Examination of frost seeding spring small grains and alternate crops in eastern Montana
by Kenneth David Kephart

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Agronomy
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Abstract:
The alternate crop-fallow system used in Eastern Montana is not an effective means of moisture conservation. The technique of frost seeding shows promise as an alternative cropping practice to the crop-fallow system. Three experiments were conducted in this study to determine the effects of frost seeding on emergence, stand, and yield of small grain and various alternate crops on fallow and recropped land.

In Experiment I, yields of "CC-XXX-F" barley, winter barley, winter-graze hybrid, and "Rinal" fababean were 1,006, 2,220, 2,230, and 376 kg/ ha, respectively, greater when frost seeded than when planted at a normal seeding date. Except for crambe, "Hector" barley, "Norana" spring wheat, safflower, and cow cockle also exhibited a trend toward higher yield when frost seeded than when normally seeded. All crops emerged slower when frost seeded than seeded at the normal date. The slowest emerging frost seeded crop, cow cockle, completed emergence 12 days prior to the fastest emerging normal seeded crop, CC-XXX-F barley. CC-XXX-F barley, Norana spring wheat, wintergraze hybrid, and Rinal fababean required 0.5, 0.6, 1.2, and 1.5-more days, respectively, to emerge on recropped land than on fallowed land. Only frost seeded safflower and cow cockle showed significant stand reduction as compared to the normal dated seeding treatment.

Under dryland conditions of Experiment II, frost seeded spring barley yields on fallow and spring grain stubble were 1,128 and 660 kg/ha, respectively, greater than yields obtained on fallow and spring grain stubble planted on the normal seeding date. Spring wheat frost seeded on fallow and spring grain stubble yields were 431 and 401 kg/ha, respectively, greater than comparable normal seeded spring wheat yields.

No difference occurred between barley and wheat yields frost seeded on winter wheat stubble as compared to the normal dated seeding.

Experiment III was conducted at six locations along a chinook belt transect. Spring barley and spring wheat were frost and normally seeded on fallow and recropped land. Application of 66 kg N/ha increased yields of barley and wheat by 670 and 419 kg/ha, respectively, compared to no application of nitrogen. Nitrogen increased yields uniformly, regardless of seeding method or seedbed. No difference in yield was observed between frost seeded and normally seeded crops.

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AND ALTERNATE CROPS IN EASTERN MONTANA

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A thesis submitted in partial fulfillment
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ABSTRACT

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Under dryland conditions of Experiment II, frost seeded spring barley yields on fallow and spring grain stubble were 1,128 and 660 kg/ha, respectively, greater than yields obtained on fallow and spring grain stubble planted on the normal seeding date. Spring wheat frost seeded on fallow and spring grain stubble yields were 431 and 401 kg/ha, respectively, greater than comparable normal seeded spring wheat yields. No difference occurred between barley and wheat yields frost seeded on winter wheat stubble as compared to the normal dated seeding.

Experiment III was conducted at six locations along a chinook belt transect. Spring barley and spring wheat were frost and normally seeded on fallow and recropped land. Application of 66 kg N/ha increased yields of barley and wheat by 670 and 419 kg/ha, respectively, compared to no application of nitrogen. Nitrogen increased yields uniformly, regardless of seeding method or seedbed. No difference in yield was observed between frost seeded and normally seeded crops.

INTRODUCTION

The alternate crop-fallow cropping system common throughout the eastern portion of Montana is not an efficient means of moisture conservation (5). Approximately 80% of moisture received during the fallow period is lost to evaporation, percolation, and runoff (5) with moisture accumulation becoming sufficient for development of saline seeps in soils overlaying crustated shale formations commonly occurring in eastern Montana (6). Cropping procedures which improve water use would subsequently be advantageous in development of alternatives to crop-fallow farming. Frost seeding would be helpful in the development of alternative cropping practices. Frost seeding is the planting of spring crops with an ordinary drill in early spring when the soil is thawed but with sufficient surface frost to support the equipment and maintain traction (23). The principle advantages of this farming practice are: early emergence, use of early spring moisture, earlier crop maturity, escape from mid-summer droughts, and spreading of seasonal labor requirements.

The purpose of this study is to determine the effects of frost seeding on emergence, stand, and yield on recropped and fallow land.

LITERATURE REVIEW

Frost seeding involves establishing spring crops under environmental conditions assumed too adverse to permit adequate germination and emergence. Seeds of frost seeded crops must imbibe water, germinate, and emerge during a period when the soil is frozen and nighttime air temperature is frequently subfreezing. Survival factors are similar to the cold hardiness and desiccation resistance found in winter hardy perennials and winter annuals (46). However, frost seeded spring crops are not subject to the extreme conditions of overwintering.

Over 3,000 cold hardiness studies have been conducted (1). Most studies have dealt with winter hardiness of perennials and winter annuals, and cold hardiness of annual species susceptible to early fall frost. These have been summarized by Alden and Herman, Mayland and Cary, and Steponkus (1,31,46). Many greenhouse studies have also involved seedling survival at freezing temperatures (2,3,4,13,21,25,29,31,34,41,46,50). However, only three authors (16,22,23,47,48) have reported on field studies of frost seeding methods.

Late sown spring oats and barley are vulnerable to high temperature and disease (16). Grafius and Wolfe (16) planted these small grains in frozen soil in late February to early March when approximately 2.5 cm of the surface frost had thawed. No difficulty was experienced with excessive mud adhering to either the tractor or conventional grain drill. Three year average yield increases of frost seeded grains over normal seeded grains were 205 percent and 90 percent for barley and oats, respectively (16).

Stoskopf et al. (47,48) conducted frost seeding experiments with barley, spring wheat, and oats at the Ontario Agricultural College, Guelph, Ontario. Conventional seeding drills performed satisfactory but increased soil compaction. Seed placement 2.5 to 3 cm deep in a frozen loam soil delayed germination and reduced emergence because the soil failed to warm quickly at these depths. Frost seeding with a broadcast seeder provided satisfactory stands. Seed remaining on the surface germinated and the primary roots penetrated the surface and provided anchorage. Subsequent advantitious root growth provided an ample root system.

In an attempt to double crop barley in the Yellowstone valley of southcentral Montana, frost seeding barley studies were initiated in 1969 (22). The double cropping system did not prove feasible with barley due to dwarf yellows of the second crop. The frost seeding methods were unknowingly similar to those previously investigated (16,47). Seeds left uncovered in shallow furrows germinated. Some seeds sank into the soil surface during warmer daytime temperatures. The furrow afforded some wind protection to the young seedlings. Under dryland and irrigated conditions, no crop failures occurred over a 6 year period when using the technique, even though temperatures occasionally dropped to -9 C (23).

Stoskopf et al. (47) reported frost seeded barley outyielded normal seeded barley by 18 percent and 53 percent in 1965 and 1967, respectively. Successful establishment was obtained in 1966, but severe weed infestations prevented harvesting. Krall (23) reported frost seeded dryland barley outyielded normal seeded barley by 12 percent and 13 percent on recropped and fallow land, respectively, over a 4-year period. Under irrigation, yields increased 30 to 40 percent (22). All frost seeded grains had higher test weights than normal seeded grain. The high yield increases reported by Grafius and Wolfe (16) is probably due to their using much higher frost seeding rates.

Cooler temperatures during plant development enhanced tillering of short stemmed plants (23,47,48). Shorter plants have less lodging problems when high rates of nitrogen fertilizers are used (47,48). Stoskopf et al. (47) stated "slow early growth of frost seeded cereals does not permit adequate competition with weeds" and advocated a chemical weed control program. Conversely, Krall (23) observed reduced weed infestation. This was attributed to shallow planted grain emerging sooner than most common weeds, particularly wild oats. Frost seeded crops matured 10 to 14 days earlier than normal seeded crops (22). Soil moisture use efficiency was also increased as cooler soils decrease moisture evaporation during plant development (23,47,48).

Soil moisture, low temperature imbibition, seed moisture content, resistance to freezing temperatures, photosynthesis, level of reserve food supplies and other factors affect the seedling survival (1,2,3,4, 13,31,34,46). These factors also contribute to the cold hardiness of annual species susceptible to early fall frost.

Imbibing seeds must attain a specific moisture content in order to germinate (19). Species and cultivar differences exist for the ability to germinate over the entire range of soil moisture from field capacity to wilting point (19,42). A given specie cannot imbibe water beyond a specific soil moisture tension level. Formation of ice crystals in the soil water increases the soil moisture tension. Frost seeded small grains have been observed to survive soil freezing temperatures (16,23, 47,48), however, the plant-soil-water relationships which exist under these conditions have not been reported.

Moisture content level of the soil indirectly affects plant survival under freezing conditions (1,21). The high specific heat property of water, compared to soil particles, increases the conductivity and storage of heat. Water releases 80 calories of heat per gram upon freezing. At temperatures to -20 C, plant death occurs sooner but progresses at a slower rate on soils having high moisture contents (21). Below -20 C, soil moisture does not contribute to plant survival. Low oxygen content of the soil substrate increased low temperature sensitivity (36).

Seed imbibition at subfreezing temperatures have not been reported. Coffman (8), in 1923, reported on the imbibition and germination of four small grains at the temperature of melting ice. Temperature could be maintained only, because of antiquated procedures, within ±6 C. The declining order of germination was: 1) barley, 2) rye, 3) wheat, and 4) oats. Within a species, starchy type seeds were less resistant to low temperature imbibition than flint or oily types (8). Subsequent research has assumed 5 C as a minimal cardinal temperature for imbibition and germination (7,9,10,11,12,14,17,18,32,33,35,36,37,40,43,45).

Imbibition at moderately low temperatures is greatly retarded (15, 18). Working with small legumes, Fayemi (Fayemi) observed it required 120 and 72 hours for all viable seeds to germinate at 5 C and 25 C, respectively. The rate of swelling of viable seed decreased with low temperature. Seeds imbibing within the initial 6 hours failed to germinate at either temperature. Close examination revealed these seeds were damaged, diseased, or nonviable (15), and that low temperature did not affect this rate of imbibition. Only crimson clover showed reduced germination as a result of the low imbibitioned temperature (15,18).

Powell and Mathews (38) observed imbibitional uptake rates of pea seeds with and without the testa intact. Rapid imbibition in seeds minus the testa reduced germination 30 percent and decreased respiration and relative growth rates. Imbibitional uptake was reduced in both seed lots by low (7-10 C) temperatures, but damage to seeds minus the tests was increased. Rapid water uptake displaced cell contents and caused cell death on the abaxial side of the cotyledons. Increasing initial seed moisture content prior to imbibition decreased rapid imbibitional injury but increased susceptibility to possible ensuing subfreezing temperatures (43).

Rapid imbibitional injury at low (2 to 7 C) temperatures or chilling injury has also been reported in cotton (*Gossypium hirsutum* L. and *G. barbadense* L.) (11), corn (*Zea mays* L.) (7,9,10), soybeans (*Glycine max* L.) (17,33), lima beans (*Phaseolus lunatus* L.) (35,37), crimson clover (*Trifolium incarnatum* L.) (18,45), fababeans (*Vicia faba*) (40), cacoa (*Theobroma cacao* L.) (20), and sorghum (*Sorghum bicolor* Moenchi) (9).

Imbibitional chilling damage in cotton, corn, and crimson clover induces tissue separation in the radicle. Cohn and Obendorf (10) observed that nonuniform absorption during low temperature imbibition created sufficient mechanical stress to form stellar lesions. Reduction of tissue ATP content also occurs.

Chilling damage in large seeded legumes is isolated to the cotyledons. Uneven absorption during imbibition creates adequate mechanical stress to cause transverse cracking of the cotyledons (17,33,37,40). Reduced seedling growth and vigor was associated with a decreased capacity to use cotyledon food reserves. The cotyledons afforded some protection to the embryonic axis. Excised axes display chilling injuries to the radicle and plumule similar to cotton and corn (17,37) upon low temperature imbibition.

All previously mentioned crops exhibited maximum imbibitional chilling injury at low (5 to 8 percent) initial seed moisture content.

Increased seed moisture content (13 to 20 percent) decreased or alleviated damage symptoms following imbibition. In some instances, injury reversal was observed when affected seedlings were transferred to non-chilling temperatures (12,20). Pollock and Toole (37) suggested that intact seeds avoid injury by not imbibing water and that this avoidance mechanism is itself temperature sensitive. Scott and Hanson (41) suggest that maximum survival to chilling injury may not be avoidance of it but rather the ability to overcome it.

Reported observations of seedling survival to freezing temperatures at various stages of growth associate frost resistance with the level of stored carbohydrate reserves. Winter and spring wheat seedlings exhibit two levels of frost resistance during early development (2,13,24,34,49). Cold resistance drops rapidly upon imbibition. The first level of resistance occurs shortly following imbibition and remains until exhaustion of endosperm food reserves. The second level occurs at the 4 to 5 leaf stage of growth where resistance remains low until photosynthetic reserve levels build up. Andrews (3) reported a third intermediate level of frost resistance in winter wheat at the one and a half to two leaf stage. Subsequent studies failed to reproduce this phenomenon.

Similar levels of frost resistance have been observed in barley (13, 34), small seeded legumes (4,50), and grasses (4,13,25,34,41,50). Arakeri and Schmid (4) reported cotyledons of small seeded legumes provide additional protection to the growing point prior to emergence. Crops possessing larger carbohydrate reserves usually possess greater initial frost resistance (4,50). Larger seeded crops tend to be more adaptable to frost seeding.

Cellular physiological aspects regarding frost resistance and changes due to freezing exposure are summarized in the review articles by Alden and Herman (1), Mayland and Cary (31), and Steponkus (46).

METHODS AND MATERIALS

This study involves information collected within three experiments. Experiment I was conducted during the 1977 growing season at the Agronomic Field Research Laboratory (R5E, T2S, S7) 11 kilometers west of Bozeman, Montana. Experiment II was conducted during the 1975, 1976, and 1977 growing seasons at the Southern Agricultural Research Center (SARC) (R28E, T2N, S16), Huntley, Montana. The third experiment was conducted along a chinook transect involving six harvested locations in northcentral Montana during the 1977 growing season (Figure 1).

Experiment I

This experiment compared the effects of frost and normal seeding operations on emergence, stand, and yield of cereal grains, oilseed, and annual forage crops (Table 1).

A split-split plot completely random designed with four replications was used. Fallow versus recrop were whole plots; frost seeding versus normal seeding were sub-plots; and species were sub-sub plots. Whole plots were not adjacent to each other and each replication consisted of two tiers, due to land availability.

Two weeks prior to planting the experiment was sprayed with 1.1 kg active ingredient (AI) per hectare of glyphosate (Roundup) herbicide[1/]. Frost seeded subplots were planted on both recrop and fallow whole plots

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[1/] Monsanto Chemical Company, St. Louis, Missouri.

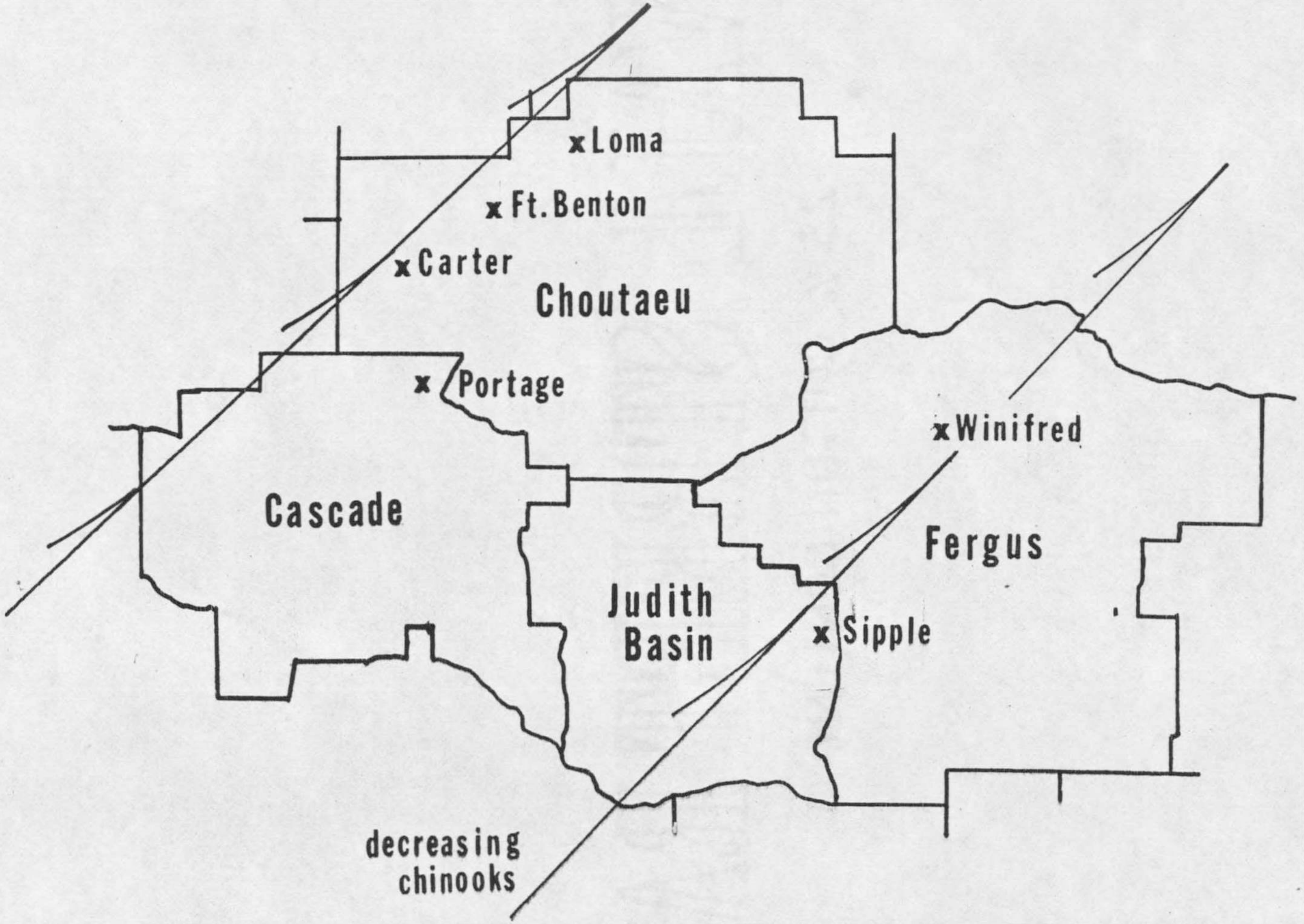

Figure 1. Location of chinook belt transect and planting sites of Experiment III in north central Montana, 1977.

Table 1. Scientific name, common name, and germination test of species used to evaluate frost seeding techniques on recrop and fallow land at Bozeman, Montana, in 1977.

Species Name	Common Name	Tested % Germ.
Hordeum disticum L.[1/]	Spring barley	88.3
Hordeum disticum L. var. Hector	Spring barley	90.8
Triticum aestivum L. var. Norana	Spring wheat	99.0
Vicia faba L. var. Rinal	Fababean	80.0
Pisum sativum L.	Austrian winter peas	85.0
Vaccaria segetalis (Neck.) Garcke.	Cow cockle	37.5
Carthamus tinctorius L.	Safflower	92.8
Crambe abyssinica Hochst.	Crambe	17.0
Hordeum vulgare L.[2/]	Winter barley	89.3
Agropyron triticum	Wintergraze hybrid	91.8

[1/] Composite cross XXX-F (39).

[2/] Sampled from the winter barley world collection.

on April 18, 1977. Individual plots, 4.6 × 1.2 m, were seeded with an experimental no-till drill utilizing rolling coulters and John Deere M-71 unit planters[2/]. Alamco fluted seed cones[3/] replaced the standard seed boxes. The seeds were placed at 5 cm deep in rows 35 cm apart. Except for fababeans, seeding rates were adjusted to provide 20 live seeds per 30 cm length of row. Fababeans were seeded at the rate of 10 live seeds per 30 cm row. The plots were later trimmed to 3.6 m in length to provide for 1.0 m alleys between replications and tiers within replications. Normal seeded subplots were established using the same procedures on May 9, 1977.

Visual observation was used to determine the number of days each specie required to emerge after planting. Hand counting of established plants in 1.8 m of row determined an emergence number. Forage species were harvested with a flail-type forage harvester[4/]. An area of 1.5 m^2 was harvested with yields weighed from each plot, and a subsample taken for moisture content. Total dry matter for each plot was later calculated and cuttings totaled for seasonal yield.

With the exception of safflower, 1.5 m^2 of the grain and oil crops were hand harvested and threshed with a gravity-type Vogel thresher[5/].

[2/] John Deere Equipment Company, Moline, Illinois.

[3/] Allen Machine Company, Ames, Iowa.

[4/] Rem Ltd., Swift Current, Saskatchewan, Canada.

[5/] Bill's Welding, Pullman, Washington.

Safflower plots were trimmed to 1.2 × 2.4 m and harvested with a Chain plot combine[6/]. Grain samples were weighed for yield and bulk density was determined with an Ohaus test weight apparatus[7/]. Oil percentages of safflower and crambe were obtained by nuclear magnetic resonance (NMR) spectroscopy analysis[8/].

The percent change of frost yields over normal seeded yields were indexed for comparison of all species on both cropping regimes. All data was analyzed by an analysis of variance of the split plot design. Where applicable, mean separation was conducted by testing for the least significant difference (L.S.D.) among treatment means or by using Duncan's multirange test (DMRT) (28,44).

Experiment II

General

The purpose of this experiment was to compare: 1) the effects of frost and normal spring seeding operations on the yield of barley (1975, 1976, and 1977) and spring wheat (1976 and 1977); and 2) to determine if different stubble types had an effect on the yield of barley and wheat when frost and normal spring seeding operations were used. A split plot completely random design with three replications was used. Whole plots

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[6/] Chain Manufacturing Company, Ames, Iowa.

[7/] Ohaus Scale Corporation, Union, New Jersey.

[8/] NMR spectroscopy procedure performed at Eastern Agricultural Research Center, Sidney, Montana.

were stubble types (spring wheat, winter wheat, barley, fallow) and subplots were frost versus normal spring seeding operations. Fertilization was based on the yearly soil test results. The data were analyzed by analysis of variance for split plot design, and, when applicable, L.S.D.'s or Duncan's multirange rest (DMRT) were used to separate means (28,44). Barley and spring wheat were analyzed separately. As in Experiment I, yield means were indexed to compare all crops with the four cropping regimes.

In 1975, frost and normal seeded plots of "Unitan" barley were established in the four cropping regimes on March 25 and April 12, respectively. Plots were 1.4 × 6 m with four rows 36 cm apart. The drill used in Experiment I, with a standard drill box instead of fluted cones, was used for planting. Roundup (1.1 kg AI/ha) was applied the previous fall, and post-emergence broadleaf weed control was obtained with 0.55 kg/ha of dimethylamine salt of 2,4-dichlorophenoxyacetic acid (2,4-D amine). All plots were post-emergence broadcast fertilized with 33 kg/ha of nitrogen (N). At maturity plots were trimmed an area of 0.72 × 4.9 m and hand harvested to obtain grain yields.

In 1976 "Hector" barley and "Lew" spring wheat were frost and normal seeded into the four cropping regimes on March 26 and April 10, respectively. The same planting procedure and equipment that were used in 1975, except that no Roundup was used and 101 kg N/ha fertilizer was broadcast applied. Plots were 2.2 × 6 m with six rows spaced 36 cm apart. The plots were trimmed to 1.4 × 4.9 m, then harvested with a Hage[9/] plot combine at maturity.

In 1977 Hector barley and "Norana" spring wheat were frost and normal seeded into four cropping regimes on March 14 and April 13, respectively. An experimental no-till drill developed with a grant from the Old West Regional Commission (24) was used. Plots were 2.9 × 6 m with eight rows spaced 36 cm apart. Weed control was obtained with 0.55 kg/ha 2,4-D applied post-emergence. Sixty-six kg N/ha was applied to all plots. Plots were harvested as in 1976.

Experiment III

This experiment was conducted on six separate sites along a chinook belt across northcentral Montana (Figure 1) in conjunction with another study monitoring weather conditions along the chinook belt. The purpose of this experiment was to compare frost and normal seeded yields of barley and spring wheat planted on fallowed and recropped land at varying locations.

Frost and normal seeded plots were planted on March 15 and 16 and April 13 and 15, 1977, respectively. Plots were 4.3 × 18.3 m with 12 rows spaced 36 cm apart. All plots were sprayed pre-plant with 1.1 kg 2,4-D amine/ha post-emergent to control subsequent broadleaf weed growth. The entire area was later split to allow post-emergence broadcast

[9/] Hage, A.G., Munich, Germany.

fertilization of half the area at the rate of 88 kg N/ha and 88 kg P_2O_5/ha. Each location was harvested by cutting 1.5 m^2 of grain by hand and threshed with a gravity type Vogel thresher.

Each selected transect site contained only a single replication of each treatment. Therefore, each site was considered as a replication variance source in the analysis of variance of a split-split plot design (28,44). To compare the effort of frost seeding at different locations with fertility and cropping regimes, yields were indexed as previously mentioned.