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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EXAMINATION OF FROST SEEDING SPRING SMALL GRAINS AND ALTERNATE CROPS IN EASTERN MONTANA

by

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

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ABSTRACT

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In Experiment I, yields of "CC-XXX-F" barley, winter barley, wintergraze 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.

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 nonchilling 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.

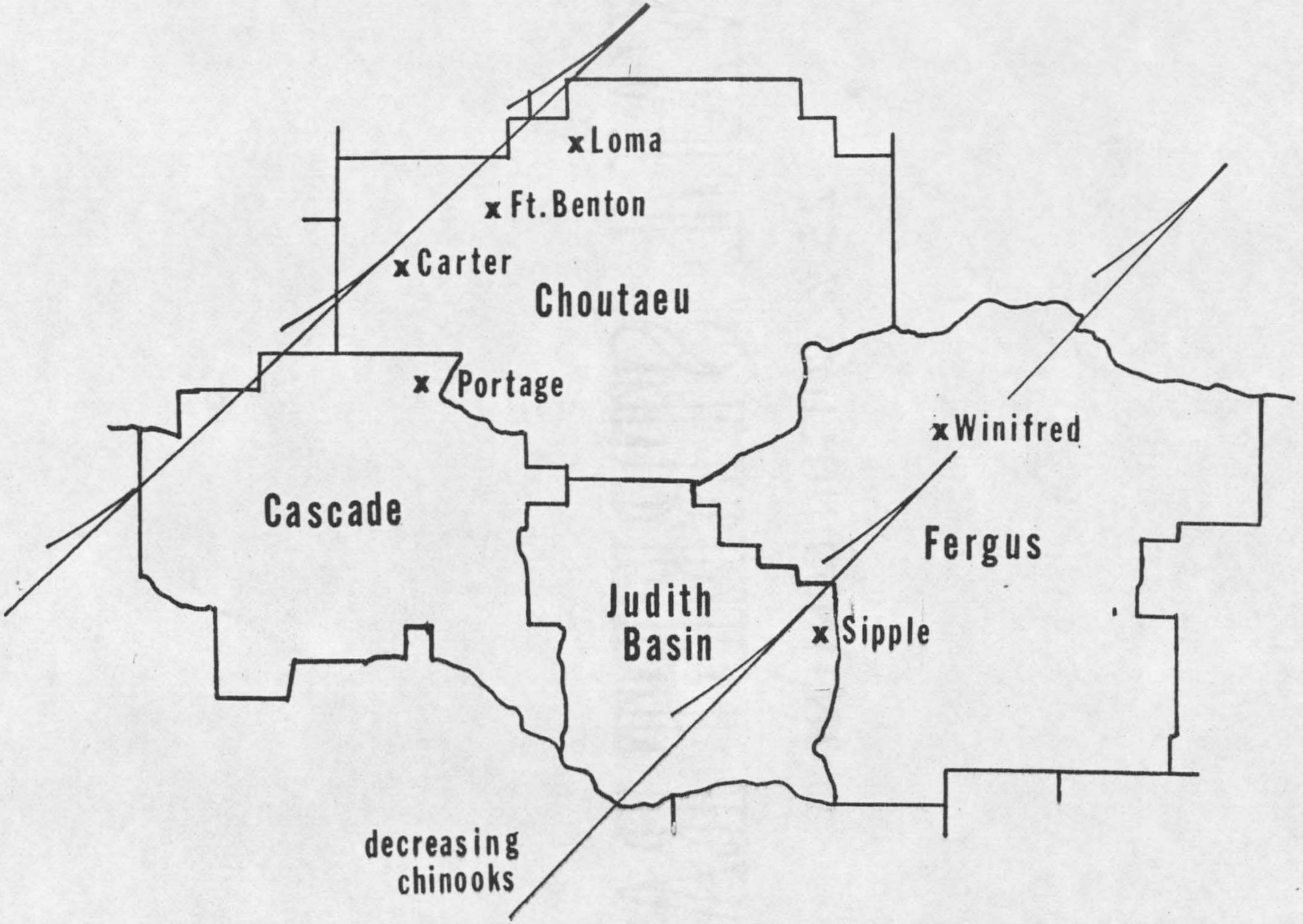

Figure 1. Location of chinook belt transect and planting sites of Experiment III in north central Montana, 1977.

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].

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[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

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[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.

RESULTS AND DISCUSSION

Experiment I

Selection criteria of an April 15th target date for frost seeding at Bozeman, Montana, was based on trends of average minimum air temperatures for the five previous seasons (Table 2). Nighttime soil surface temperatures were assumed to approximate the minimum air temperatures. The five year average indicated that fourteen nights with subfreezing temperatures follow April 15th. Actual planting date was April 18th, followed by only three nights with subfreezing temperatures. Therefore, the frost seeded crops were not exposed to the degree of subfreezing temperatures desired.

Days to emergence were observed to determine the effect of cooler temperatures on development. All ten crops required significantly more days to emerge under frost seeding conditions (Table 3). Hector barley, Norana spring wheat, and winter barley required 0.8, 1.8, and 1.0 more days, respectively, to emerge on frost seeded recropped land compared to the frost seeded fallow. The "CC-XXX-F" barley, Norana, 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. Shade and reduced air movement in standing stubble may have kept the soil cooler which resulted in the longer emergence time. The standing stubble did not prolong the emergence of the normal seeded Hector and winter barley.

Table 2. Minimum air temperatures and departure from previous five year average during period of frost and normal seeding dates, 1977, Bozeman, Montana.

April	1977 Temp.	5 Year Ave. C	Depart.	May	1977 Temp.	5 Year Ave. C	Depart.
15	-2.8	-2.8	0.0	1	2.8	-1.4	5.2
16	-0.8	-2.9	2.1	2	2.8	-1.6	5.4
17	1.1	-1.8	2.9	3	5.0	0.9	4.1
18[1]	-2.7	-2.1	-0.6	4	0.0	1.8	-1.8
19	-2.2	-2.8	0.6	5	-1.7	1.7	-3.4
20	-3.3	-1.4	-1.9	6	0.0	1.8	-1.8
21	0.0	-2.0	2.0	7	4.9	0.3	4.6
22	3.8	-0.9	4.7	8	4.4	2.6	1.8
23	6.5	0.4	6.1	9[2]	2.9	0.6	2.3
24	4.4	0.2	4.2	10	5.5	1.0	4.5
25	0.6	1.4	-0.8	11	5.0	0.9	4.1
26	3.3	-0.9	4.2	12	1.1	1.3	-0.2
27	4.3	-1.0	5.3	13	3.9	2.0	1.9
28	3.3	-0.8	4.1	14	6.6	2.8	3.8
29	2.9	-0.2	3.1	15	0.0	2.9	-2.9
30	6.5	-1.8	8.3	16	-0.6	3.4	-4.0

[1] Frost seeded planting date.

[2] Normal seeded planting date.

Table 3. Days to emergence for all crops comparing frost and normal seeding methods on fallow and recropped land, 1977, Bozeman, Montana.

	Fallow		Recrop		Seeding Method		Cropping Method	
	Frost	Normal	Frost	Normal	Frost	Normal	Fallow	Recrop
1. CC-XXX-F barley	9.0	6.8	10.3	6.5	9.7[2/]	6.7b	7.9b	8.4a
2. Hector barley	8.5b[1/]	7.0c	9.3a	6.8c	8.9a	6.9b	7.8	8.1
3. Norana spring wheat	9.0b[1/]	7.3c	10.8a	6.8c	9.9a	7.1b	8.2b	8.8a
4. Rinal fababean	13.0	12.3	15.0	13.3	14.0a	12.8b	12.7b	14.2a
5. Cow cockle	14.8	12.3	14.3	10.3	14.6a	11.3b	13.6a	12.3b
6. Safflower	10.5	8.3	10.5	8.5	10.5a	8.4b	9.4	9.5
7. Crambe	12.5	10.0	11.8	10.3	12.2a	10.2b	11.3	11.1
8. Winter barley	9.0b[1/]	7.0c	10.0a	7.0c	9.5a	7.0b	8.0	8.5
9. Wintergraze hybrid	9.3	7.8	11.0	8.5	10.2a	8.2b	8.6b	9.8a
10. Austrian winter pea	11.0	10.0	11.3	10.3	11.2a	10.2b	10.5	10.8

[1/] Treatment means within a row accompanied by different letters are significantly different at P = .05 (DMRT).

[2/] Seeding method means and cropping method means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

Emergence counts (Table 4) show that, except for safflower and cow cockle, no significant differences occur between stands of frost and normal seeded crops. Frost seeded safflower stands were significantly reduced. Normal seeded cow cockle stands had 18.3% fewer plants than frost seeded stands. The lack of significance between frost and normal seeding for the remaining eight crops show no detrimental effect from frost seeding.

Crambe had better stands on normal seeded fallow and frost seeded recropped land. These differences should probably be discounted. The coefficients of variance (CV_a and CV_b for emergence of crambe are 26.9 and 29.8, respectively) express more variation from treatment effects than anticipated. This was probably due to the poor germinating of crambe.

Yield of CC-XXX-F barley, Hector barley, the wintergraze hybrid, and Rinal fababeans on fallowed land was significantly greater than on recropped land (Table 5). CC-XXX-F barley, winter barley, wintergraze hybrid, and Rinal fababean frost seeded yields were 1,006, 2,220, 2,320, and 376 kg/ha, respectively, greater than normal seeded yields. Except for crambe, the remaining four harvested crops exhibited higher frost seeding yields than normal seeding yields. Yields of Hector barley, in declining order, were frost fallow, normal fallow, normal recrop, and frost recrop.

Table 4. Emergence of all crops comparing frost and normal seeding methods on fallow and recropped land, 1977, Bozeman, Montana.

	Fallow		Recrop		Seeding Method		Cropping Method	
	Frost	Normal	Frost	Normal	Frost	Normal	Fallow	Recrop
	plants per 1.8 m of row							
1. CC-XXX-F barley	121.5	123.0	123.5	122.8	122.5	122.9	122.3	123.2
2. Hector barley	127.8	125.8	133.3	127.3	130.6	126.6	126.8	130.3
3. Norana spring wheat	135.3	136.5	140.5	135.3	137.9	135.9	135.9	137.9
4. Rinal fababean	77.8	77.0	76.0	69.8	76.9	73.4	77.4	72.9
5. Cow cockle	38.0	34.3	41.0	30.3	39.5a	32.3b	36.2	35.7
6. Safflower	111.5	125.8	117.5	121.3	114.5b	123.6a	118.7	119.4
7. Crambe	50.8b[1]	94.3a	86.8a	33.5b	68.8	63.9	72.6	60.2
8. Winter barley	130.5	136.0	139.5	135.8	135.0	135.9	133.3	137.7
9. Wintergraze hybrid	112.3	116.5	120.0	121.0	116.2	118.8	114.4	120.5
10. Austrian winter pea	119.3	121.3	117.3	118.0	118.3	119.7	120.3	117.7

[1] Treatment means within a row accompanied by different letters are significantly different at P = .05 (DMRT).

[2] Seeding method means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

Table 5. Yield of all crops comparing frost and normal seeding methods on fallow and recropped land, 1977, Bozeman, Montana.

	Fallow		Recrop		Seeding Method		Cropping Method	
	Frost	Normal	Frost	Normal	Frost	Normal	Fallow	Recrop
				kg/ha				
1. CC-XXX-F barley	4,713	3,737	3,611	2,575	4,162a[3]	3,156b	4,225a	3,093b
2. Hector barley	6,866a[2]	5,597b	4,277d	4,602c	5,572	5,100	6,232a	4,440b
3. Norana spring wheat	5,554	4,454	4,545	4,481	5,050	4,468	5,004	4,513
4. Rinal fababean	1,511	1,063	881	576	1,196a	820b	1,287a	729b
5. Cow cockle	2,760	2,288	1,719	2,025	2,240	2,157	2,524	1,872
6. Safflower	6,762	4,917	5,508	5,172	6,135	5,022	5,840	5,318
7. Crambe	6,195	6,681	5,125	4,870	5,660	5,776	6,438	4,998
8. Winter barley[1]	5,483	2,766	5,493	3,769	5,488a	3,268b	4,125	4,631
9. Wintergraze hybrid[1]	6,070	3,136	4,329	2,613	5,200a	2,880b	4,608a	3,471b

[1] Forage yield.

[2] Treatment means within a row accompanied by different letters are significantly different at P = .05 (DMRT).

[3] Seeding method means and cropping method means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

The percent yield change by frost seeding over normal seeding was indexed to compare frost seeding effect on yield between species and cropping regimes (Table 6). Index values greater than 100 indicate the frost seeded treatments yielded more than the normal seeded treatments. All indexed values for species are greater than 100. Frost seeded crop yields average 50.2 and 41.0 percent greater than normal seeded crop yields on fallowed and recropped land, respectively. In spite of the fact that frost seeded safflower stands are significantly less than normal seeded stands, frost seeded safflower yields were 66 percent greater. It is evident that frost seeding crops shows no detrimental effect on yield.

Reduced vegetation growth from development under cooler temperatures may result from frost seeding without affecting yield. Reduced straw to grain ratios would be expected under frost seeding. Norana spring wheat frost seeded straw to grain ratio was 0.17 less than the normal seeded straw to grain ratio (Table 7). As Norana seeding method yields are not different, the straw to grain ratio reduction from frost seeding must represent a reduction of vegetative growth. Straw to grain ratio for frost seeded CC-XXX-F barley on recrop is significantly less than the straw to grain ratio for normal seeded recropped CC-XXX-F barley. No difference was observed among the seeding method straw to grain ratio of the fallow planted CC-XXX-F barley.

Table 6. Indexed yield values for all crops comparing frost and normal seeding methods on fallow and recropped land, 1977, Bozeman, Montana.

	Fallow	Recrop	Means
1. CC-XXX-F barley	128.5	138.6	133.6c[1/]
2. Hector barley	122.8	85.2	109.0c
3. Norana spring wheat	131.0	103.2	117.1c
4. Rinal fababean	180.7	209.7	195.2a
5. Cow cockle	125.3	87.8	106.6c
6. Safflower	138.4	193.5	166.0abc
7. Crambe	102.2	108.1	105.2c
8. Winter barley	218.5	147.6	183.1ab
9. Wintergraze hybrid	204.5	185.3	194.9a
Means	150.2	141.0	

[1/] Crop average means accompanied by different letters are significantly different at P = .05 (DMRT).

Table 7. Straw to grain ratios for all small grains comparing frost and normal seeding methods on fallow and recropped land, 1977, Bozeman, Montana.

	Fallow		Recrop		Seeding Method		Cropping Method	
	Frost	Normal	Frost	Normal	Frost	Normal	Fallow	Recrop
1. CC-XXX-F barley	1.47a[1]	1.38a	1.19b	1.50a	1.33[2]	1.44	1.43	1.35
2. Hector barley	1.07	1.00	0.98	0.95	1.03	0.98	1.04	0.97
3. Norana spring wheat	1.25	1.31	1.13	1.40	1.19b	1.36a	1.28	1.27

[1] Treatment means within a row accompanied by different letters are significantly different at P = .05 (DMRT).

[2] Seeding means with a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

Small grain crop quality was measured by test weight in kg/hl (Table 8). Norana spring wheat test weight from frost seeded recrop (81.2 kg/hl) is significantly greater than normal seeded recrop (79.4 kg/hl) which is significantly greater than test weights for both seeding methods on fallow (78.5 kg/hl). Test weights for frost seeded Hector barley and Norana spring wheat are 2.3 and 0.8 kg/hl, respectively, greater than test weights for normal seeded Hector barley and Norana spring wheat. Test weight for Hector on fallow is greater than that on recrop, 68.2 and 66.5 kg/hl, respectively, whereas the reverse is true of Norana test weights on fallow and recrop, 79.8 and 79.0 kg/hl, respectively. Although not significant, all other test weights were greater under frost seeding conditions.

Oil seed crop quality was measured as test weight in kg/hl and percent oil content (Table 9). Percent oil content of frost seeded safflower on fallow and recrop was greater than normal seeded fallow. Frost seeded test weight and oil content for safflower is 6.3 kg/hl and 0.9% greater than normal seeded test weight and oil content. Safflower quality is highest with frost seeded treatments. Safflower oil content is 1.0% greater on recropped land. Crambe exhibits no significant differences in crop quality from frost seeding, however, variability among crambe treatment means was greater than the variability among safflower treatment means.

Table 8. Test weights for all small grains comparing frost and normal seeding methods on fallow and recropped land, 1977, Bozeman, Montana.

	Fallow		Recrop		Seeding Method		Cropping Method	
	Frost	Normal	Frost	Normal	Frost	Normal	Fallow	Recrop
	kg/hl							
1. CC-XXX-F barley	70.4	66.9	66.4	64.8	68.4[2]	65.9	68.7	65.6
2. Hector barley	68.9	67.4	68.0	64.9	68.5a	66.2b	68.2a	66.5b
3. Norana spring wheat	78.4c[1]	78.5c	81.2a	79.4b	79.8a	79.0b	78.5b	80.3a

[1] Treatment means within a row accompanied by different letters are significantly different at P = .05 (DMRT).

[2] Seeding method means and cropping method means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

Table 9. Test weights and oil content for safflower and crambe comparing frost and normal seeding methods on fallow and recropped land, 1977, Bozeman, Montana.

	Fallow		Recrop		Seeding Method		Cropping Method	
	Frost	Normal	Frost	Normal	Frost	Normal	Fallow	Recrop
Test Weights	kg/hl							
1. Safflower	58.7	49.4	57.4	54.1	58.1a[2]	51.8b	54.1	55.8
2. Crambe	35.1	32.2	34.2	46.8	34.7	39.5	33.7	40.5
Oil Content	percent of weight							
1. Safflower	29.4a[1]	27.9b	29.8a	29.5a	29.6a[3]	28.7b	28.7b	29.7a
2. Crambe	38.4	36.9	44.5	36.4	41.5	36.7	37.7	40.5

[1] Treatment means within a row accompanied by different letters are significantly different at P = .05 (DMRT).

[2] Test weight seeding method means or cropping method means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

[3] Oil content seeding method means or cropping method means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

Experiment II

In 1975, frost seeded barley outyielded normal seeded barley, but significant differences only occurred on the barley and spring wheat stubble (Table 11). Fallow and recropped winter wheat stubble probably provide more uniform moisture content throughout the soil profile with different absolute moisture content accounting for the high and low yield comparison. Spring crops do not deplete soil water to the extent of winter wheat and recropping reduces the accumulation of soil water between seasons. The soil moisture content was probably most variable under the spring wheat and barley stubbles between the two seeding dates. As Unitan frost seeded on spring wheat stubble outyielded the frost seeding on fallow, the opposite was true for the normal seeding (Table 11). This supports varying soil moisture content on the spring stubble types between seeding dates. Over all cropping regimes frost seeded Unitan barley significantly outyielded the normal seeded by 593 kg/ha (Table 12). Unitan seeded on barley stubble and fallow significantly outyielded the Unitan seeded on winter wheat stubble by 1,570 and 1,191 kg/ha, respectively (Table 13). Although not significant, yield on spring wheat stubble outyielded those on winter wheat stubble by 868 kg/ha.

In 1976, Hector barley yields also showed a significant interaction among cropping regimes and seeding methods (Table 11). With the exception of the frost seeded barley stubble and fallow treatments, yields on all other treatment combinations were not significant. Precipitation

Table 10. Monthly precipitation and departure from normal for Experiment II, 1975-1977, SARC, Huntley, Montana.

	1975		1976		1977	
	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure
Month			cm			
January	2.95	1.96	1.17	0.18	2.24	1.25
February	0.94	-0.08	1.42	0.41	T	-1.02
March	1.88	0.43	1.37	-0.08	2.97	1.52
April	4.80	1.55	8.20	4.95	2.11	1.14
May	11.15	6.10	5.41	0.36	5.69	0.64
June	4.67	-2.67	7.77	0.43	2.69	-4.65
July	3.33	1.24	1.27	-0.81	1.30	-0.79
August	1.60	-0.89	0.89	-1.60	4.39	1.91
September	0.99	-2.54	2.79	-0.74	3.25	-0.28
October	6.68	4.75	2.54	0.61	3.20	1.27
November	4.15	2.67	1.83	0.36	1.22	-0.25
December	2.74	1.45	0.46	-0.84	4.39	3.10
Annual Total	45.87	13.97	35.13	3.23	33.45	1.55

Table 11. Yield of barley and spring wheat comparing frost and normal seeding methods on fallow and recropped land with three stubble types, 1975-1977, SARC, Huntley, Montana.

	Seedbed							
	Fallow		Barley Stubble		Spring Wheat Stubble		Winter Wheat Stubble	
	Frost	Normal	Frost	Normal	Frost	Normal	Frost	Normal
	kg/ha							
Unitan barley (1975)	3,154a[1]	2,728b	3,483a	3,157a	3,182a	1,934c	1,886c	1,614c
Hector barley (1976)	3,300a	1,117c	2,176b	932c	1,129c	1,178c	1,395c	1,082c
Hector barley (1977)	2,614	1,839	1,765	1,181	2,304	1,694	1,726	1,928
Lew spring wheat (1976)	2,211	1,103	2,472	1,324	1,532	1,039	1,570	1,085
Norana spring wheat (1977)	1,420	1,667	1,335	1,410	1,512	1,473	1,800	1,765

[1] Treatment means within a row accompanied by different letters are significantly different at P = .05 (DMRT).

Table 12. Yield of barley and spring wheat comparing frost and normal seeding methods, 1975-1977, SARC, Huntley, Montana.

	Seeding Method	
	Frost	Normal
	kg/ha	
Unitan barley (1975)	2,951a[1]	2,358b
Hector barley (1976)	2,000a	1,077b
Hector barley (1977)	2,102a	1,661b
Lew spring wheat (1976)	1,946a	1,151b
Norana spring wheat (1977)	1,517	1,579

[1] Seeding method means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

Table 13. Yield of barley and spring wheat comparing fallow and recropped land with three stubble types, 1975-1977, SARC, Huntley, Montana.

	Seedbed			
	Fallow	Barley Stubble	Spring Wheat Stubble	Winter Wheat Stubble
	kg/ha			
Unitan barley (1975)	2,941a[1]	3,320a	2,608ab	1,750b
Hector barley (1976)	2,209a	1,554b	1,154c	1,239c
Hector barley (1977)	2,227a	1,473b	1,999a	1,827ab
Lew spring wheat (1976)	1,657a	1,898a	1,286b	1,328b
Norana spring wheat (1977)	1,544	1,373	1,493	1,783

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[1] Treatment means within a row accompanied by different letters are significantly different at P = .05 (DMRT).

for 1976 (Table 10) was 1.27 cm above normal rainfall. As compared to 1975, the reduced precipitation and increased use of nitrogen fertilizer in 1976 may have produced more uniform results between treatment combinations. The moisture advantage the fallow and barley stubble possessed at frost seeding may have been lost before the normal seeding date.

Frost seeded Hector barley and Lew spring wheat (Table 12) significantly outyielded normal seeding by 923 and 795 kg/ha, respectively. Fallow seeded Hector barley significantly outyielded the Hector planted on barley stubble by 655 kg/ha which significantly outyielded Hector planted on both spring wheat and winter wheat stubbles by 400 and 315 kg/ha, respectively (Table 13). Lew spring wheat seeded on fallow and barley stubble significantly outyielded Lew seeded on both spring wheat and winter wheat stubble by 371 and 329 kg/ha, respectively, and 612 and 570 kg/ha, respectively.

In 1977 precipitation was 1.68 cm less than in 1976 (Table 10). Fertilizer rates were reduced from 101 kg N/ha to 66 kg N/ha. Frost seeded Hector significantly outyielded the normal seeding by 411 kg/ha (Table 12). Unlike the previous years, Hector yield on fallow and spring wheat stubble was significantly greater than the barley stubble by 754 and 526 kg/ha, respectively (Table 13). Although not significant, Hector on winter wheat stubble outyielded the barley stubble by 354 kg/ha. Norana spring wheat yields exhibited no significant differences between the seeding methods or the cropping regime on which it was seeded.

Balanced application of nitrogen fertilizer for the plant available water during the 1977 growing season may account for the increased uniformity among grain yields.

Yield values were indexed on the percent change of yield attributed to frost seeding over normal seeding in order to compare all crops to cropping regimes over the three year period. The significant interaction for the indexed values (Table 14) among crops and the cropping regime indicates the change in yield due to frost seeding was not uniform between all crops over the three year period or within the four cropping regimes. However, these differences may also be attributed to N fertility, varieties, yearly soil moisture changes, and other unknown factors.

Frost seeding increases were significantly different between the four cropping regimes (Table 14). Increases of yield on fallow were greater than the increased yields on spring wheat and winter wheat stubble by 50.5 and 62.8 percent, respectively. Fallow grain yields were better than barley stubble grain yields by 26.4 percent. Hector barley and Lew spring wheat planted in 1976 showed significantly greater increases from frost seeding then either barley or spring wheat seeded in any other year.

Table 14. Indexed yield values for barley and spring wheat comparing percent change of frost to normal seeding method on fallow and recropped land with three stubble types, 1975-1977, SARC, Huntley, Montana.

	Seedbed				
	Fallow	Barley Stubble	Spring Wheat Stubble	Winter Wheat Stubble	Means
Unitan barley (1975)	117.5d[1]	110.6d	170.4bcd	116.8d	128.8b[2]
Hector barley (1976)	335.8a	248.7ab	105.5d	130.6d	205.2a
Hector barley (1977)	146.8cd	147.8cd	138.8cd	89.6d	130.6b
Lew spring wheat (1976)	234.8bc	187.0bcd	152.2bcd	159.0bcd	183.4a
Norana spring wheat (1977)	87.7d	96.4d	103.3d	112.3d	99.9b
Means	184.5a[3]	158.1ab	134.0b	121.7b	

[1] Treatment means accompanied by different letters are significantly different at P = .05 (DMRT).

[2] Means within last column accompanied by different letters are significantly different at P = .05 (DMRT).

[3] Means within bottom row accompanied by different letters are significantly different at P = .05 (DMRT).

Experiment III

No significant difference in yield resulted from the seeding methods, frost vs. normal seeding, for either barley or spring wheat. Barley yields (Table 15) on fallow were 824 kg/ha greater than yields on recropped land. Spring wheat yields were 439 kg/ha greater on fallow than on the recropped land. Both barley and spring wheat responded to applications of nitrogen with improved yields. Increases in yield of 670 and 419 kg/ha for barley and spring wheat, respectively, resulted from the treatment of 66 kg N/ha (Table 16). The lack of interaction between seeding methods and cropping methods to the fertility rates (Table 15) indicates a uniform response to the application of nitrogen.

Compared to the normal seeding date, the indexed yield approach (Table 17) indicates that except for fertilized recropped barley, all other treatment combinations showed some response to frost seeding. Although not significant, over all treatment combinations, frost seeding improved yields 15.6% and 10.4% for barley and spring wheat, respectively, compared to normal seeding methods (Table 18). This approach to testing frost seeding across transects in central Montana is a logical method for testing the practice. Climatic conditions, such as growing season, chinooks, and precipitation, vary across the transect, thus the adaptability of the practice can be more accurately assessed. It is unfortunate that resources were not available for continuation of this approach.

Table 15. Yields for barley and spring wheat comparing frost and normal seeding methods on fallow and recropped land with two fertility rates at six chinook transect sites across north central Montana, 1977.

	Fallow				Recrop			
	Frost		Normal		Frost		Normal	
	0 kg N/ha	66 kg N/ha	0 kg N/ha	66 kg N/ha	0 kg N/ha	66 kg N/ha	0 kg N/ha	66 kg N/ha
	kg/ha							
Barley	2,314	2,980	2,055	2,527	1,360	1,935	1,157	2,126
Spring wheat	1,435	1,686	1,424	1,667	833	1,567	805	1,251

Table 16. Mean yields for barley and spring wheat comparing fertility levels, seeding methods, and cropping methods used in Experiment III, 1977.

	Fertility Levels		Seeding Method		Cropping Method	
	0 kg N/ha	66 kg N/ha	Frost	Normal	Fallow	Recrop
	kg/ha					
Barley	1,722b[1]	2,392a	2,147	1,966	2,469a[2]	1,645b
Spring wheat	1,124b	1,543a	1,380	1,287	1,553a	1,114b

[1] Fertility means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

[2] Cropping method means within a row accompanied by different letters are significantly different at P = .05 (L.S.D.).

Table 17. Indexed yield values for barley and spring wheat comparing percent change of frost to normal seeding methods on fallow and recropped land with two fertility levels, 1977.

Barley				Spring Wheat			
Fallow		Recrop		Fallow		Recrop	
0 kg N/ha	66 kg N/ha	0 kg N/ha	66 kg N/ha	0 kg N/ha	66 kg N/ha	0 kg N/ha	66 kg N/ha
124.5	117.7	130.0	90.0	112.1	110.7	103.2	115.4

Table 18. Mean indexed values comparing percent change of frost to normal seeding methods with fertility levels, cropping methods, and crops, 1977.

Fertility Levels		Cropping Method		Crop	
0 kg N/ha	66 kg N/ha	Fallow	Recrop	Barley	Spring Wheat
117.5	108.5	116.3	109.7	115.6	110.4

Even though no great differences were found between the two dates of seeding, the dates do show that frost seeding could become a practice. Frost seeding would spread the work load for spring recropping, resulting in better crop establishment when surface moisture would be adequate and reduce volunteer and weeds within the crop as crop emergence would be sooner than the weeds (22,23).

SUMMARY

Three experiments were conducted to determine the effect of frost seeding on emergence, stand and yield of small grains, and various alternate crops on fallow and recropped land.

Experiment I was performed to observe the effect of frost seeding on nine different species representing a broad variety of crops grown on fallowed and recropped land in a split plot design. Frost seeded crops did not receive the degree of cold weather exposure anticipated. As compared to normal seeded crops, frost seeded crops required significantly more time to emerge but exhibited little difference in stand. Frost seeded CC-XXX-F barley, Rinal fababean, winter barley, and wintergraze hybrid yields were significantly greater than when normally seeded. Except for crambe, the yields of the remaining crops indicate that frost seeding is superior to the normal seeding date.

Experiment II was a three year study conducted under dryland conditions. Spring barley and spring wheat were frost and normally seeded on fallow and recropped into spring barley, spring wheat, and winter wheat stubble. The yield of the barley and spring wheat was best when frost seeded into fallow or recropped into spring grain stubble, as compared to the normal seeding date. Yield results of both frost seeded barley and spring wheat were least satisfactory on winter wheat stubble than when normally seeded. Barley expresses more improvement of yield to frost seeding than does spring wheat.

Experiment III was conducted at six locations along a chinook belt transect in Cascade, Choteau, Fergus, and Judith Basin counties of north-central Montana. Spring barley and spring wheat were frost and normally seeded on fallow and recropped land at two fertility levels. Application of 66 kg N/ha significantly improved yield of both barley and wheat as compared to no application of nitrogen. Nitrogen increased yield uniformly, regardless of seeding or cropping methods used. No difference in yield of either barley or wheat was observed among seeding method treatment means.

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Table 19. Sources of variation for all measured components for all species comparing frost and normal seeding methods on fallow and recropped land, 1977, Bozeman, Montana.

Source	DF	Ft. Ellis Barley	Hector Barley	Norana Spring Wheat	Safflower	Crambe	Winter Barley	Winter-graze Hybrid	Rinal Fababean	Cow Cockle	Austrian Winter Pea
Yield											
Cropping methods	1	113,906*	285,324*	21,462	24,258	184,470	22,725	114,921*	12,656*	37,830*	
Error A	6	16,173	4,722	15,343	86,279	70,935	30,801	15,414	406	8,226	
Seeding methods	1	90,000*	19,811	30,102*	110,058	1,190	437,913*	478,172*	27,889*	625	
Crop. × seed.	1	81	56,525*	23,870	47,633	12,210	21,830	32,400	462	13,456	
Error B	6	8,496	7,275	6,239	34,217	54,116	13,893	10,390	1,744	8,249	
Total	15										
Days to Emergence											
Cropping methods	1	1.00*	0.25	1.56*	0.06	0.25	1.00*	6.25*	9.00*	9.00*	0.25
Error A	6	0.13	0.58	0.15	0.23	0.58	0.17	0.58	0.79	0.17	0.58
Seeding methods	1	36.00*	16.00*	33.06*	18.06*	16.00*	25.00*	16.00*	6.25*	36.00*	4.00*
Crop. × seed.	1	2.25	1.00*	5.06*	0.06	1.00	1.00*	1.00	1.00	4.00	4.00
Error B	6	0.63	0.17	0.23	0.40	0.83	0.17	0.50	0.46	1.67	0.33
Total	15										
Emergence per 1.8 m of Row											
Cropping methods	1	3.06	49.0	16.0	2.3	613.0	76.6	150.1*	81.0	1.0	27.6
Error A	6	13.81	65.0	23.0	61.3	320.0	42.2	27.9	30.5	185.0	47.1
Seeding methods	1	0.56	64.0	16.0	324.0*	95.0	3.1	27.6	49.0	210.0*	7.6
Crop. × seed.	1	5.06	16.0	42.3	110.3	9,361.0	85.6	10.6	30.3	49.0	1.6
Error B	6	8.65	130.2	130.3	41.0	392.0	73.6	26.7	12.5	34.0	11.2
Total	15										

Table 19. Continued.

Source	DF	Ft. Ellis Barley	Hector Barley	Norana Spring Wheat	Safflower	Crambe	Winter Barley	Winter-graze Hybrid	Rinal Fababean	Cow Cockle	Austrian Winter Pea
Test Weight											
Cropping methods	1	21.9	7.02*	8.12*	7.29	107.6					
Error A	6	13.1	0.99	0.18	2.53	81.2					
Seeding methods	1	15.0	12.30*	1.82*	97.02	53.7					
Crop. × seed.	1	2.2	1.56	2.10*	22.10	138.7					
Error B	6	5.3	0.38	0.17	6.51	79.7					
Total	15										
Straw to Grain Ratio											
Cropping methods	1	0.024	0.02	0.001							
Error A	6	0.051	0.03	0.013							
Seeding methods	1	0.046	0.01	0.112*							
Crop. × seed.	1	0.152	0.002	0.040							
Error B	6	0.010	0.04	0.014							
Total	15										
Percent Oil Content											
Cropping methods	1				4.40*	31.7					
Error A	6				0.66	52.2					
Seeding methods	1				3.09*	91.4					
Crop. × seed.	1				1.15*	44.3					
Error B	6				0.18	55.3					
Total	15										

*Significant difference at P = .05.