. The factor of interest in his work was water availability. This has been the most common use of the phrase since that time.

Cumulative Water Use

Yield of forage and vegetative crops generally begins with the first increment of water use by the crop, and increases in a linear fashion with increasing cumulative water use (Downey, 1972; Salter and Goode, 1967). Total dry matter production of cereal crops follows this type of relationship; seed yield does not because of the critical period phenomenon (Downey, 1972; Slavik, 1965).

In the field, crops are not exposed to conditions of constant soil moisture availability. There is a period of low stress following irrigation or significant rainfall, followed by a progressive increase in plant water stress because of the extraction of soil water (Downey, 1972; Salter and Goode, 1967; Slavik,1965).

One method of investigating the effect of near constant soil moisture stress is to lower the osmotic potential of the soil solution and maintain a high soil moisture content (Downey, 1972). Downey (1972) summarized the results of three researchers who used this approach. A linear, or nearly linear, response in yield was obtained in all cases. This suggests that when soil water potential limits plant water use, grain yield is a simple, linear function of water use.

In the field, a crop is progressively stressed by soil water removal until the soil profile is recharged. In most irrigation scheduling programs, the parameter of interest is the allowed soil moisture depletion before irrigation is started. Dubetz (1961) grew spring wheat in pots in the greenhouse on a loamy and a sandy soil. He allowed depletion of 25%, 50%, and 75% of the plant available water before irrigating, across five N fertility levels. Significant grain yield differences were observed between water treatments on the loam but not the sandy soil. This indicates that water availability remained high in the sandy soil, probably due to the high hydraulic conductivity of this type of soil in the range of moisture contents studied. In contrast the response to water on the loamy soil shows that water was limiting at the commonly recommended MAD of 50%. Ehlig and LeMert (1976) studied the response of winter wheat to differing amounts of seasonal evapotranspiration (Et). Irrigation treatments were imposed by applying varying fractions of the water used by wheat in a well watered weighing lysimeter. Grain yield was reduced in all treatments drier than 90% of maximum evapotranspiration (Et_{max}). There was no increase in water use efficiency due to a restricted water supply. Heading and flowering dates were earlier on the plots with restricted water supplies and the yield response obtained may have been due to the longer period of assimilation in the well watered plots.

Effects of Crop Growth Stage

Downey (1972) summarized the results of fourteen published irrigation experiments on nine different grain crops. For each of the fourteen experiments, Et/Et_{max} was plotted against yield (Y) / maximum yield (Y_{max}). These data show no yield for any treatment with seasonal water use less than half of that required to achieve maximum yield. This observation supports the hypothesis that one half of the seasonal Et is required to bring the crop to the reproductive phase. Yields averaged 50% of Y_{max} and ranged from 30% to 80% of Y_{max} at Et/Et_{max}=70%. Yields ranged from 40% to 95% of Y_{max} for Et/Et_{max}=80%. The broad range of yield values associated with each Et deficit (Et_d) level arises from two primary causes. First, the plant stress indicators measured were not the same in all cases. Leaf water potential, measured by thermocouple psychrometry or pressure bomb, were used in most of the experiments, while some other data used in the summary were based on controlling Et by lowering soil water potential. Any relationship between soil water potential and seasonal Et is subject to large errors because the plant response to soil water potential is strongly affected by the prevailing climatic conditions. Stegman et al.(1976) carried out a stepwise regression procedure to determine the relative importance of soil moisture, ambient air temperature, wet bulb temperature, solar radiation intensity, and wind velocity on leaf water potential. They concluded that ambient air temperature is a critical factor in determining the effect of a particular level of soil water potential on leaf water potential. The second cause of the wide range of results in Downey's summary is the critical period phenomenon. If a particular amount of Et_d occurs during a critical period in the plants' life, there will be a relatively large yield reduction. An Et_d of equal magnitude occuring in a non-critical period will cause little yield loss, or may even cause a slight increase in final yield over that of a non-stressed plant (Singh, 1981).

Many studies have been conducted to determine the time and duration of the critical periods in wheat. Robins and Domingo (1962) imposed irrigation treatments by eliminating irrigation at each of four phenological stages of spring wheat. Four levels of N fertility were applied in factorial combination with the irrigation treatments. Their results show an increase in yield with increasing amount of water used, modified by the timing of irrigation treatments, in relation to the critical periods of crop sensitivity to moisture stress. They identified the critical periods for wheat as the boot to maturity stages, while moisture stress during the early vegetative (pre-boot) and late grain fill stages did not cause a significant yield reduction. There were no measurable interactions between N and irrigation levels except for total dry matter in one of two years. Robins and Domingo recommended deferring irrigation until the boot stage unless severe leaf curling or 'firing' is evident during the period of vegetative growth.

Schreiber and Stanberry (1965) obtained similar results with barley for four stages; 1) plant establishment, 2) tillering to boot, 3) pollination, and 4) grain fill to maturity. They allowed soil moisture depletion to 40.4 kPa tension in 'wet' treatments, and 1.0 to 1.4 MPa in 'dry' treatments. Moisture stress timing was described as; continuously wet, wilted before irrigation during early growth, and periodic wilting up to pollination. No yield effects were found for the irrigation treatments. Therefore, irrigation prior to pollination was not recommended.

Mogensen (1980) used indices of drought stress intensity and duration to investigate the drought sensitivity of barley at differing development stages. Treatments with stress in the pre-boot stages developed late tillers, which were considered insignificant to yield and were not harvested. Regression analyses showed yield reductions of 14% for stress in the jointing stage, 8% in booting stage, and 4% if stress occurred during the heading period.

Singh (1981) also investigated intensity and duration of drought stress to arrive at an optimal sequencing of Et_d's for winter wheat. Singh related wheat yields to Et_dd's for four seasons and divided the Y/Et ratios into classes of optimal (<17% yield reduction), and suboptimal (51 to 78% yield reduction) irrigation levels. He concluded that the timing of a particular amount of Et_d was of less importance than the intensity, in determining final yield. His data show a linear relation between percent yield reduction and percent Et_d for all timing sequences. Singh also looked at the effect of hardening on the drought tolerance of the winter wheat. He found that without prior conditioning in the vegetative period, any Et_d occurring in the boot to heading period caused a reduction of the Y/Et ratio. When the crop was conditioned by Et_d's of 10 to 18%

in the vegetative period, the crop could tolerate Et_d's of 30 to 35% in the boot to heading stages, and as much as 39% for flowering to grain development stages, without reducing the Y/Et ratio. Singh concluded that the three growth stages could be rated in order of sensitivity to drought as; booting to heading > flowering to grain development > vegetative stage. However, when water supplies are expected to be inadequate for full irrigation, the anticipated Et_d should be evenly distributed over the growing season to benefit from the hardening effect. By allowing some Et_d during the vegetative period, the sensitivity of the critical period is lessened, and the net yield reduction with some Et_d in all periods will be less than if all of the Et_d occurs in the least sensitive period. This differs from the common conception of critical period scheduling, where it is recommended that no Et_d be allowed during the critical period, thereby concentrating the seasonal Et_d completely in the less critical growth stages.

Stegman et al. (1976) arrived at a deficit irrigation scheduling technique by looking at the level of Et_d which caused stomatal closure and reduced photosynthesis. They related the stomate closing threshold to percent soil moisture depletion and ambient air temperature. The stomate closing thresholds accounted for the differing drought sensitivies of the growth stages. When this scheduling method (MAD modified by ambient air temperature) was used, 15 to 21% savings in applied irrigation water were realized, compared to conventional scheduling at 40 to 50% MAD. These water savings were made in simulation runs using a ten year weather record.

Brown (1971), working with dryland winter wheat, found that fertilizing with N at 67 or 268 kg/ha increased grain yield, consumptive water use (CU), and water use efficiency. The water use was keyed to crop growth stage and showed a progressively greater amount of CU for the fertilized treatments from about the boot stage to full ripe. The increase in CU of the dryland crops was met by greater depletion of the deeper soil layers. Brown also noted that the lower leaves remained green longer at the higher N rates.

The general response of cereals to water has been described by Slavik (1965) in a review of worldwide literature prior to 1965. Many researchers have shown a regular decrease in yields with a decrease in osmotic potential of expressed cell sap. The response to decreases in total potential is more obscure. According to Slavik, "Although drought reduces the yield of spring cereals at all stages of their ontogeny, it is still possible to delimit to some extent periods in which the damage is greatest; this is so when the growing point experiences a water deficit." Drought during the period of rapid leaf growth will reduce the number of fertile tillers; during spikelet formation, the number of spikelets per spike; in anthesis, the total number of grains; and during grain formation, the weight per seed. Slavik also states that "During ontogenesis, high hydration levels are associated with the maintenance of the physiological characteristics of 'youth', chiefly the prolongation of cell division and of extension growth and, associated with these, morphological characteristics such as fewer larger stomata per unit area and a thinner cuticle." Young leaves have a higher photosynthetic activity, which in turn increases the growth rate. Slavik also notes the hardening effect in pointing out that sudden drought periods in a previously unstressed crop are much more serious than when the crop is grown at a more constant but lower level of stress. However, if drought stress can be entirely avoided by irrigation, the prolongation of youthfullness can be exploited to achieve maximum yields.

Continuous Variable Designs

In conventional experimental designs treatments are applied in discrete units to plots which are spatially randomized. This arrangement requires borders between treatments, and at the perimeter of the experimental area. These borders involve additional costs of materials and labor. A continuously varying treatment set can be more efficient for demonstrating crop responses and generating response surfaces which are visually apparent in the field , and do not require statistical analysis (Hundtoft and Wu, 1974).

One of the first reported uses of the continuous variable design (CVD) was by Fox (1973). He applied 5.5kg/ha increments of N to consecutive individual plants in a row of N deficient corn, giving treatments from 0 to 200 kg/ha N to demonstrate the response curve concept to students. Fox remarked on the small amount of labor and land required for the design and the large number of data points generated to elucidate the shape of the response curve. He also mentioned the possibility of placing two treatment sets at right angles to one another to create a systematically arranged factorial combination which would yield a visible response surface for observable responses such as plant height. Additional development of the CVD was done by Fox and I-Pai Wu, with an interdisciplinary team at the University of Hawaii on the two variable, response surface methodology. In 1974, Hundtoft and Wu published a paper advancing a regression analysis technique for two factor CVD's capable of removing treatment by location interactions and providing valid regression coefficients and confidence intervals. Basically, the method establishes a response vector for each variable and a lack of fit term including the location effects, by comparison of individual means with pooled subgroup means. They verified the methodology by creating a hypothetical field with an intrinsic yield gradient, random variability in individual sample responses, and the two treatment response vectors. The analysis of the simulated experiment demonstrated that the technique gave "appropriately conservative" inferences as to the effects of the treatment set used. To date there have been no published results of CVD experiments using this analysis technique.

Bauder (1975) used trickle irrigation and small increments of N, to establish a continuous variable irrigation by N response surface on silage corn. The trickle system produced the desired irrigation pattern but was costly and labor intensive to install and operate. Hanks et al. (1974) developed a line source sprinkler irrigation system, suitable for applying a continuously varying amount of irrigation water across an experimental plot. The system consisted of a single stationary irrigation pipe with impact sprinkler heads closely spaced so as to give a large overlap between heads. This layout produced a constantly varying but uniform gradient in water application, with the heaviest application at the center line of the plot grading to zero applied water at the outside edges. When a fertility gradient is applied at right angles to the irrigation gradient the response surface emerges.

The following design criteria were found necessary to achieve the line source effect:

1. Sprinklers must be closely spaced along the line, so that spacing is less than 25% of wetted diameter of the sprinklers used.
2. Individual sprinklers must have a radially decreasing pattern of water application.

When these conditions were met, the pattern of water application was uniform along the line's length (about 30 m.) and smoothly decreased from the center outward. The system performed adequately at line pressures from 0.3 to 0.4 MPa when the wind velocity was less than about 0.95 m/s if wind was perpendicular to the line or less than 2.39 m/s if parallel to the line. Hanks et al. (1974) point out several limitations of this system; it may only be operated in very calm wind conditions; all irrigation treatments must be applied at the same frequency; the high application rate at the center of the line must be kept low enough to prevent runoff between treatment levels; application rates should be monitored during each irrigation because of the extreme sensitivity to wind conditions. In addition, the useability of the design is hampered by its inapplicability to statistical analysis. Hanks (1980) addressed the randomization weakness of the CVD, especially when using the line source sprinkler system. A nonrandomized placement of both treatments makes it impossible to arrive at a valid error term with which to make comparisons or tests of significance. While randomization of the irrigation treatments is impossible due to the nature of the irrigation system, the second treatment could be randomized within replications. When this is done the visible response in the field is no longer sytematically arranged. There is, however, a valid error term for making inferences about the second treatment effects and the second treatment by irrigation interactions.

Bauder et al. (1975) compared results of paired production function experiments using a CVD and a randomized block, split plot design (RBSD). The results from the CVD were equivalent to those from the RBSD, although the analyses of the CVD were done using standard methods and ignoring the randomization restriction. They point out that the CVD design required about 1/4 as much land as the RBSD, even though the CVD had apprximately 10 times as many treatment combinations. Bauder notes that the greater number of treatment combinations comes with the price of a smaller sampling unit with attendant higher sample variability, and a larger number of samples to be analyzed.

CHAPTER 3

MATERIALS AND METHODS

Field Study

On 1 June, 1981, a line source irrigation and N fertilizer experiment was set up on established 'Wampum' spring wheat (*Triticum aestivum* L.) on the Evan Vervick farm near Fairfield, Montana. The objectives of this experiment were to:

1. Determine the yield response of Wampum spring wheat to N and water.
2. Evaluate the line source CVD as a method of gathering production function data.

The field plot was located at the NW1/4 of the NW1/4,T22N,R2W.

Site Selection Criteria. An experimental site was sought which could provide:

1. A source of irrigation water within 50 feet of the experimental area.
2. Established spring wheat at the time a location was being sought.
3. The best drainage possible (The spring of 1981 was extremely wet with record flooding in several

areas. The site originally chosen, at the MSU Horticulture Farm was too wet to be planted by 1 June, 82.)

4. The capability to not irrigate the experimental plot when the rest of the field was irrigated.

At the selected site the wheat was in the early tillering stage on 1 June, 1981 when the treatments were applied. The field was flood irrigated from a ditch at the northwest corner and the experimental plot was placed in the northeast corner to prevent flooding by the irrigation water while allowing the farmer access to the ditch at the high corner of the field. The wheat had been planted on 28 April, 1981 in 20.3 cm rows at the rate of 103 kg/ha, with an International Harvester model 150 drill. Emergence was on 9 May, 1981. The farmer had broadcast (pre-plant) 135 kg N/ha, 0 phosphorus (P), and 28 kg potassium (K)/ha of bulk blended, dry mix materials. Additional fertilizer materials were banded with the seed in the amount of 45 kg P/ha and 22 kg K/ha. Weeds were controlled by a tank mix of 'Ronox' (153 cm^3/ha) and Banvel (146 cm^3/ha). Soil samples were taken to 120 cm depth, or the maximum depth possible, with a hand driven probe. Samples were analyzed for N, P, K, sulfur (S), organic matter percentage (OM), and pH. Soil moisture was estimated by feel as 50% of available water holding capacity (AWHC) in the zero to 60 cm depth, and 100% of AWHC in the 60 to 120 cm depth. The initial soil test results other than N are shown in Table 1. The pre-treatment, soil nitrate-nitrogen levels are shown in Table 2.

Table 1. Field Pre-treatment Soil Test Results (0 to 30 cm depth).

Block	SO_4-S (ppm)	P (ppm)	K (ppm)	OM (%)	pH	E.C. (mmhos/cm)
1	10	14	319	2.1	8.1	0.6
2	49	6	236	1.8	8.2	0.7
3	53	9	194	1.5	8.3	0.6
4	44	6	248	1.8	8.3	0.6

A line source irrigation system similar to that of Hanks et al. (1974) was assembled from ten 6.1 m sections of 7.6 cm irrigation pipe with latch type, quick-connect couplers. Royal Coach model 10120 impact sprinkler heads with 5.2 mm range nozzles were mounted on 2.54 cm diameter risers 30.5 cm high, at each pipe coupler. The sprinklers are rated at 32 m wetted diameter and 0.58 l/s flow rate, when operated at 414 kPa. A pressure gauge was inserted on the first riser to monitor the sprinkler operating pressure.

Table 2. Field Pre-treatment Soil Nitrate-Nitrogen Results.

Block	Depth (cm)	NO_3-N (ppm)
1	0-30	5.0
2	0-30	2.4
	30-60	3.4
3	0-30	2.4
	30-60	2.1
	60-90	2.6
	90-120	4.0
4	0-30	3.3
	30-60	3.2
	60-90	3.4
	90-120	6.2

Water supply was from an adjacent canal of the Greenfield Irrigation District. A centrifugal pump (Berkely Pump Co., Berkely CA, model 460H-75 with 30.8 cm impeller) with an outlet pressure gauge, powered by a six cylinder Ford industrial motor mounted on a trailer chassis was used. The duration of each irrigation event was measured by an hour meter wired through an oil pressure switch. The procedure for each irrigation was to start the engine, prime the pump via an exhaust stack venturi, open the outlet valve to fill the irrigation pipe, and adjust the engine throttle to maintain 414 KPa at the first sprinkler. This procedure took less than five minutes and the hour meter stopped