



Effects of moisture and nitrogen on seed and forage yield and seed quality of Regar meadow brome grass, Critana thickspike wheatgrass and Luna pubescent wheatgrass
by Karen Kay Keck

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
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Abstract:

Production of seed on most grasslands is restricted by the availability of both nitrogen and water. Seed quality, in terms of vigor, has shown to be affected by both factors. Producing grass seed is a long term enterprise, requiring a minimum time of two to three years before the first seed crop is harvested. Grass seed can then be planted for hay, pasture, soil protection and/or wildlife habitats.

'Regar' meadow brome grass, *Bromus biebersteinii*, was grown to determine the optimum combination of water and nitrogen treatments for the production of vigorous seed. Forage yield, seed yield, carbohydrates and N content of forage carbohydrates, and seed vigor were measured and compared for each treatment.

'Luna' pubescent wheatgrass, *Agropyron trichophorum*, and 'Critana' thickspike wheatgrass, *Agropyron dasystachyum*, were grown on a moisture gradient. They were evaluated for seed and forage yield, and seed vigor.

Several laboratory tests were used to determine the relationship between field conditions under which the three grasses were grown and seed vigor. Standard germination, accelerated aging, and respiration tests were used to evaluate seed vigor of seed during a two year period.

The line source irrigation system effectively imposed a moisture gradient across the field plots in 1988 and 1989. Evapotranspiration increased linearly with increased amounts of applied water for all three grass species. Forage and seed yields were less in the second harvest year than the first. There was a positive linear relationship in both years between seed yield and forage yield for Regar meadow brome grass and Luna pubescent wheatgrass, which suggested that as forage yield increased, seed yield increased. Critana thickspike wheatgrass exhibited no similar effect. Water treatments affected seed and forage yields, and some seed quality tests. The only response to increased levels of N in this study was a decrease of Regar seed yield in 1989.

EFFECTS OF MOISTURE AND NITROGEN ON SEED AND FORAGE YIELD
AND SEED QUALITY OF REGAR MEADOW BROMEGRASS,
CRITANA THICKSPIKE WHEATGRASS AND LUNA PUBESCENT WHEATGRASS

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Production of seed on most grasslands is restricted by the availability of both nitrogen and water. Seed quality, in terms of vigor, has shown to be affected by both factors. Producing grass seed is a long term enterprise, requiring a minimum time of two to three years before the first seed crop is harvested. Grass seed can then be planted for hay, pasture, soil protection and/or wildlife habitats.

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'Luna' pubescent wheatgrass, *Agropyron trichophorum*, and 'Critana' thickspike wheatgrass, *Agropyron dasystachyum*, were grown on a moisture gradient. They were evaluated for seed and forage yield, and seed vigor.

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INTRODUCTION

Research in the Northern Great Plains has established that production of seed on most grasslands is restricted by the availability of both nitrogen (N) and water. Growers ask specific questions regarding the best conditions for attaining increased seed and forage yield, and improved seed vigor. The objective of this study was to evaluate 'Regar' meadow bromegrass seed production when using varying N and water regimes, and to determine the effects of these treatments on subsequent field performance of the seed produced. Levels of N and water will occur at which seed and forage yield or seed and forage quality will be limited. In general, Regar seed production drops off rapidly with time and stand establishment from seed can be difficult. Seed vigor decreases with high amounts of applied water.

'Luna' pubescent wheatgrass and 'Critana' thickspike wheatgrass will be studied due to their importance as a crop for revegetation and animal forage. These grasses will be evaluated in terms of their response to varying water levels. Seed vigor, seed yield, and forage yield will be evaluated in relationship to amount of moisture applied.

LITERATURE REVIEW

Crop DescriptionEvaluation of Regar Meadow Bromegrass
(*Bromus biebersteinii* 'Regar')

'Regar' meadow bromegrass (*Bromus biebersteinii* Roem and Schult.) is a forage cultivar which was selected from the Turkish accession PI-172390 for its vigorous regrowth characteristics. Regar was tested and released by the USDA Plant Introduction Station Agricultural Research Service in 1959, and has since gained popularity as an improved grass cultivar throughout the northern U.S. and Canada (Cooper et al., 1978, Foster et al., 1966). It is morphologically characterized by numerous, dominantly basal, slightly pubescent leaves which are light green in color. The erect seed stalks extend in an open panicle above the leaf mass, with the seeds having a short awn.

Regar's dense, persistent sod makes it an excellent erosion control plant, but it is primarily used for forage production. Livestock graze Regar in preference to smooth bromegrass at all stages of growth (SCS, 1972).

Regar is winterhardy, surviving -70C wind chill temperatures in Montana in 1988. It is also moderately drought-tolerant, usually requiring between 18 and 20 cm of

precipitation during the growing season for production of vigorous seed stands. Regar is adapted for seed increase under irrigated and non-irrigated conditions.

Planting is limited by the lack of adapted seed due to the inability of brome grass to maintain vigorous growth over a long period of years. Seed is ready to harvest when the panical turns brown and a few seeds start to shatter. Seed shatter can be a problem (SCS, 1972).

Regar is adapted to a wide range of soil conditions including shallow to deep, coarse to medium textured, well to moderately well drained, and moderately-acidic to weakly saline-alkali. Best performance is on fertile, moderately-deep, well-drained soils. Regar is not as well adapted to wet soils or to saline-alkali conditions as smooth brome grass.

Evaluation of Critana Thickspike Wheatgrass
(*Agropyron dasystachyum* 'Critana')

'Critana' thickspike wheatgrass is a native perennial grass of Montana. Critana is strongly rhizomatous and grows to about 10 to 12 inches in height on good sites. It produces abundant, fine, light green leaves and a dense sod under dryland conditions.

Critana is adapted to medium- to coarse-textured soils. It is also adapted to soils derived from granulated shales and clays that behave like coarse-textured soils. It grows in the 10- to 20-inch precipitation zone in the northern Rocky

Mountains and adjacent Great Plains regions. Critana adapts to elevations ranging from 2,000 to 7,000 feet.

Critana can be used to vegetate and reduce erosion on disturbed sites such as mined lands, roadsides, recreation areas, and construction sites. Critana is excellent for reseeding range sites that are severely eroded. It can be seeded in late fall and early spring, and fertilizers are not usually necessary to establish the stand (SCS, 1981).

Evaluation of Luna Pubescent Wheatgrass
(*Agropyron trichophorum* 'Luna')

'Luna' pubescent wheatgrass was selected from a Russian introduction in 1934 and developed in New Mexico for its drought-tolerance and adaptability to low-fertility sites (SCS, 1974). It is a long lived, sod-forming, cool season grass, with pubescent stems, leaves and seeds. It can be used as hay, pasture, or as a soil binder, but it is used most often in early and late fall pastures. It is moderately coarse and may become unpalatable after maturity. Luna has short, thick rhizomes which may not be apparent until the second or third year of growth. Because of its relative drought resistance and sodding, it is a good ground cover in mixtures with bunchgrasses. It has been used in ranch reseeding and for conservation of eroded or wind-blown areas (Dubbs et al., 1974).

Luna is best adapted to medium to fine textured, well-drained soils, but will do well on some of the coarser

textured soils in higher rainfall areas. It is adapted to moderately deep to shallow soils (SCS, 1974).

Water and Nitrogen Effects

Nitrogen is generally considered the key element in grass seed production (Buller, 1955; Anderson, 1946; Cooke, 1967). Seed formation and development sets as a sink for carbon and nitrogen compounds manufactured by the photosynthetic tissue, after vegetative growth requirements are met (Harrison, 1941). Research suggests that grasses recover twice as much top dressed N as other arable crops (Cooke, 1967). The possible reason for this is that grass occupies the land for the whole growing season. The roots of an established stand permeate the top few inches of soil and can take up most nitrate or ammonium present or applied. Grass roots improve soil structure and prevent aggregates from packing, which favors aerobic conditions over anaerobic denitrification.

Power and Alessi (1970) have suggested that fertilizer N is probably immobilized by all components of the soil-grass ecosystem, especially grass roots. Mineralization of this immobilized N may contribute to residual effects. Fertilizer N applied in excess of the immobilizing capacity of the ecosystem remains in mineral form until required by the grass. The presence of a mineral N pool suggests that N has been

eliminated as a growth-limiting factor and maximum production from the available water is being achieved. Power and Alessi (1970) also suggest that considerable fertilizer N may be immobilized by other components in the soil-plant system in addition to that required for top growth. Once sufficient fertilizer N is applied to saturate the mineral-N immobilizing capacity of the soil-plant system, the system then operates at a new and higher level. Any fertilizer N applied in excess to this requirement remains in the soil in mineral form. Therefore, with available water, mineral N becomes non-limiting for maximum plant growth and production.

Dry matter and seed production responses of forage grasses to N fertilizers can be large but variable. Nitrogen concentration in forage grasses generally increases with fertilizer N rate, but the increase may only occur at rates above some threshold value (Colville et al., 1963; Power, 1980). Generally, N recovery by grasses is low. Power (1980) found that among seven grasses, smooth brome grass (*Bromus inermis* Leyss.) recovered the highest proportion of fertilizer N (30% calculated over a 5 to 6 year period). There was no effect of rate of annual N application on N recovery.

In the Southern High Plains, the most efficient irrigation management of tall fescue and smooth brome grass is early spring application with subsistence irrigation for the rest of the year (Eck, 1981). Dry-matter yields of smooth

bromegrass were significantly increased by the application of irrigation water as compared to no irrigation (Lorenz et al., 1961; Olson et al., 1982). Studies have shown (Power, 1986) that most cool-season grasses which grow in semi-arid regions respond to increased stored soil water and to greater spring precipitation. Highest production occurs in years of above-normal growing season (April-June) precipitation, and least growth in years of below-normal precipitation.

Smooth bromegrass exhibited less drought stress than crested wheatgrass and altai wildrye (Bittman and Simpson, 1987; Eck, 1981). Knowles and White (1949) speculated that because of its mesic origin at forest margins, smooth bromegrass tends to maintain a high leaf area in order to shade competing plants and make use of intermittent rainfall.

Regression analyses (Colville et al., 1963) show forage yield of smooth bromegrass at the 0 or 40-lb per acre (45 kg ha⁻¹) N applications failed to respond significantly to changing quantities of precipitation. The addition of 80 lb per acre (90 kg ha⁻¹) of N or more resulted in yield increases that were linearly related to precipitation.

Forage Yield

'Regar' begins growth early in the spring and has good seasonal forage yield distribution, with yields similar to orchardgrass (*Dactylis glomerata* L.) and tall fescue (*Festuca*

arundinacea Schreb.) Regar has more pubescence than most pasture grasses, but is palatable to grazing animals. Nutritional quality of Regar forage is similar to smooth brome grass. The forage appears to be palatable for all classes of livestock, both as green forage and as cured hay (Cooper et al., 1978, Foster et al., 1966) In some cases, semimature standing forage of Regar has been more completely utilized by livestock than comparable forage of smooth brome grass.

Regar is popular when planted with legumes, such as alfalfa (*Medicago sativa* L.), cicer milkvetch (*Astragalus cicer* L.), or birdsfoot trefoil (*Lotus corniculatus* L.) in hay mixtures and used again in autumn pastures (Cooper et al., 1978, Foster et al., 1966). Regar is a bunchgrass, but vegetative spreading often occurs, especially under irrigation. Regrowth following clipping is very rapid and occurs from new tillers and from elongation of cut tillers. Regar does not form as dense a sod as smooth brome grass, which makes it more compatible when planted with other perennial grasses and legumes because it tends not to crowd other crops out of available growing space. Regar is used in pasture and hay seedings under irrigation or where precipitation is above 15 inches annually. It does not go dormant under high temperatures as does smooth brome.

Seed Yield

'Regar' seed yields are generally high the first production year with a significant decline in the following years (Cooper et al., 1978, Foster et al., 1966). In Idaho, dryland seed yields decreased from 336 kg ha⁻¹ in the first harvest year to 112 kg ha⁻¹ in the third harvest year (Foster et al., 1966). Experiments that have been done in Montana suggest that seed yield decline in Regar may be associated with the available soil moisture. Under dryland conditions, seed yields declined from 572 kg ha⁻¹ in the first harvest year to 265 kg ha⁻¹ in the third harvest year, a 54% decrease. Seed yields in stands irrigated every two weeks decreased from 470 kg ha⁻¹ in the first harvest year to 18 kg ha⁻¹ in the third harvest year, a 96% decrease. The more dense stand and larger amount of forage in the irrigated plots suggested a sodbound condition. Generally, more root and vegetative growth was produced at the expense of seed production. Nitrogen fertilization and post-harvest residue removal are two cultural practices which in some cases have resulted in increased seed yields and seed stand longevity of cool-season perennial grasses (Weisner, 1987).

Forage Quality

Nonstructural carbohydrates, being readily mobile, are energy sources available to the plant. Total nonstructural carbohydrates (TNC) are those that can be accumulated and then readily mobilized for metabolism or translocation to other plant parts (Smith, 1981). Grasses of the temperate origin accumulate fructosans, the concentration of which can be measured and related to plants of other replications. Fructosans, the nonstructural polysaccharides that occur in grass and legume tissues (Akazawa, 1976; Hirst, 1957; Smith, 1972), are storage carbohydrates and vary widely in concentrations. Fructosans are highly water soluble and very acid labile. TNC from the forage tissue of Regar meadow brome grass was extracted in a single extraction that employed a diastatic enzyme solution, in a method described by Weinmann (1946), changed slightly by Lindahl et al. (1949), then updated for modified laboratory conditions by Smith (1981).

The potential for near infrared reflectance spectroscopy (NIRS) to rapidly and accurately determine feeding quality of temperate and tropical forages was demonstrated by Norris et al. (1976). NIRS is based on the fact that each of the major chemical components of a sample has near infrared absorption properties which can be used to differentiate one component from the others. The summation of these absorption properties, combined with the radiation-scattering properties

of the sample, determines the diffuse reflectance of a sample. Therefore, the near infrared diffuse reflectance signal contains information about the composition of the sample.

Marten et al. (1983, 1984) reported that concentrations of acid detergent fiber, neutral detergent fiber, acid detergent lignin, crude protein, and in vitro digestible dry matter in small grain and forage-legume herbage could be measured by NIRS to a degree of accuracy equal to or greater than that generally obtained from conventional analysis procedures. For this study NIRS was used, using Kjeldahl values from plant N analysis, to form a calibration curve for Regar forage.

Seed Quality

Seed vigor was defined in 1977 by the International Seed Testing Association (ISTA) as "the sum of those properties which determine the potential level of activity and performance of the seed or seed lot during germination and seedling emergence".

Seed vigor decreases as the level of seed deterioration increases; therefore, vigor tests are sensitive indexes of seed quality. Seed vigor tests should also be interpretable and correlated with emergence under field conditions. They must be rapid, objective, simple and economically practical. Vigor tests must be reproducible, and to be of most value the

results must correlate with a field performance characteristic (AOSA, 1981).

Woodstock and Feeley (1965) sought a measurement of seed vigor that had a biochemical basis. A process was sought that 1) played such a fundamental and essential role in germination that it would necessarily be closely associated with seed viability; 2) involved the coordinated activity of many enzymes thereby serving as a measure of general metabolic activity and 3) could be relatively easily measured, preferably without killing the seed. Respiration met these requirements. Respiration is the means by which energy is acquired for seed germination and seedling growth. The relationship between respiratory rates and germinative capacity may be based on two factors: 1) respiratory activity provides energy to the germinating embryo, and 2) respiratory activity reflects both the integrity and overall activity of the metabolic machinery.

Woodstock and Feeley (1965) showed injurious treatments could be detected by measuring seed respiration in several species. Other researchers have found oxygen uptake to be poorly related to seed quality. Abdul Baki (1969) observed that in deteriorating barley the decrease in oxygen uptake lagged behind changes in germination, shoot growth and glucose utilization. Anderson (1970) reported that in wheat, oxygen uptake did not correlate with either percentage germination or age.

A decrease in the rate of respiration of germinating seeds has been shown to precede a decrease in the rate of seedling growth (Woodstock and Grabe, 1967). Significant positive correlations were observed between the rate of oxygen uptake during imbibition and seedling growth (Woodstock and Grabe, 1967). Hall (1987) found that multiple stepwise regression selected respiration rate and accelerated aging as the best model for predicting first year forage yield of 'Regar' meadow bromegrass.

The accelerated aging test is a vigor test that stresses seeds prior to germination. It was first developed by Delouche (1965) to predict the life of seed in storage. Seeds are exposed to temperatures of 40-45 C and nearly 100% humidity for 72 hours. The seeds are placed in a single layer on a screen above the water surface in a plastic germination box (McDonald and Phaneendranath, 1978). Those seeds producing normal seedlings following aging are considered vigorous. To be useful, accelerated aging results should be compared with the results of a germination test before aging.

The accelerated aging test predicts seed storability (Delouche and Baskin, 1973) by stressing seeds with ambient temperature and seed moisture, the two factors that affect seed viability. Ambient temperature indirectly regulates the relative humidity surrounding the seed microenvironment which modifies seed moisture levels (McDonald, 1977). Although time, temperature and moisture content during aging affected

the rate of deterioration, temperature had the greatest affect.

The Association of Official Seed Analysts (1981) (AOSA) reported that the accelerated aging test has shown excellent correlations with soybean field emergence over a wide range of soil conditions. Baskin (1970) proposed using the accelerated aging test to predict stand establishment of peanuts. Other studies have shown that this vigor test functions equally well of estimating stand establishment in pea (Caldwell, 1960), bean (Roos and Manalo, 1971), and soybean (Byrd and Delouche, 1971).

Refinements have been made in the accelerated aging procedure (AOSA, 1981) which reduce laboratory variability in testing results. These include:

- 1) determining sample size on a weight basis (rather than seed number),
- 2) precisely monitoring the temperature during aging,
- 3) leaving the door of the outer aging chamber closed during aging,
- 4) preventing the accumulation of water due to condensation on the top lids of the inner chamber trays, and
- 5) measuring seed moisture following aging.

The germination test is universally accepted and used as a seed quality test. The test results establish the maximum plant producing potential of seed lots and correlate with

emergence under favorable field conditions., The AOSA "Rules for Testing Seeds" (1978) defines germination as "the emergence and development from the seed embryo of those essential structures which, for the kinds of seeds in question, are indicative of the ability to produce a normal plant under favorable conditions". Inadequacies of the germination test stem from three main factors (Delouche, 1969; Delouche and Caldwell, 1960): the philosophy of germination testing, the nature of seed deterioration and its relation to germinability, and advances in agricultural technology including the technology of seed production. The germination test, by using optimal germination conditions, is the principal and accepted criterion for seed viability.

Speed of germination is one of the oldest concepts of seedling vigor. Germination rate offers a simple method for evaluating seedling emergence (Maguire, 1962). Speed of germination tests are based on the concept that more vigorous seeds germinate faster than less vigorous seeds.

The number of days a lot requires to reach 90% germination was used by Belcher and Miller (1974) to measure germination speed. The following formula was suggested to measure germination rate (Maguire 1962):

$$X = \frac{\text{number of seedlings}}{\text{days to first count}} + \dots + \frac{\text{seedlings from previous count}}{\text{days to final count}}$$

METHODS AND MATERIALS

Field studies for the varieties of Regar meadow brome grass, Critana thickspike wheatgrass and Luna pubescent wheatgrass were conducted at the Montana State University research area near Manhattan, Montana. The soil is classified as Manhattan sandy loam, coarse-loamy, mixed, typic Calciborrol. The seed planted was certified and obtained from the State Seed Testing Laboratory. Four replications were planted in May, 1987. All field experiments were conducted as a randomized complete block for N rates, with irrigation regimes fixed. Plot size was 2.44 m X 4.27 m and each plot contained eight rows spaced .305 m apart. Seeding rate was 66 pure live seeds per meter of row, and seed was planted 1.25 cm deep.

Water

The plots were irrigated with a line source system to evaluate the responses of the grasses to five soil moisture regimes. The line source irrigation system, described by Hanks et al. (1976), is a field technique capable of providing a uniform water gradient across plots planted perpendicular to the water source. It allows imposition of a water gradient

within a relatively small plot area at a single field site. Use of collection cups in each plot at the time of irrigation allows for determining the quantity of water received there, and for monitoring the uniformity of irrigation water being applied. A limitation in using the line source system involves the validity of certain statistical tests. A valid F-test cannot be made for the main effects of irrigation level using analysis of variance (ANOVA) since the irrigation levels are fixed. Hanks et al, (1980) stated that irrigation main effects are generally large enough to be obvious and that statistical analysis is not critical.

The line system utilized Model 25 sprinkler heads with 4 mm nozzles (Rain Bird Sprinkler Mfg. Co., Glendora, California)¹. Sprinkler pipe diameter was 5 cm and sprinkler heads on 2.5 x 90 cm risers were spaced 4.6 m apart. Irrigations were applied when there was no or little wind, to minimize drift.

In this study five irrigation levels were created by the line source system. Irrigation level 0 (IL0) was the dryland level because it was furthest from the line source and received no irrigation water. The next irrigation level, irrigation level 1 (IL1), received very small amounts of irrigation water. Irrigation level 2 (IL2) was the middle irrigation level of the five. Irrigation level 3 (IL3) was

¹ Mention of a specific brand, trade, or chemical name does not imply endorsement of that product over others of a similar nature or function.

the second highest level and received high levels of irrigation water relative to IL0, IL1, and IL2. Irrigation level 4 (IL4) received the greatest amount of irrigation water and was the level closest to the line source.

Soil water was measured with a neutron probe (Campbell 503DR Hydroprobe, Campbell Pacific, Pacheco, California)¹ to a depth of one meter, in 20 cm increments. Soil water was measured when plant growth began in the spring, before and after each irrigation, and after the final harvest. Water use for a given period was determined with ETPROBE, a computerized system for the management and interpretation of neutron probe data (Bunker, 1988). The input required to run the program are a calibration number, amount of precipitation between each set of probe readings (mm), the average daily standard count for the neutron probe, the increment between each reading depth (cm), and a properly configured data file containing the raw neutron counts. The program outputs are the percent soil moisture by volume, the cumulative soil water depth over all depth increments calculated per access tube at each reading date, soil water depleted between each set of probe readings at each depth (cm), the cumulative ET (mm) over time, and the total seasonal ET.

A weather station was maintained throughout the growing season at the test site. Temperature was recorded throughout the season with a hydrothermograph, and precipitation amounts were recorded. The 25-year precipitation average near the

Manhattan location is 11.7 cm. Precipitation for production of the first seed crop was 4.7 cm, or 7.0 cm below average. Precipitation for production of the second seed crop was 15.1 cm, or 3.4 cm above average.

Nitrogen

Nitrogen in the form of urea ($\text{CO}(\text{NH}_2)_2$) was randomly applied to the plots across each of the irrigation levels. The nitrogen was applied at four rates: 0 kg ha⁻¹ (level 1), 45 kg ha⁻¹ (level 2), 90 kg ha⁻¹ (level 3), and 134 kg ha⁻¹ (level 4). It was applied randomly to the plots, in rows parallel to the line source system. The fertilizer was applied in the fall after field plot stubble had been burned off. The amount of fertilizer to be applied was pre-weighed and bagged for each plot, then applied by hand to maintain an equal distribution of fertilizer over each plot.

Soil samples at 15 cm and 30 cm were taken from plots representing each of the treatments in May 1988, September 1988, and April 1989 to determine the location of nitrogen gradients formed from the applied N. In 1988 the soil was tested for NO₃-N, P and K. In 1989 only NO₃-N content was determined. All soil tests were performed by the M.S.U. Soil Testing Laboratory after being oven-dried for 24 h at 30C.

Forage Yield

Forage yield was determined by harvesting one row per plot using a Rem¹ flail harvester. The harvested forage was weighed after being cut, dried, and reweighed. Percentage moisture was calculated from the differences of wet and dry weights, and conversions to an acre yield at 0% moisture were made for each treatment. After yield samples were taken, residue was removed with a tractor-drawn baler.

Seed Yield

Seed yield was determined by hand-harvesting 1.53 m² of the center 3 rows of each plot. Stems were cut close to the seed head for ease of threshing. Seed was threshed and cleaned to a minimum purity of 90% using a Hannaford "Seedmaster" resilient taped threshed (Alf Hannaford and Co. Pty. Ltd., Welland, So. Australia)¹. Seed was weighed and yields were calculated in kilograms per hectare.

In 1988, prior to harvest, seed in the two driest treatments suffered hail damage. All seed lots were stored at room temperature (22C) in the laboratory following harvest during the course of these experiments.

Forage Quality

The plant tissue was dried at 50C for 24 hours, then ground with a 40-mesh size Wiley¹ mill. Dried tissue was stored in plastic film cannisters in a dry storage area.

Determination of total nitrogen in the plant tissue was determined using the Kjeldahl (1896) Method. These results were later used to determine a protein calibration, specific for Regar, for the Near Infrared Reflectance Spectroscopy (NIRS). For NIRS analysis, approximately 2 g of each sample were placed in a sample holder that had a 30-mm diam window. Samples were exposed to monochromatic near infrared radiation and the diffuse reflection (R) was collected in a 400R Model NIR monochromator (Technicon InfraAnalyzer 400, Technicon Instruments Corporation, Tarrytown, New York)¹. The signal was digitized and recorded as log values. The NIRS calibration equation for analysis of total N in Regar forage was developed from 30 randomly selected samples of the 40 available. Log values were collected for each sample from NIR filters normally used in proteins (total N) estimations. Filter readings were regressed on Kjeldahl N values and an equation was developed by use of multiple regression analysis (Lund, 1987). Coefficients from this multiple regression equation were used to calibrate the NIR to read total N.

The Smith (1981) Procedure was used, with minor procedural modifications, to test for total non-structural

carbohydrate (TNC) differences among the plant tissues. Modifications include use of 0.25% Clarase 40,000 as enzyme solution for the hydrolysis of TNC to sugars, and incubation at 44C for 24 hours. A 20-minute boiling time during hydrolysis was another modification made to adjust for high altitude. The starch was gelatinized by boiling the tissue in distilled water. Acetate buffer and a Clarase enzyme solution were added, which hydrolyzed disaccharides and starch in the tissue. The mixture was then incubated for 24 hours. On the second day, the protein-precipitates were separated by filtration and fructosans were acid hydrolyzed. Reducing power was determined with the Schaeffer-Somogyi copper-iodometric titration method described by Heinze and Murneek (1940). Calculations were based on the amount of titrant used.

Seed Quality

Four groups of 100 seeds from each plot were placed in 13 x 13.5 cm plastic germination boxes containing two moistened blotter papers. Seeds were germinated for 14 days at alternating temperatures of 15C for sixteen hours and 25C for eight hours (15-25C). Normal seedlings were evaluated according to "Rules for Testing Seed" (Association of Official Seed Analysts [AOSA], 1978) and expressed as percentage germination.

The accelerated aging tests were conducted as recommended by AOSA (Tekrony, 1985) with minor procedural modifications (Hall, 1987). Four grams of seed per plot were surface sterilized in 30 ml of 1.5% sodium hypochlorite (NaOCl) for 15 minutes, rinsed thoroughly with distilled water, and oven-dried at 32C for 24 hours. Seed was uniformly distributed on wire mesh trays inside covered plastic boxes containing 40 ml of water. Plastic boxes were placed inside a Stults Scientific accelerated aging chamber¹ for 48 hours. Temperature and humidity were maintained at 41C and 100% relative humidity, respectively. Following the aging period, seed samples were removed and standard germination tests conducted, using four replications of 50 seeds per plot. The remaining aged seeds of each plot were removed, weighed immediately, oven-dried at 105C for 24 hours, and re-weighed to determine seed moisture content (wet-weight basis).

Measurement of the net gas exchange in respiring seeds was obtained with a Gilson Differential Respirometer (Gilson Medical Electronics, Inc., Middleton, WI)¹. Twenty-five seeds from each plot were weighed and imbibed on blotters moistened with distilled water in plastic germination boxes for 24 hours. Two ml of distilled water were added to the reaction flask, 0.2 ml of 10% KOH was added to the center well of each reaction flask, and a 1 cm x 2 cm filter paper wick was cut, pleated, and put into the center well. Seeds were placed in the active reaction flask, attached to the respirometer, and

submerged in a 25C water bath. The seeds were oscillated at 80 oscillations min^{-1} . The system was equilibrated for 30 minutes, and readings were taken every 30 minutes for 90 minutes. Respiration rate was reported as microliters of oxygen absorbed $\text{seed}^{-1} \text{ hour}^{-1}$ ($\text{microLO}_2 \text{ seed}^{-1}\text{hr}^{-1}$).

Data Analysis

Data for each variable were averaged over replications for each growing season. The response to irrigation and N application was determined by regressing forage and seed parameter means over ET, applied N, and the interaction between ET and N using a polynomial model. The response variables for forage and seed parameters were seed yield, forage yield, percentage germination, speed of germination, respiration per seed, and percentage germination after accelerated aging.

The irrigation treatment was the main plot and N level the subplot, as explained by Hanks (1980) in a split-plot analysis. In the analysis herein, the regression over ET simulated the kind of analysis described by Hanks, but with pooling of the whole plot and split plot error terms.

A preliminary analysis of variance using each water level and each N level allowed examination of main effects and interaction. Data were analyzed by first looking for significant interactions ($p \leq .05$) between N and irrigation

treatments for each dependent variable. Each of the irrigation levels were then individually used for regressions between N and each of the dependent variables to detect significant interactions. Contrasts were made on each parameter using MSUSTAT (Lund, 1987) which confirmed the polynomial model, showing the effect of water levels (i.e. as measured by ET) and N on the response variables.

The R^2 reported herein is calculated from the difference in the R^2 produced from the regression over each variable, including replication effects, and the R^2 for the regression over replication effects alone. This reported R^2 is therefore the difference in R^2 with and without the variable(s) of interest, but always with replications in the model. All coefficients for polynomial models derived from regression have significant p-values at $p \leq .05$. All polynomial models report intercept values $\pm$ standard error.

RESULTS AND DISCUSSION

Seasonal Evapotranspiration (ET)

Regar Meadow Bromegrass

Total seasonal evapotranspiration (ET) of Regar increased linearly as soil moisture increased (Figure 1), with ET ranging from 104 mm to 328 mm across the soil moisture regimes in 1988. ET rates across the irrigation regimes in 1989 (Figure 2) ranged from 155 mm to 999 mm in a curvilinear response to water.

ET mean values (Table 4, Appendix) correlated positively with the amount of water applied to the plots through irrigation and rainfall during the growing seasons. The line-source irrigation system was effective in imposing a moisture gradient on Regar as measured by seasonal ET (Table 1, Appendix).

R^2 values of .90 and .92 for 1988 and 1989, respectively, suggest that seasonal ET of Regar can be attributed primarily to measured amounts of water applied from irrigation and rainfall. Leakage from the line-source irrigation system and evaporation from the irrigation measuring cups or rain gauge are possible sources of error. Drift of water by the wind

are possible sources of error. Drift of water by the wind during irrigation is a source of variation among replications.

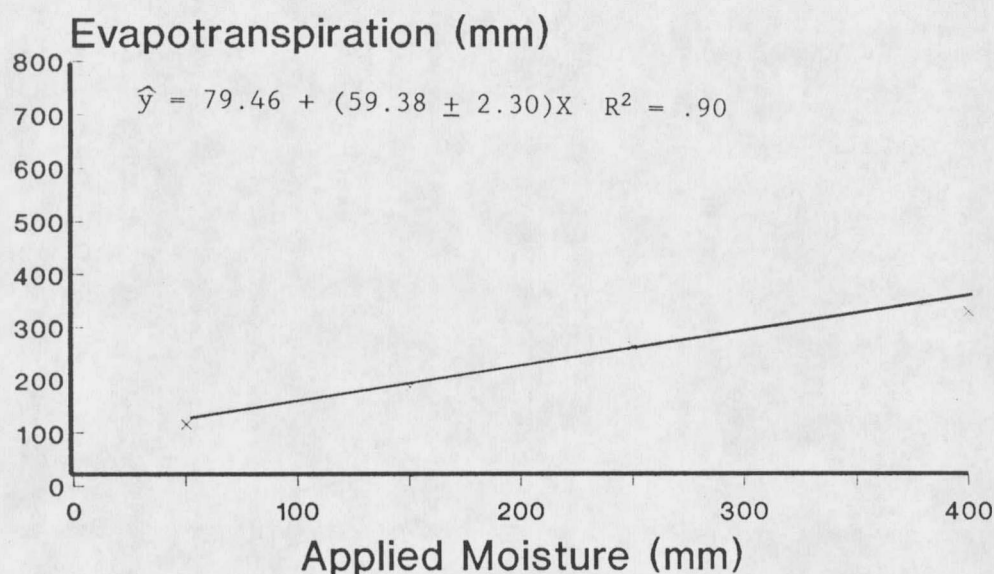


Figure 1. Effects of applied moisture from a line-source irrigation system on seasonal evapotranspiration of Regar meadow brome grass grown at Manhattan, Montana, in 1988.

Critana thickspike wheatgrass

During the 1988 growing season ET exceeded the amount of water received from the plots by rainfall or irrigation. The difference between applied water values and ET values was less in IL3 and IL4 than in IL0, IL1, or IL2 (Table 5, Appendix). In the 1989 growing season the water applied in IL3 and IL4 exceeded the amount of total seasonal ET, suggesting decreased water stress in those regimes. During both growing seasons

the ET response to applied water was linear (Figure 3) with R^2 values of .83 and .31 in 1988 and 1989, respectively.

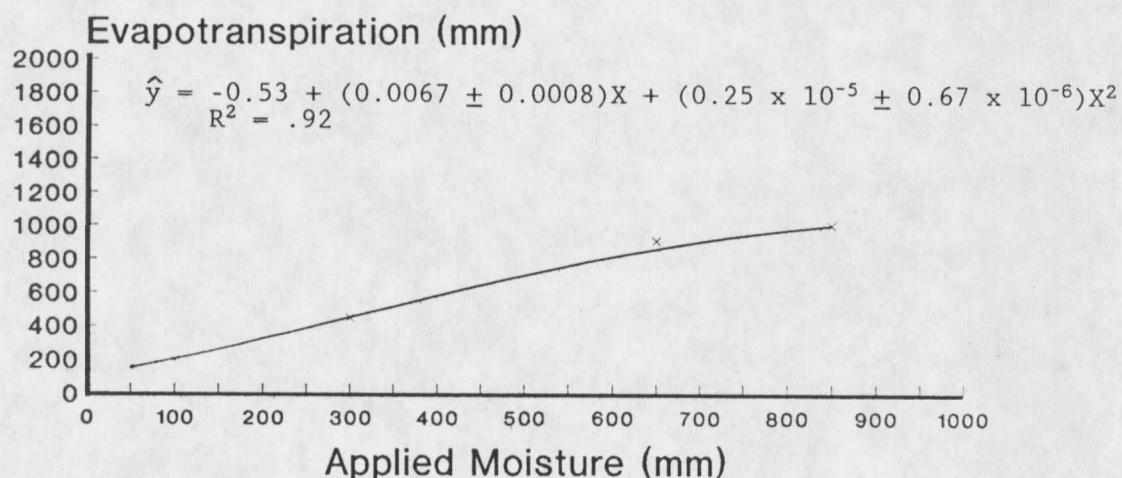


Figure 2. Effects of applied moisture from a line-source irrigation system on seasonal evapotranspiration of Regar meadow brome grass grown at Manhattan, Montana, in 1989.

Luna Pubescent Wheatgrass

Evapotranspiration was greater across all irrigation regimes than the seasonal applied water during the 1988 growing season. Mean ET values in 1988 increased linearly from 72 mm to 305 mm, and increased curvilinearly in 1989 from 170 mm in IL0 to 257 mm in IL4 (Figure 4).

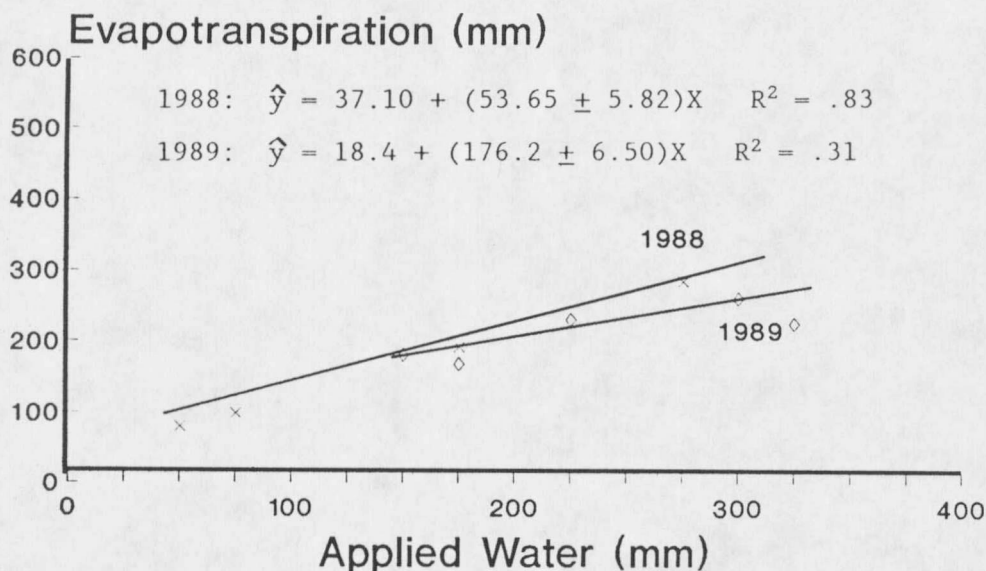


Figure 3. Effects of applied moisture from a line-source irrigation system on Critana thickspike wheatgrass grown at Manhattan, Montana in 1988 and 1989.

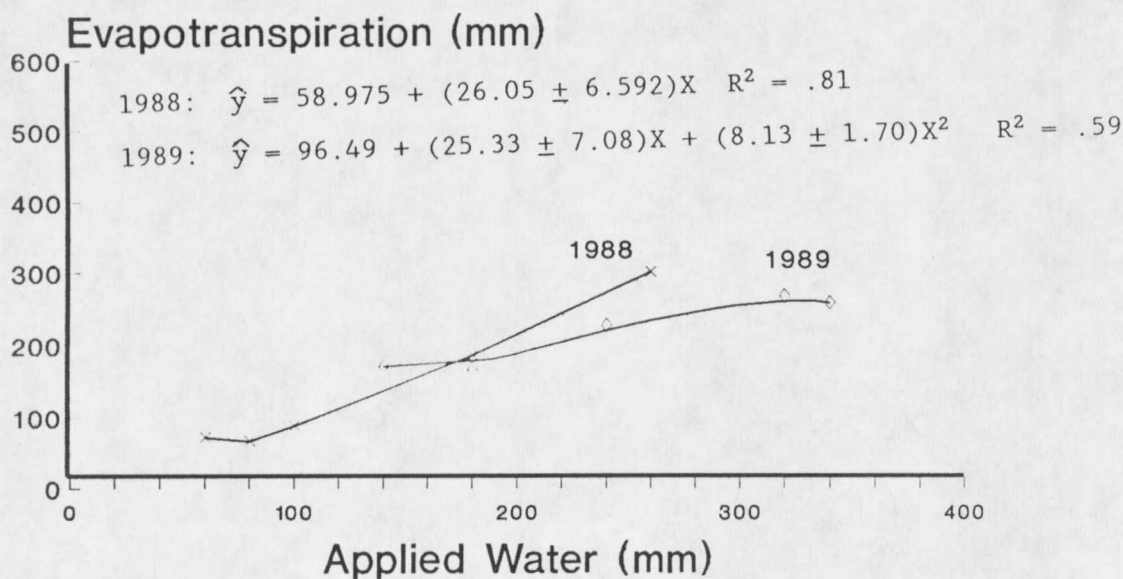


Figure 4. Effects of applied moisture from a line-source irrigation system on Luna pubescent wheatgrass grown at Manhattan, Montana in 1988 and 1989.

In 1988 the ET measured was greater than the amount of water applied (Table 6, Appendix), which may be due to a combination of stored soil moisture use, rapid growth, and warm weather. The curvilinear response in 1989 may have been the result of maximum ET for Luna since the amount of water applied exceeded the amount of ET measured.

Forage Yield

Regar Meadow Bromegrass

Forage yields in 1988 increased linearly from 5672 kg ha⁻¹ to 9634 kg ha⁻¹ as soil moisture increased. Forage yields had polynomial responses to ET, ranging from 6621 kg ha⁻¹ to 13,126 kg ha⁻¹ in 1989 (Figure 5). Higher amounts of moisture reduced drought stress and contributed to high forage yields. Total forage yields showed an approximate 67% increase from 1988 to 1989. This increase may be primarily attributed to a large difference in water, which was more available in 1989 from rainfall. Lodging was a problem during harvest in the areas of highest irrigation.

Forage yield in 1988 and 1989 was not significantly affected by N levels. In 1988, water levels may not have been high enough to allow utilization of N present in the soil from fertilizer and previous legume occupation.

Critana Thickspike Wheatgrass

Critana forage yields increased linearly (Figure 6) with increased levels of applied irrigation water in both seasons of data collection. There was no significant difference in the amount of forage produced between 1988 and 1989. This suggests that Critana's forage producing capacity from the first year of production to the second year of production is not diminished when N application is in the autumn and residue is removed.

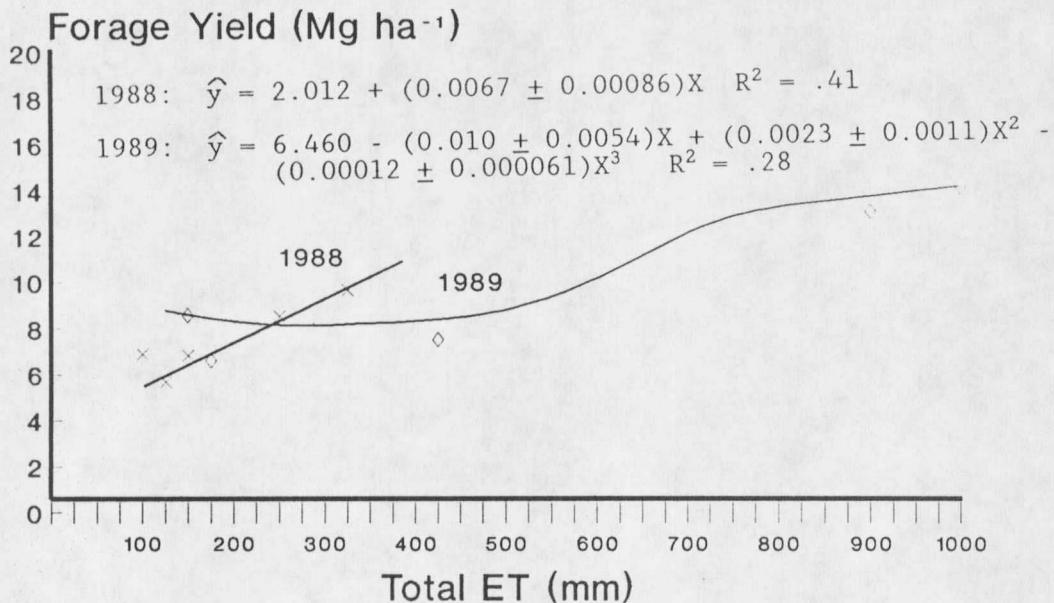


Figure 5. Effects of evapotranspiration on forage yield of Regar meadow brome grass grown under a line-source irrigation system at Manhattan, Montana in 1988 and 1989.

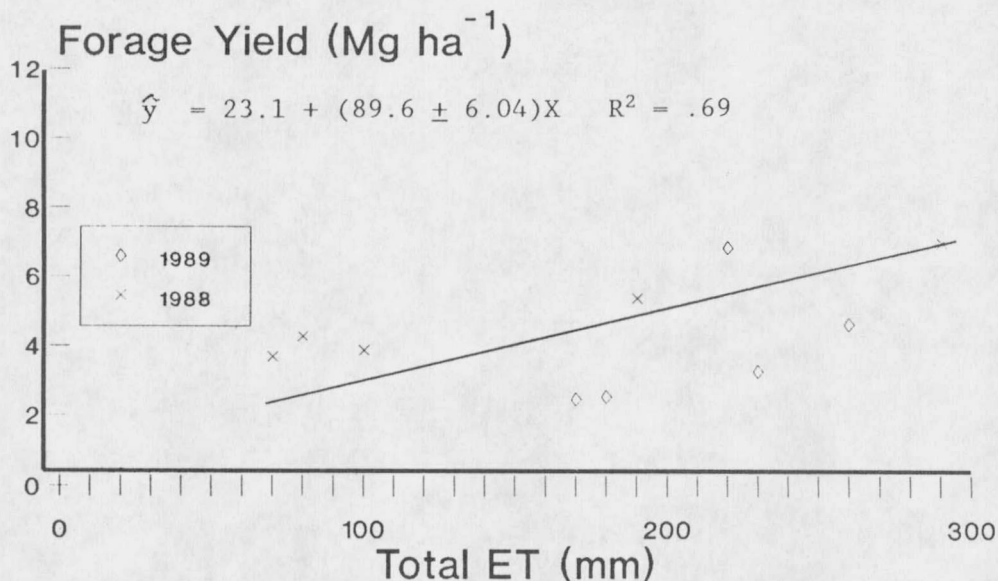


Figure 6. Effects of evapotranspiration on forage yield of Critana thickspike wheatgrass grown under a line source irrigation system in Manhattan, Montana, in 1988 and 1989.

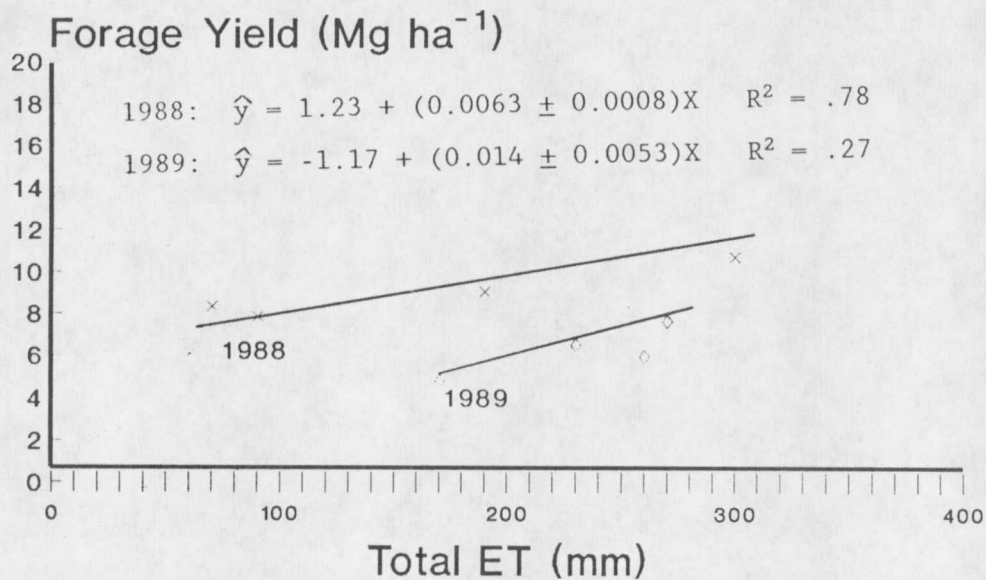


Figure 7. Effects of evapotranspiration on forage yield of Luna pubescent wheatgrass grown under a line-source irrigation system at Manhattan, Montana, in 1988 and 1989.

Luna Pubescent Wheatgrass

Luna forage yields increased linearly with ET in 1988 and 1989 (Figure 7), although yield decreased by 72% from the former year to the latter. Forage yield means increased, from 6054.7 kg ha⁻¹ in IL1 to 10666 kg ha⁻¹ in IL4 in 1988 and from 4760.0 in IL1 to 7616.0 kg ha⁻¹ in IL3 in 1989, with the increasing ET values.

Seed Yield

Regar Meadow Bromegrass

Regar seed yields (Figure 8) in 1988 increased linearly from 187 kg ha⁻¹ to 723 kg ha⁻¹ as ET increased. No statistically significant N effect was observed. From IL1 yields increased linearly as the amount of available water increased. The lack of an N effect could be due to high N residual from previous legume crops at the experimental site.

Seed yield in 1989 was affected curvilinearly by N, yielding an R² of .07 without replication effect, but was not significantly affected by seasonal ET. Regar seed yields in 1989 were lowest in IL4, with only 123.6 kg ha⁻¹ produced. The seed yields in 1989 were significantly lower than the yields in 1988. In 1988, Regar seed yield calculations exhibited a positive slope and an R² that explained 65% of the response to ET in terms of differing water levels. Only 7% of the seed yield responses in 1989 can be explained by the influence of

N. When replication effect is included in the analysis, R^2 increases to .34.

A border effect was seen at IL0 from the line source system. Although these plots received less irrigation water over the growing season, there was no significant difference between their ET values and the ET values from IL1. Plots furthest from the line-source system may have utilized water stored in adjacent fallow soil on the south side, and water from irrigated cropland on the north side. Mean forage and seed yields were greater in 1989 in IL0 than the yields from IL1.

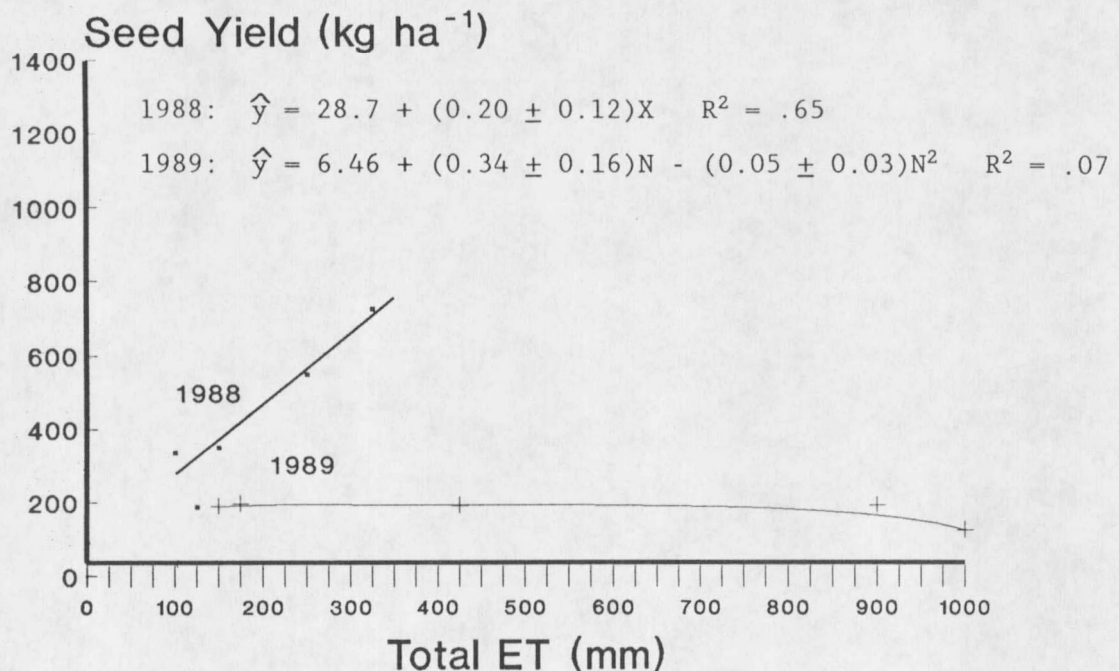


Figure 8. Effects of evapotranspiration on seed yield of Regar meadow brome grass grown under a line-source irrigation system in Manhattan, Montana, in 1988 and 1989.

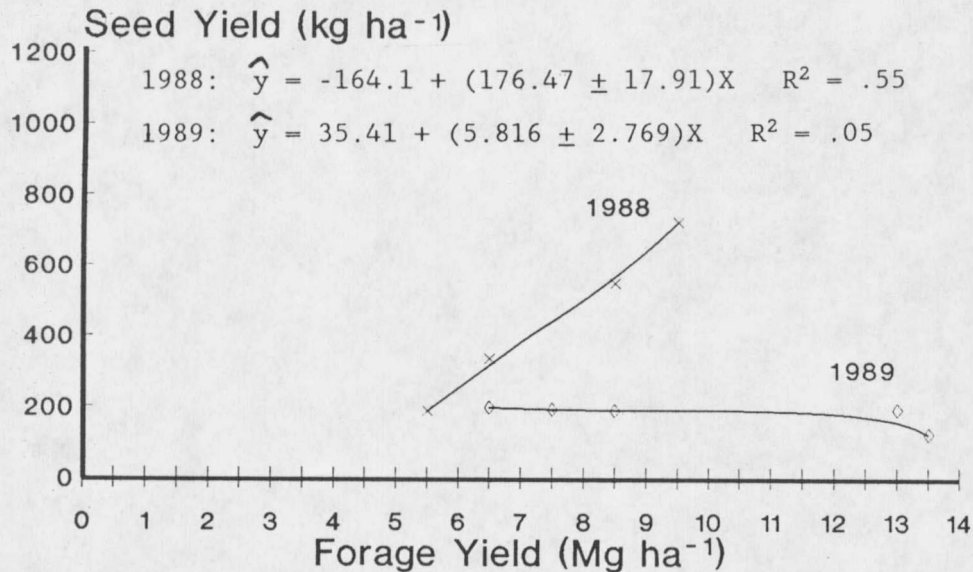


Figure 9. Effects of forage yield on seed yield of Regar meadow brome grass grown under a line-source irrigation system in Manhattan, Montana, in 1988 and 1989.

In 1989, the second year of seed production, the Regar was infected with covered head smut, caused by the organism *Ustilago bullata* Berkley. The loss of viable seed to smut was not severe. Seed damage to Regar by head smut (SCS, 1972) has been most severe on low-fertility, saline-alkali, and/or poorly drained soils where Regar is not well adapted. All seed used for seed increase should be treated with an effective fungicide prior to planting.

When regressed against forage yield, seed yield responded linearly for both seasons of growth. In 1988, as forage yield

increased seed yield increased. No response existed in 1989 (Figure 9).

Critana Thickspike Wheatgrass

Seed production, in response to ET, in 1988 was highest in IL3 with a mean of 869 kg ha⁻¹, and lowest in IL2 with 616.80 kg ha⁻¹ (Table 4). Overall seed production in 1988 was high compared to 1989 (Figure 10). In 1989 IL2 and IL3 produced the most seed among treatments, 318 and 298 kg ha⁻¹ respectively. The highest irrigation level, IL4, produced the least seed. Seed yield in 1988 increased linearly from the treatments with the least irrigation to 869 kg ha⁻¹ in IL3, and then decreased slightly to 759 kg ha⁻¹ at IL4. Overall, seed yield decreased 31% from 1988 to 1989. The response was not significant in 1988 or 1989 to forage yield when seed yield was regressed over forage yield (Figure 11).

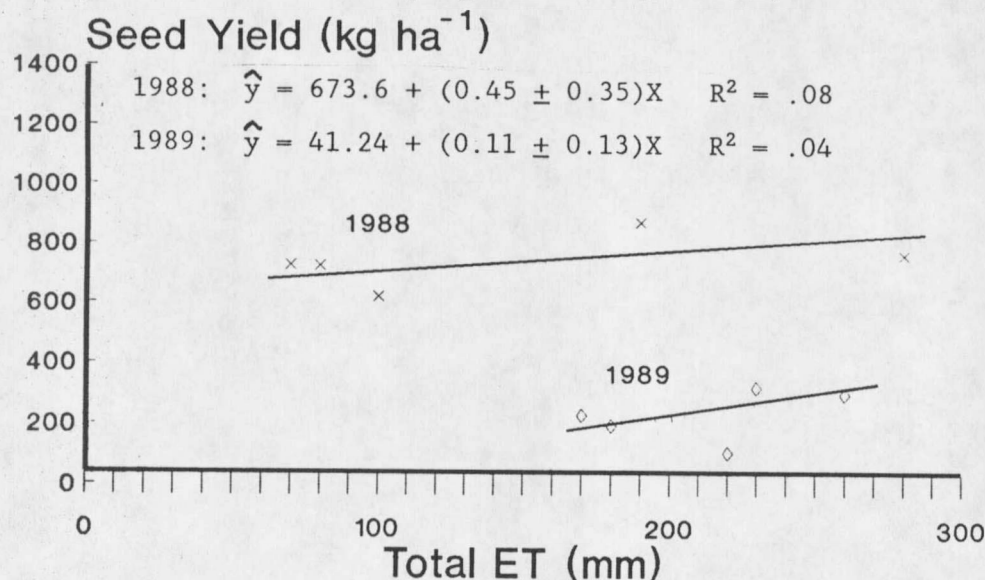


Figure 10. Effects of evapotranspiration on seed yield of Critana thickspike wheatgrass grown under a line-source irrigation system in Manhattan, Montana, in 1988 and 1989.

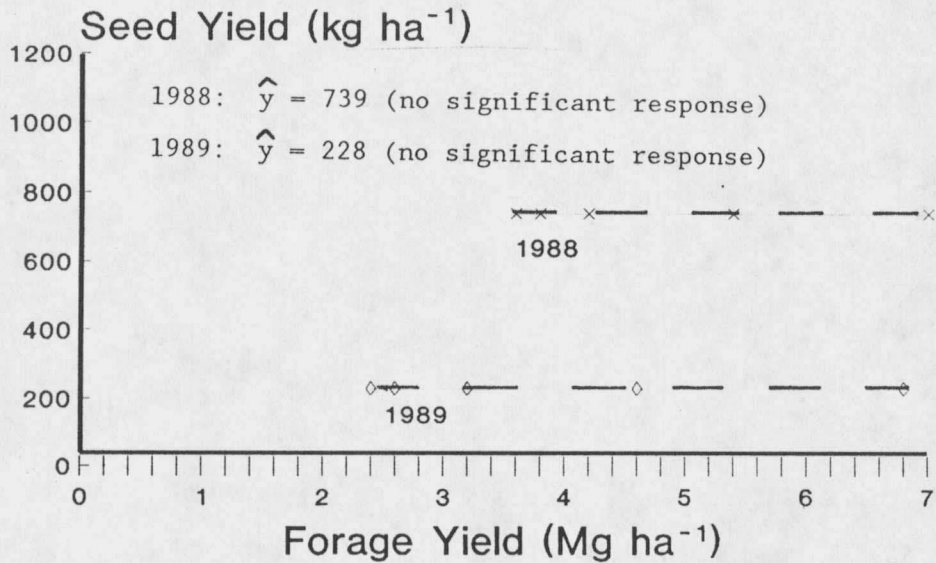


Figure 11. Effects of forage yield on seed yield of Critana thickspike wheatgrass grown under a line-source irrigation system in Manhattan, Montana, in 1988 and 1989.

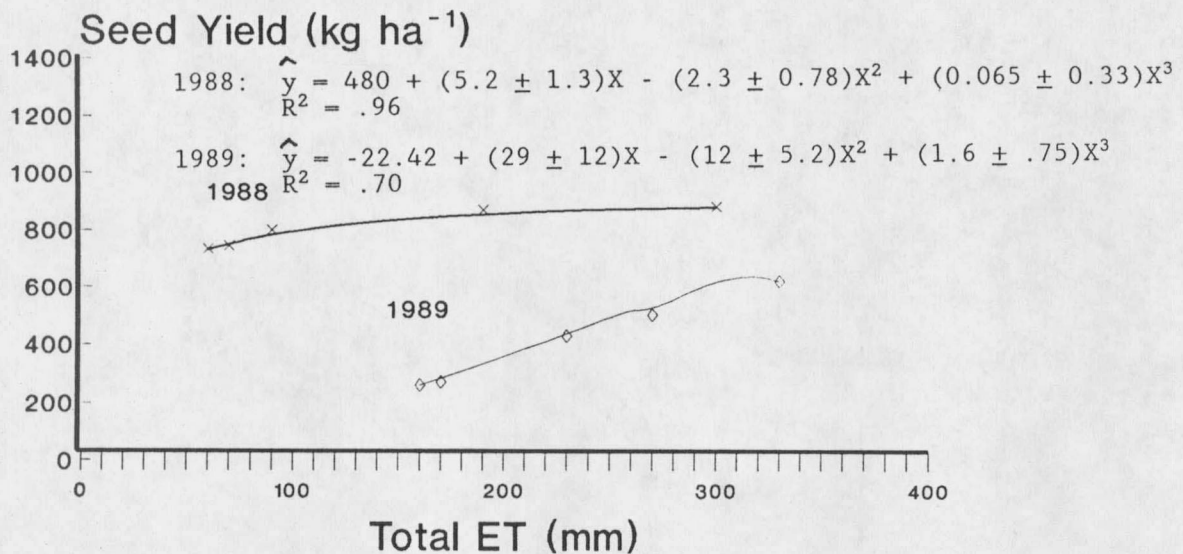


Figure 12. Effects of evapotranspiration on seed yield of Luna pubescent wheatgrass grown under a line-source irrigation system in Manhattan, Montana, in 1988 and 1989.

Luna Pubescent Wheatgrass

Although Luna produced more seed in 1988 than in 1989, the production for both years followed similar patterns. IL0 and IL1 had the lowest seed production, and yields increased in a cubic response pattern over ET. In both seasons increased seed yield was correlated with the amount of soil moisture available, ranging from 732 kg ha⁻¹ to 879 kg ha⁻¹ in 1988 and from 258 kg ha⁻¹ to 618 kg ha⁻¹ in 1989. Total seed yield in 1989 was approximately 52% less than in 1988. There was a linear relationship between seed yield and forage yield, which suggests that seed yield increased as forage yield increased (Figure 13). High forage yields did not prevent high seed yields.

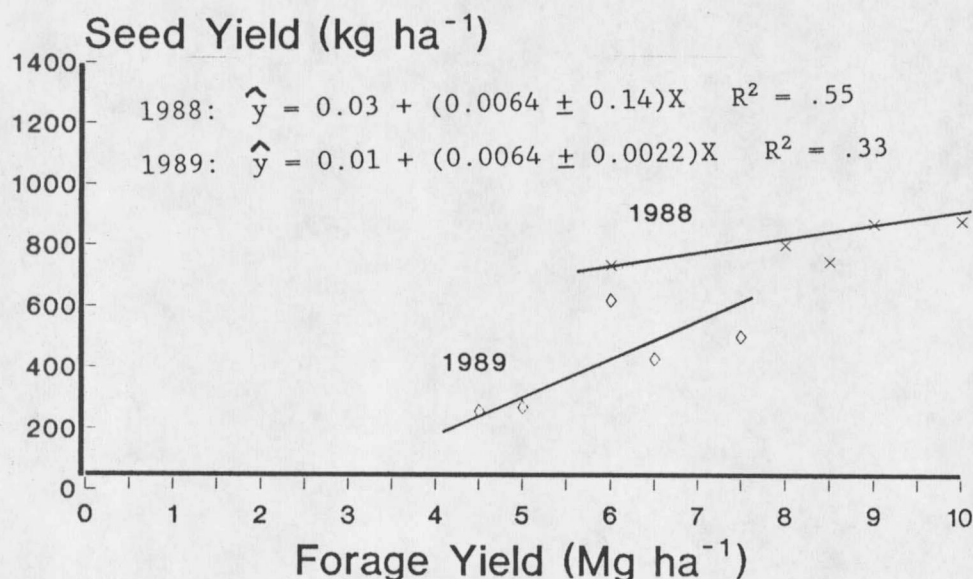


Figure 13. Effects of forage yield on seed yield of Luna pubescent wheatgrass grown under a line-source irrigation system in Manhattan, Montana, in 1988 and 1989.

Forage Quality

Regar Meadow Bromegrass

Total Nitrogen in forages is often a measure of quality. The squared coefficient of multiple determination (R^2) of the total N NIR calibration equation was .61, based on the best 4-variable model found. The resulting equation was $y = 0.190 + 33.23(X_{2208}) + 11.81(X_{2180}) + 79.97(X_{1982}) - 120.05(X_{2100})$.

When Kjeldahl N, TNC, and NIR values were submitted to multiple regression, no significant correlations were found. Kjeldahl N and NIR N were associated but not highly enough to allow NIR to predict with adequate precision.

Due to lack of correlation between Kjeldahl N, TNC, and NIR values, it may be concluded that neither Kjeldahl N nor NIR has any predictive value for TNC. All are independent observations.

The calibration curve developed between the Kjeldahl and NIR values accounted for 61% of the variation among forage samples. Several causes might be listed for this low correlation between Kjeldahl N and NIR:

1. There may have been inherent error in the Kjeldahl data.
2. When creating the calibration curve the appropriate filters may not have been used.
3. The range of Kjeldahl N in samples of the calibration set may have been too small.

4. Too few samples may have been used, creating a small degree of statistical freedom.
5. At forage harvest the plant parts may not have been carefully separated, so different proportions of plant parts in the samples may have introduced a great variation.

Seed Quality

Regar Meadow Bromegrass

Across all moisture levels seeds that had been exposed to accelerated aging germinated approximately 40% less than seeds germinated by the standard method (Figure 14). The speed of germination did not vary significantly across moisture levels. These results suggest that seed quality in 1988 may not have been significantly affected by N or water treatments.

Total percentage germination in 1989 exhibited a negative quadratic response to ET and a positive cubic response to increased levels of N. The interaction between ET and N was not significant. The R^2 is .31, which does not include replication effect. The regression model for 1989 speed of germination data was not statistically significant. These results suggest that seed quality in 1989 may have been affected by increased in N and water.

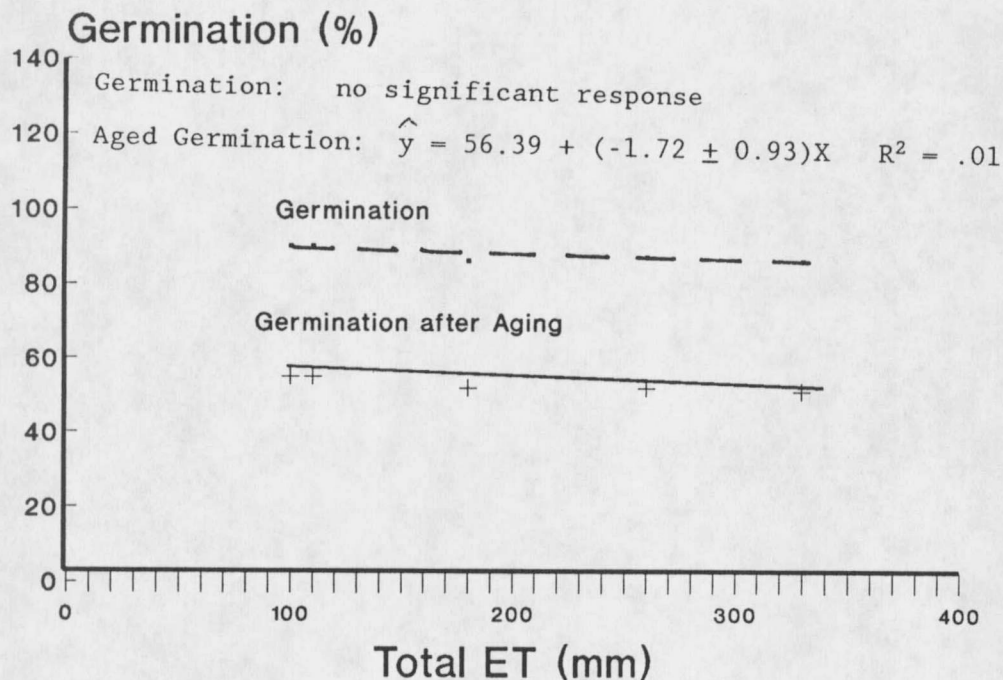


Figure 14. Effects of ET on percent germination and percent germination after accelerated aging on Regar meadow bromegrass seed grown under a line-source irrigation system in Manhattan, MT in 1988.

Respiration, the most sensitive vigor test performed on this seed, exhibited a linear response to moisture in 1988 (Figure 15), but no significant response in 1989. This suggests that either soil water did not significantly affect respiration, or that the moisture gradient imposed was not great enough to create vigor differences, or error was too large to detect a difference.

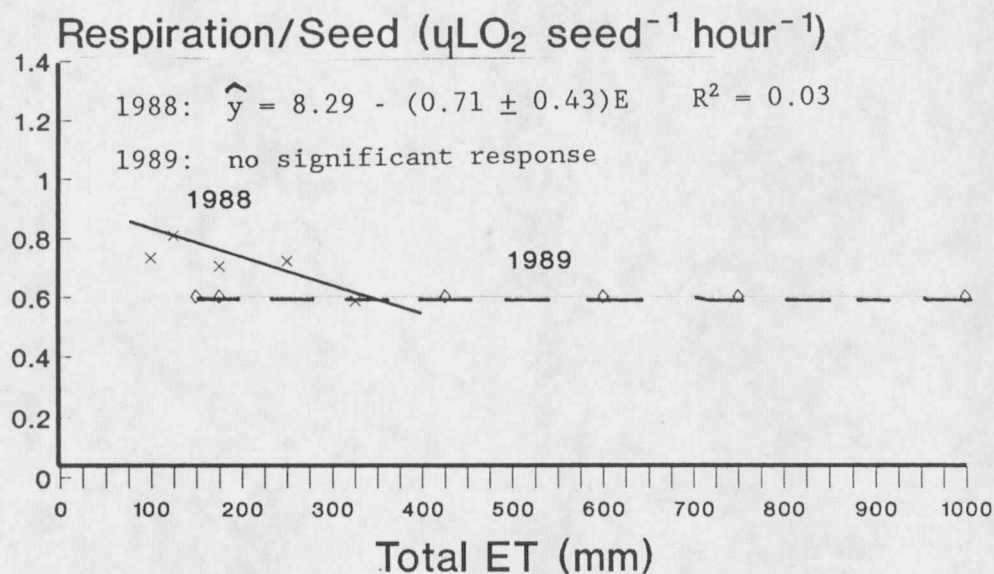


Figure 15. Effects of ET on respiration per seed ($\mu\text{LO}_2 \text{ seed}^{-1} \text{ hour}^{-1}$) on Regar meadow brome grass seed under a line-source irrigation system in Manhattan, MT in 1988 and 1989.

Critana Thickspike Wheatgrass

The mean percentage germination of seed harvested in 1989 was highest, 83%, for the IL2 and lowest, 70%, for the IL3 treatment. However, these means were not significantly different (Figure 16). A significant negative linear response to ET occurred in 1989, resulting in an R^2 of .29, which indicates that as ET increased, percentage germination decreased.

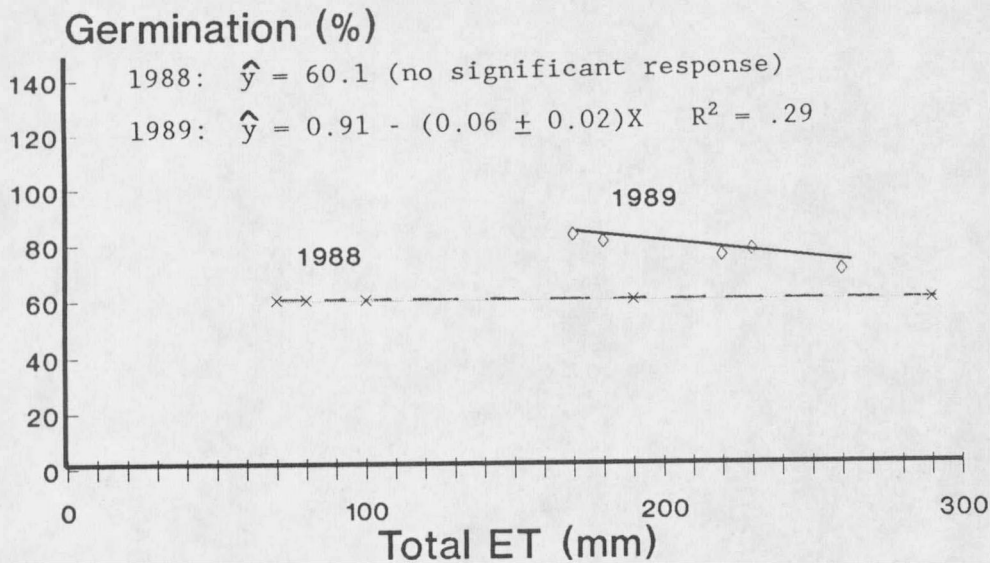


Figure 16. Effects of evapotranspiration on percent germination of Critana thickspike wheatgrass grown under a line source irrigation system in Manhattan, Montana, in 1988 and 1989.

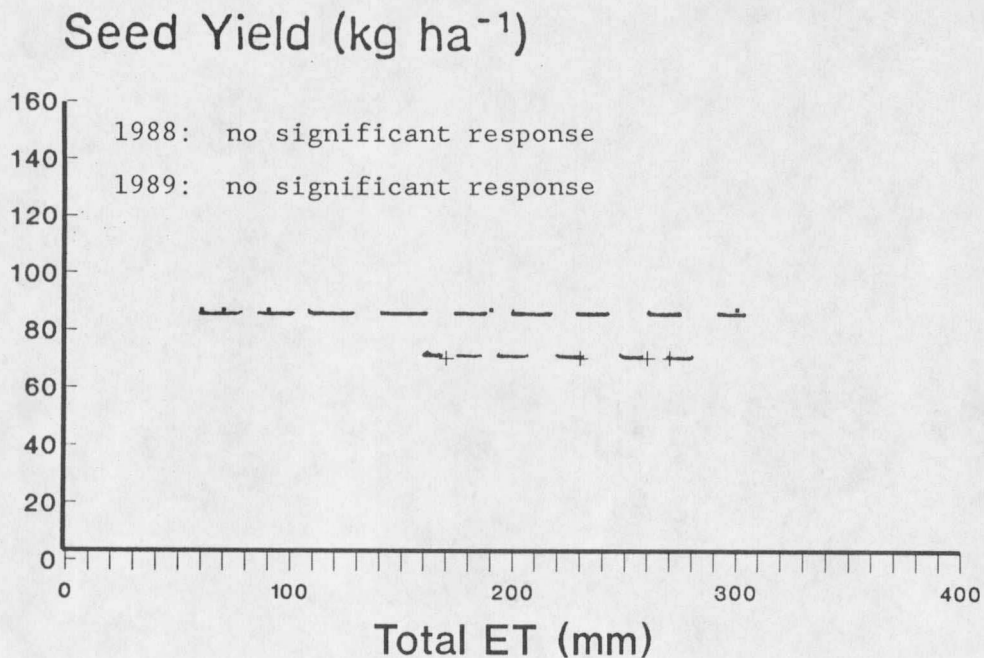


Figure 17. Effects of evapotranspiration on percent germination of Luna pubescent wheatgrass grown under a line-source irrigation system in Manhattan, MT, in 1988 and 1989.

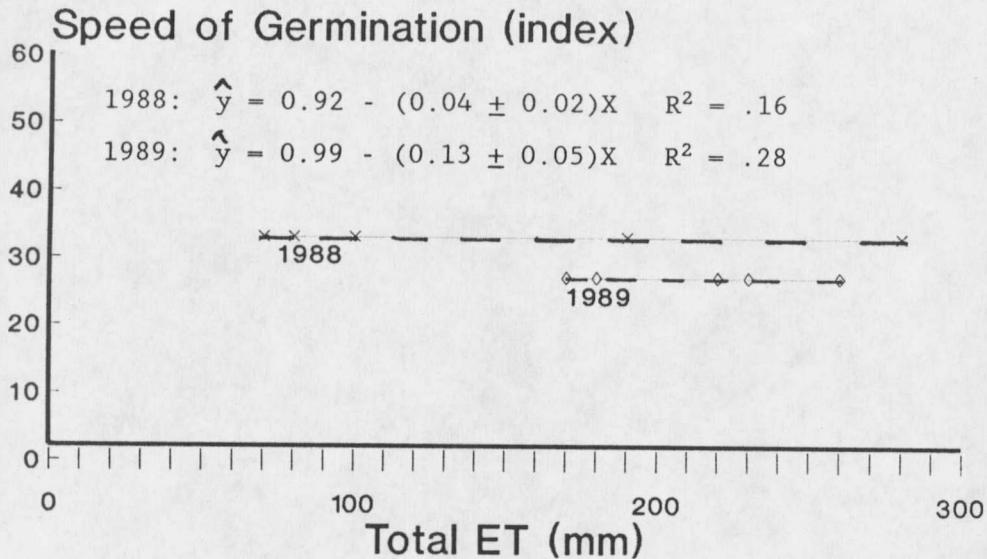


Figure 18. Effects of evapotranspiration on speed of germination of Critana thickspike wheatgrass grown under a line-source irrigation system in Manhattan, Montana, in 1988 and 1989.

No significant responses (Figure 18) to ET for the speed of germination were measured in 1988 or 1989. The mean speed of germination in 1988 was 33%, and 27% in 1989.

Luna Pubescent Wheatgrass

Mean percent germination, was lowest in IL4 in 1988, and lowest in IL3 and IL4 in 1989. The germination response to ET was linear (Figure 17) in 1988 and 1989. These data suggest that increased moisture reduced seed germination.

Over all irrigation levels, the speed of germination was not significantly different (Figure 19) for Luna seeds in 1988 and 1989. The speed of germination response to ET was

curvilinear in both 1988 and 1989, resulting in R^2 values of .35 and .36, respectively.

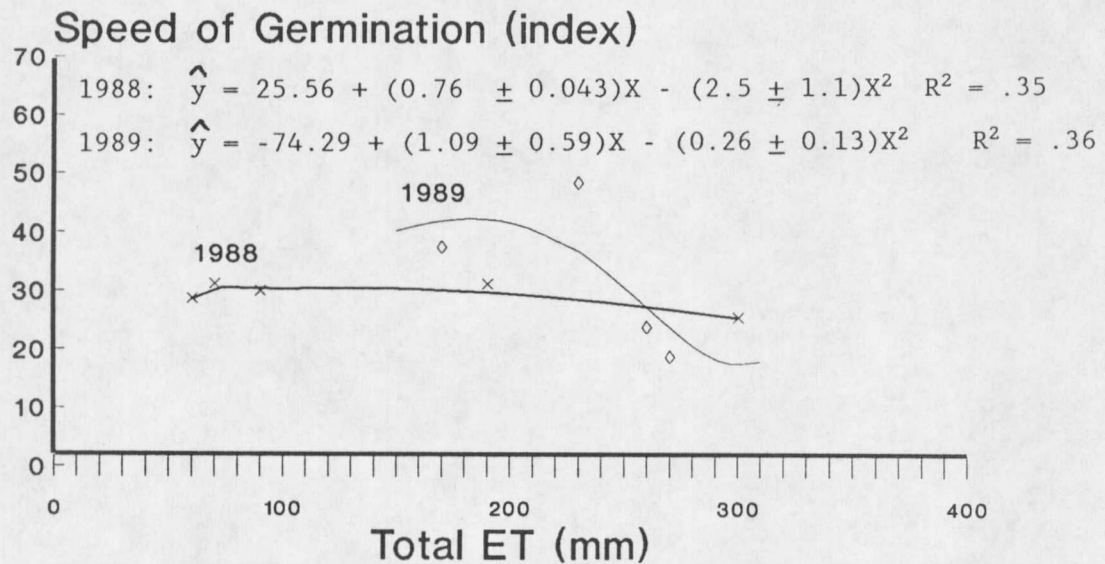


Figure 19. Effects of evapotranspiration on speed of germination of Luna pubescent wheatgrass grown under a line-source irrigation system in Manhattan, Montana, in 1988 and 1989.

SUMMARY

In this study in the first year of Regar forage production, the amount of forage depended on the amount of available water, and high yields were attained at approximately 30 cm of applied water. Forage production in the second year was less than in the first year. First year seed yield was increased with increasing water, but percentage germination will begin to decrease when more than 20 cm of water was applied.

The first year Regar meadow brome grass responses of forage yield, seed yield, accelerated age percentage germination, and respiration over ET are expressed with first degree polynomial models (Table 2, Appendix). Quadratic models were not significant, nor were models that included a significant response to N. Yields were affected by the amount of water available to them, but did not appear affected by the different levels of N in the soil. In general, the amount of N available to the Regar in 1988 was variable enough to create significant responses among the seed quality response variables. Increased moisture levels, however, caused decreased respiration and accelerated age percentage germination.

Nitrogen should be included up to 134 kg ha^{-1} when the objective is to produce a high quantity of Regar seed in the second year of seed production. When vigorous seed is also desired, the precipitation should not exceed approximately 20 cm in a growing season. Forage production increased with increased amounts of water up to approximately 95 cm in a season but lodging, when adequate N was available, occurred.

The Regar models from 1989 included a cubic component for forage yield over ET (Table 3, Appendix), and a quadratic component for seed yield over N. The seed quality variables of speed of germination and accelerated age germination have quadratic models over ET. As the amount of applied water and the amount of nitrogen increase, germination decreases. The germination model has a quadratic term for ET and a cubic term for N. The water and N treatments had no significant impact on the rate of respiration. Increased water positively affected forage yield, and high nitrogen levels affected seed yield negatively. Seed vigor was affected by both nitrogen and water. Percentage germination has a negative slope over the quadratic ET term at the highest irrigation levels, but a positive slope over N, suggesting that a water level was reached that did not contribute positively to seed quality. Speed of germination had a negative slope as water levels increased, but accelerated age germination sloped upward as water levels increased.

In the first and second years of Critana forage production, yields increased with increased levels of water. Seed yields increased in the first and second years up to approximately 30 cm of water applied, with seed quality not affected the first year, but perhaps decreasing the second year.

In the first year of Luna production, forage and seed yield increased with levels of water up to 30 cm. Percentage germination in both years, however, decreased as water levels increase linearly to approximately 30 cm.

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Table 1. Mean seasonal evapotranspiration (ET) of three grass cultivars grown under a line-source irrigation system at Manhattan, Montana, in 1988 and 1989.

Irrigation Levels	ET†					
	Regar		Critana		Luna	
	1988	1989	1988	1989	1988	1989
Dryland (IL0)	104	155	79	180	72	170
Low (IL1)	114	183	68	169	67	171
Medium (IL2)	185	437	99	231	88	226
Medium-high (IL3)	191	261	191	261	189	267
High (IL4)	328	999	286	225	305	257

† Seasonal evapotranspiration = $CSM_i + P + I - CSM_f - RO - D$, where CSM_i is initial soil water content, P is precipitation amount, I is irrigation amount, CSM_f is final soil water content, RO is runoff, and D is deep drainage. Runoff and deep drainage were negligible.

Table 2. Comparison of mean square errors (MSE) and significant (<.05) p-values for field and laboratory parameters of Regar meadow brome grass grown at Manhattan, Montana in 1988.

	<u>FY†</u>	<u>SY‡</u>	<u>G§</u>	<u>SP¶</u>	<u>AA#</u>	<u>Resp††</u>
MSE	0.45	13763	56.53	42.22	53.24	0.12
ET ¹	*	*	-	-	*	*
ET ²	-	-	-	-	-	-

† FY, forage yield Mg ha⁻¹

‡ SY, seed yield, kg ha⁻¹

§ G, germination, %

¶ SP, speed of germination, index

AA, germination after accelerated aging, %

†† Resp, uLO₂ seed⁻¹ hour⁻¹

¹, variable to the first power

², variable to the second power

* p-values ≤ .05

Table 3. Comparison of mean square errors (MSE) and significant (<.05) p-values for field and laboratory parameters of Regar meadow brome grass grown at Manhattan, Montana in 1989.

	FY †	SY ‡	G §	SP ¶	AA #	Resp ††
MSE	0.94	829.86	16.09	74.49	301.31	74.49
ET						
ET ¹	*	-	*	-	*	-
ET ²	*	-	*	*	*	-
ET ³	*	-	-	-	-	-
ET ⁴	-	-	-	-	-	-
N ¹	-	*	*	-	-	-
N ²	-	*	*	-	-	-
N ³	-	-	*	-	-	-

† FY, forage yield, Mg ha⁻¹

‡ SY, seed yield, kg ha⁻¹

§ G, germination, %

¶ SP, speed of germination, index

A

A, germination after accelerated aging, %

†† Resp, uLO₂ seed⁻¹ hour⁻¹

¹, variable to the first power

², variable to the second power

³, variable to the third power

⁴, variable to the fourth power

* p-values ≤ .05

Table 4. Irrigation and nitrogen effects on Regar meadow brome grass at Manhattan, Montana.

		Field Parameters			Laboratory Parameters			
		1988						
IL†	H ₂ O (mm)	ET (mm)	Yield		GERM (%)	Vigor		AA (%)
			FORAGE (kg ha ⁻¹)	SEED (kg ha ⁻¹)		SPEEDGERM (index)	RESP/SEED (μLO ₂ seed ⁻¹ hr ⁻¹)	
0	54	104.0	6863	332	90	38.12	.7319	55
1	71	114.2	5672	186	89	39.72	.8056	55
2	147	184.6	6823	348	87	36.14	.7044	52
3	222	260.8	8514	547	86	38.44	.7206	52
4	292	327.6	9634	722	86	38.80	.5856	51
N level (kg ha ⁻¹)								
0		202.8	6982	394	89	38.63	.6870	52
45		197.1	7643	449	88	38.55	.6215	53
90		198.2	7724	420	89	39.42	.8350	55
134		194.8	7656	443	85	36.60	.6950	51
		1989						
IL								
0	151	154.7	8558	189	91	43.96	.6045	13
1	168	183.1	6621	196	90	41.35	.5641	7
2	376	437.3	7501	192	92	41.05	.6283	6
3	749	906.1	13057	192	89	32.93	.6201	10
4	949	998.9	13126	123	79	27.71	.6034	18
N level (kg ha ⁻¹)								
0		539.6	7355	124	90	37.91	.6094	12
45		548.5	8984	195	91	38.70	.5945	7
90		531.7	11578	204	84	35.58	.6117	11
134		524.3	11171	196	88	37.40	.6007	13

†Irrigation level, ET is seasonal evapotranspiration, FORAGE is forage yield, SEED is seed yield, GERM is germination, SPEEDGERM is speed of germination, RESP/SEED is respiration per seed, AA is percentage germination after accelerated aging.

Table 5. Comparison of irrigation effects on Critana thickspike wheatgrass grown in Manhattan, Montana in 1988 and 1989.

	Field Parameters				Laboratory Parameters	
	1988					
	H ₂ O (mm)	ET (mm)	Yield		GERM (%)	Vigor
IL†			FORAGE (kg ha ⁻¹)	SEED (kg ha ⁻¹)		SPEEDGERM (index)
0	53	78.75	4245	723	54	27.14
1	56	68.00	3658	725	64	37.22
2	84	98.75	3857	616	61	35.14
3	178	191.00	5347	868	66	38.16
4	273	285.50	6966	759	54	25.58
1989						
IL						
0	151	179.5	2536	191	80	31.28
1	158	168.5	2457	226	83	27.51
2	227	231.0	3270	318	77	28.74
3	309	261.0	4621	298	70	22.59
4	332	225.3	6836	105	75	23.83

† Irrigation level, ET is seasonal evapotranspiration, FORAGE is forage yield, SEED is seed yield, GERM is percentage germination, SPEEDGERM is speed of germination, RESP/SEED is respiration per seed, AA is percentage germination after accelerated aging.

Table 6. Comparison of irrigation effects on Luna pubescent wheatgrass grown at Manhattan, Montana, in 1988 and 1989.

	<u>Field Parameters</u>				<u>Laboratory Parameters</u>	
			<u>1988</u>			
	H ₂ O (mm)	ET (mm)	<u>Yield</u>		GERM (%)	<u>Vigor</u> SPEEDGERM (index)
			FORAGE (kg ha ⁻¹)	SEED (kg ha ⁻¹)		
IL†						
0	53	71.5	8299	742	29	31.08
1	53	66.5	6055	731	85	28.52
2	74	88.0	7818	798	87	29.88
3	175	188.8	9023	867	89	31.05
4	259	305.3	10667	879	78	25.38
			<u>1989</u>			
IL						
0	151	170.0	5264	270	74	37.38
1	158	170.8	4760	257	78	35.98
2	227	226.3	6469	427	81	48.33
3	309	267.0	7616	500	59	18.71
4	332	257.0	5936	617	58	23.77

† Irrigation level, ET is seasonal evapotranspiration, FORAGE is forage yield, SEED is seed yield, GERM is percentage germination, SPEEDGERM is speed of germination, RESP/SEED is respiration per seed, AA is percentage germination after accelerated aging.

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