8-1976

Feasibility of hill plots for use in winter small grains research

Larry Douglas Robertson

To the Graduate Council:

I am submitting herewith a thesis written by Larry Douglas Robertson entitled "Feasibility of hill plots for use in winter small grains research." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

V. H. Reich, Major Professor

We have read this thesis and recommend its acceptance:

L. M. Josephson, F. L. Allen

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Larry Douglas Robertson entitled "Feasibility of Hill Plots for Use in Winter Small Grains Research." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

Vernon H Reich

V. H. Reich, Major Professor

We have read this thesis and recommend its acceptance:

L. M. Josephson

Fred L. Allen

Accepted for the Council:

Hilton A. Smith

Vice Chancellor
Graduate Studies and Research

FEASIBILITY OF HILL PLOTS FOR USE IN WINTER SMALL GRAINS RESEARCH

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Larry Douglas Robertson

August 1976

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to all who gave encouragement and assistance during the course of this study. Special appreciation is expressed to the following:

The Plant and Soil Science Department, Dr. Lloyd Seatz, Head, for providing financial assistance and necessary materials and equipment.

Dr. Vernon H. Reich for his guidance and assistance throughout the course of this study and in preparation of this manuscript.

Drs. L. M. Josephson and F. L. Allen who gave their advice and constructive criticism during the preparation of this manuscript.

Mr. Hugh Trentham of the Plant and Soil Science Field Research Laboratory (Knoxville Cotton Farm) for his labor and assistance.

Fellow graduate students for their encouragement, assistance, and fellowship throughout graduate work.

ABSTRACT

Four plot types were evaluated for use with winter small grains research. The plot types evaluated were hill plot, hill row, rod row equivalent and drill strip. The objectives of this research were to study the feasibility of the two hill plot designs for use in winter small grains research and to compare these designs to standard rod rows and drill strips in the same experiment. The plot types were evaluated with Cumberland oats (Avena sativa L.), Volbar barley (Hordeum vulgare L.), and Arthur wheat (Triticum aestivum L.). The plot types were compared for measurment of spring stand, date headed, date ripe, plant height, percent lodging, yield, and 100 kernel weight. Ranges, coefficients of variation, correlations, analysis of variance, Duncan's New Multiple Range Test, and Relative Efficiencies were used to evaluate the plot types.

All correlations between plot types were positive and significant at the 0.05 probability level. Hill plots were much more variable with oats than rod rows and drill strips for measurement of spring stand by all by all measures of variability. Five replications of hill plots of oats were needed to equal one replication of rod equivalent. Yield evaluation in hill plots of oats was affected to a large extent by the erratic nature of winterkilling in the hill plots. For yield 3.5 replications of hill plots were needed to equal one replication of rod row equivalent. Date headed and date ripe evaluation in hill plots of oats was affected to a lesser extent than yield. Hill plots of barley and wheat where winter-killing did not occur reacted more favorably than oats for yield, date

headed, and date ripe evaluation. For yield 2.5 replications of hill plots would have been as or more efficient than one replication of rod row equivalent. Two replications of hill plots would have been as or more efficient as one replication of rod row equivalent for all the other characters.

The hill row did not have enough advantage over the hill plot in reducing variability to justify its use. Although conducted at only one location for one year this study raises serious doubt on the feasibility of hill plots for use in winter small grains research when winterkilling occurs and is a factor to be evaluated.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Plant breeders have continually tried to decrease the size of test plots in order to test more experimental material in less space. Small grain breeders have moved from the use of drill strips to standard rod rows for testing experimental lines. The hill plot technique of small grains was introduced by Bonnett and Bever in 1947 (2). However, little use has been made of this technique by small grain breeders. The hill plot has the advantages of requiring less space and seed for testing. It has the potential for use in preliminary yield testing to allow both more lines to be tested and to do this with replicated yield tests.

The use of hill plots has not been reported with winter oats (*Avena sativa* L.) or barley (*Hordeum vulgare* L.). Only Hendriksen (8) has compared winter wheat (*Triticum aestivum* L.) in hill plots with standard rod rows and he was concerned mainly with it as a technique for maintaining a winter wheat cultivar. Presently, comparisons have only been made between hill plots and other types of plots where each were in different experiments.

The objectives of this research were to study the feasibility of two hill plot designs for use in winter oats, barley, and wheat; and to compare these designs to standard row rows and drill strips in the same experiment one each for oats, barley, and wheat.

CHAPTER II

LITERATURE REVIEW

Plot sizes used by researchers have varied greatly through the years. In 1908 Taylor reported plot sizes ranging from one-fortieth of an acre for hemp (*Cannabis sativa* L.) to 2 acres for cotton (*Gossypium hirsutum* L.) with plots of one-tenth and one-twentieth of an acre most common (23). He recommended one-tenth of an acre as the minimum plot size. Wianco et al. (25) found in a 1918 survey that most agronomists used plots less than one-tenth of an acre but greater than one-eightieth of an acre for small grains. They recommended that field plots should not be smaller than one-eightieth nor larger than one-twentieth of an acre (24). Frey reported that rod row plots are now used by cereal breeders in the United States to the near exclusion of all other plot types at all stages of the testing program (4). In New Zealand most cereal evaluation trials are done with large plots sown with commercial drills (5).

The rod row technique for evaluating small grains was first proposed by Norton in 1906 (18). The need for border rows was questioned by some (16, 17) but most agreed that border rows on each side of the plot are needed (6, 12, 13, 14). Correlations were used to study the relationship between rod rows and field plots (7, 15). Most correlations were positive and high enough to give confidence in the rod row method. A more drastic reduction in plot size for testing small grains has been the introduction of the hill plot (2).

Bonnett and Bever (2) first suggested the head-hill method for use in small grains. The hills were planted 18 to 20 inches apart with a jab corn planter. The method was used in studies on physiologic races of loose smut of wheat. Winterkill was less in winter wheat grown in head-hills than in head rows. Lodging was easy to judge because lodging of one hill did not affect any others. The head-hill technique was suggested as a means of growing selections at the beginning of a breeding cycle, to determine the reaction of selections and varieties to diseases, and as a means of purifying an old variety or a new selection.

The "funnel method" which originated in Germany was used by Hendriksen (8) in studies on the maintenance of a winter wheat cultivar. Thirty grains of wheat were planted by means of a funnel on the intersections of 60 cm. squares. Replicated yield trials gave good correlations with normal agricultural field trials. Yields of "funnel" plots were somewhat lower than those in normal agricultural practice.

The hill method for small grains was extended to replicated yield trials in the United States by Ross and Miller (20). They compared hill, rod row, and one-fiftieth acre drill plots. Variability in hill plots was found to be higher in yield tests. In comparisons involving hills, five of six yield correlations were significant for spring oats, and four of seven for spring barley. Data on heading, lodging, and test weight were not obtained with enough precision to measure differences among varieties in hills and were deemed of little value. They concluded that hill plots for yield testing have value only as a supplement to present testing methods when large numbers of lines are to be screened, seed supply is low, or land is limited.

Slinkard (21) found in a study with hill and rod row plots of spring barley that cultivar by planting method interactions were significant for most characters measured, but were small in comparison to corresponding cultivar and method variances. High correlations were found between rod row and hill data for heading date, maturity date, 100 kernel weight, percent plump kernels, and percent thin kernels. Hill plots were found to be vulnerable to bird damage.

Jellum, Brown and Seif (9) used early generation bulk lines of spring oat germplasm with extreme diversity to compare hill and rod row plots Fifteen of 24 correlations between hill and rod row plots were significant. Coefficients of variation ranged from 13.1 to 21.8% for hill plots and 8.0 to 12.8% for rod row plots. The authors found that hill plots were satisfactory for recording notes on height and maturity, but not for lodging and they were vulnerable to rodent damage. Hill plots were thought to have value as a supplemental method for early generation testing.

Extensive research with hill plots in spring oats was carried on by Frey (4). He found genetic correlations between rod rows and hill plots for grain yield, plant height, and heading date of .98, .96, and .96, respectively. The coefficient of variation for grain yield of hill plots was from two to five times larger than that of rod rows. There was a sizeable reduction in coefficients of variation for grain yield from increasing the number of hills per plot (especially from 1 to 2 units). Coefficients of variation for plant height, weight per volume, spikelets per panicle, panicles per plant, and weight per 100 seeds were similar for both plot types. The number of hills needed for the same efficiency as three replications of rod rows were calculated as five for grain yield, four for heading date, and two for plant height. Frey concluded that the hill plot method was efficient for early generation testing of small grains, but that final evaluations should be made in rod rows.

Linear hill plots were proposed by Jensen and Robson (10). The linear hill plots were 30.5 cm. long spaced 10 cm apart and had no borders. To give the precision of one replication of a rod row for grain yield for spring oats 2.4 replications of the linear hill plot were needed. A close agreement between the linear hill and rod row methods was observed in the ranking of varieties at the same location. Coefficients of variation for the linear hill plots were larger than those of the rod rows. The authors concluded that the linear hill plot is a useful tool for early testing of cereals and for hybrid wheat testing; and that it is superior to the hill plot.

Competition among spring oat varieties in hill plots was studied by Smith, Kleese and Stuthman (22). Cultivars that were strong competitors yielded more relative to weak competitiors when grown in a single hill plots than in rows or hills bordered by the test genotype. An association between yield and competitior height and maturity suggested the greatest effect of competition would be in tests comprised of divergent plant types. Plant height at maturity and date of heading were not influenced by competition. They concluded intergenotypic competition among hill plots can have a major effect on yield.

Khadr, Kassen and El Khishen (11) compared hill plots and rod rows for 107 F_4 lines of wheat and their parents. They found that coefficients of variation for yield were double for hill plots than with rod rows, whereas, for plant height and seed size they did not differ. Correlations between plot types were highly significant for heading date and seed size but were low for plant height and yield. Heritabilites for all characters agreed closely for both techniques on a per plot basis. It was felt that the number of entries common in the extreme 25% portion by each method justified the use of hill plots for testing large populations.

Hill and rod row plots were compared in durum (*Triticum durum* L.) and common spring wheats by Baker and Leisle (1). Genetic correlations for yield ranged from .81 to .99. Hill plots were from 55.5 to 172.2% as efficient as rod rows. They found that hill plots compared favorably with rod rows in all tests and concluded that hill plots would be useful for genetic studies and early generation selection.

Patanothai, Michel and Simons (19) compared different hill plot designs for evaluating quantitative response to crown rust in spring oats (caused by *Puccinia coronata* Cda.). The different hill plot designs were compared to rod rows. All correlations of plot types were significant at the 5% level for yield and seed weight reductions. They considered a hill plot design with test hills planted in a single block with direct inoculation of test plants as the best for evaluation of response to oat crown rust.

CHAPTER III

MATERIALS AND METHODS

Cumberland oats, Volbar barley and Arthur wheat were used for this study. Cumberland is a short, medium late cultivar of winter oats with good lodging resistance. Volbar is a tall, six-rowed, rough-awned, medium-late winter barley with lodging resistance. Arthur is an early, winter-hardy, soft red winter wheat cultivar with good straw strength.

This study consisted of three experiments one each for oats, barley and wheat with 12 replications of each laid out in a randomized complete block design. The treatments for each experiment consisted of four plot types; hill plot, hill row, rod row equivalent, and drill strip. The hill plot consisted of 9 hills of a 3 × 3 square spaced 30.5 cm. apart. A 3 × 5 block of 15 hills spaced 30.5 cm. apart in all directions comprised the hill row. The rod row equivalent plot contained four rows 2.7 m. long spaced 30.5 cm. apart. Drill strips were six rows 6.7 m. long with 18 cm. spacing between rows.

The experiments were planted at the University of Tennessee, Plant and Soil Science Field Research Laboratory (Knoxville Cotton Farm) on October 21, 1975. They were conducted on a Decatur silt loam soil with 5-12% slopes. Prior to planting 72 kg/ha of 6-12-12 fertilizer was applied with a topdress application of 18 kg/ha of NH_4HO_3 on February 27, 1976. The hill plots and hill rows were planted with a jab corn planter. The rod row equivalent plots were planted with a 4-row cone planter and the drill strip with a 6-row plot drill. Seeding rates were adjusted to 112 kg per hectare for all plot types.

Spring stand, date headed, date ripe, plant height, percent lodging, yield, and 100 kernel weight were obtained for all plots. All data were collected from the center hill of the hill plots, the center three hills of the middle row of hills for the hill rows, the center two rows of the rod row equivalent plots and the entire drill strip. Date headed was taken when the heads had emerged on all plants. Plant height and percent lodging were taken the day of harvest. The barley and wheat were harvested on June 11, 1976, and the oats on June 17, 1976. Hill plots and hill rows were cut by hand and threshed on a Alamco head and plant thresher. The rod row equivalent plots were cut and threshed on a Vogel experimental plot thresher and the drill strips were harvested by combine.

Plot types were compared by coefficients of variation for spring stand, plant height, percent lodging, yield, and 100 kernel weight. Ranges were used to compare the plot types for spring stand, percent lodging, and yield. Data from the three experiments were combined and then all possible correlations between plot types were calculated for date headed, date ripe, plant height, percent lodging, and yield.

Analyses of variance for a randomized complete block design were calculated for spring stand, date headed, date ripe, plant height, percent lodging, yield and 100 kernel weight from each experiment. All tests for significance were performed at the 5% level of probability. Duncan's New Multiple Range Test was used for mean separation of plot types when tests of significance showed differences among plot types. An analysis of variance for experiments combined over crops was run for date headed, date ripe, plant height, percent lodging, yield, and 100 kernel weight. A test for crop by plot type interaction was run for each analysis.

By using the formula of Cochran and Cox (3) for number of replications required for tests of significance it can be seen that for the same level of significance to detect the same true difference the number of replications needed is directly proportional to the standard error of the mean. Relative efficiences of plot types were calculated for spring stand, date headed, date ripe, plant height, percent lodging, yield, and 100 kernel weight. The relative efficiences (R.E.) were calculated using the rod row equivalent as the standard by the following formula:

$$\text{R.E.} = \frac{\text{Standard error of the mean for the rod row equivalent}}{\text{Standard error of the mean for the comparison plot type.}}$$

CHAPTER IV

RESULTS AND DISCUSSION

The hill plot, hill row, rod row equivalent; and drill strip were compared for measurement of various characters by several statistical procedures with oats, barley, and wheat. The characters compared were spring stand, date headed, date ripe, plant height, percent lodging, yield, and 100 kernel weight. The statistics used to compare the plot types were ranges, coefficients of variation, correlations, analyses of variance, Duncan's New Multiple Range Test, and standard errors of the mean. No winterkilling was observed in barley and wheat on any plot type and no lodging was observed with the oat hill plots and hill rows. Therefore, no statistics were calculated in these situations.

Ranges

One way to compare the four plot types is by use of ranges for various characters. Ranges for spring stand and percent lodging of oats and yield of oats, barley and wheat grown on the four plot types are presented in Table 1. The range gives the difference between the largest and smallest value of each plot type for the character.

The magnitude of the range for spring stand of oats decreased as the size of the plot increased. The ranges varied from 0-100% with the hill plots (the smallest plots) to 80-95% with the drill strip (the largest plots). Ranges for spring stand with oats indicate that small hill plots and hill rows have the potential problem of giving quite variable results

Table 1. Ranges for Spring Stand, Percent Lodging, and Yield of Oats, Barley, and Wheat Grown in Four Plot Types.

Crop and Plot Type	Spring Stand	Lodging	Yield
	%	%	(kg/ha)
Oats			
Hill Plot[1]	0-100	-----	863-5383
Hill Row[1]	30-100	-----	861-3706
Rod Row Equivalent	70-100	0-40	2252-3812
Drill Strip	80-95	0-15	2187-3161
Barley[2]			
Hill Plot	--------	0-100	3914-7096
Hill Row	--------	0-100	4348-6588
Rod Row Equivalent	--------	20-100	3833-5175
Drill Strip	--------	20-95	3980-4786
Wheat[2]			
Hill Plot	--------	0-100	2881-5065
Hill Row	--------	0-110	2494-4227
Rod Row Equivalent	--------	0-100	3762-4701
Drill Strip	--------	5-95	3529-4102

[1]No lodging observed for this plot type in this species.

[2]Spring stand 100% for all plots.

as compared to the rod row equivalent and drill strip where there is a need for winterhardiness evaluation. With the hill plot and hill row killing of just a small clump of plants would have quite drastic results on the plot whereas with a drill strip or rod row equivalent it would be barely noticed.

Barley and wheat ranges for lodging decreased with increasing plot size; however, the differences among plot types were small. The largest range was 0-100% and the smallest was 20-95%. These ranges for barley and wheat indicate that the different plot types all have quite a large degree of expression for lodging. However, the hill plots and hill rows did not show as much ability to differentiate lodging resistance due to their "all or none" effect for individual hills.

Yields of oats from hill plots ranged from 863-5383 kg/ha and the drill strip from 2187-3161 kg/ha. The oat hill plots and hill rows had extremely large ranges for yield as compared to the rod row and drill strip which can be explained by the large ranges for spring stand of the hill plots and hill rows. The problem of extremely variable winterkilling with hill plots therefore would affect the evaluation of yield when winterkilling occurred. The small hill plots and hill rows with barley and wheat expressed ranges for yield greater than the rod row equivalent plots and drill strips. The effect of any error is magnified when yield is converted to kg/ha as the size of a plot decreases. Thus, the smaller hill plots and hill rows would be more prone to experimental error where a large part of the plot is used for data collection as with yield.

Coefficients of Variation

By use of coefficients of variation (C.V.) the four plot types can be compared for the amount of variability of each in measuring various characters. Coefficients of variability for spring stand, plant height, percent lodging, yield, and 100 kernel weight are given in Table 2 for oats, barley, and wheat. The coefficient of variation gives a measure of the variance of each plot as a percentage of the mean and gives a more realistic measure of the variability of each plot type than does the range.

The C.V.'s for spring stand with oats grown on hill plots and hill rows were much greater than with the rod row equivalent plots and drill strips. The hill plot had a C.V. of 74.6% while the drill strip C.V. was only 6.3%. The C.V.'s for the oat spring stand with the hill plots and hill rows indicate the weakness of these techniques for evaluating winterhardiness.

The lodging C.V. for oat drill strips was less than half that of the rod row equivalent. The drill strip C.V.'s of barley and wheat were approximately 30% greater than those with rod row equivalent plots. Hill plot C.V.'s were approximately twice that of the rod row equivalent with barley and wheat. While the hill plots and rod row equivalent plots had similar ranges for percent lodging, the C.V.'s give a more accurate expression of the variability of these plot types. This results from the "all or none" expression of lodging with hill plots.

Yield C.V.'s consistently decreased with increasing plot size with all crops. The most drastic expression of this was with oats. The C.V. for the hill plot was 52.3% while that of the drill strip was 12.3%. The C.V.'s for barley and wheat hill plots for yield were 2 and 2.5 times that

Table 2. Coefficients of Variation for Spring Stand, Plant Height, Percent Lodging, Yield and 100 Kernel Weight of Oats, Barley, and Wheat Grown in Four Plot Types.

Crop and Plot Type	Spring Stand	Plant Height	Lodging	Yield	100 Kernel Weight
	%	(cm.)	%	(kg/ha)	(gm.)
Oats					
Hill Plot[1]	74.6	11.3	----	52.3	13.0
Hill Row[1]	32.3	10.5	----	37.4	9.7
Rod Row Equivalent	9.1	5.7	202.9	16.3	6.3
Drill Strip	6.3	8.4	95.5	12.3	3.1
Barley[2]					
Hill Plot	-----	8.0	73.9	18.2	5.9
Hill Row	-----	6.7	64.9	12.4	2.8
Rod Row Equivalent	-----	4.5	35.4	8.3	5.8
Drill Strip	-----	4.4	46.9	6.3	2.9
Wheat[2]					
Hill Plot	-----	4.6	104.5	17.2	5.3
Hill Row	-----	4.7	71.9	15.7	5.4
Rod Row Equivalent	-----	5.3	54.0	6.8	3.9
Drill Strip	-----	3.7	70.3	6.3	5.5

[1]No lodging observed for this plot type in this species.

[2]Spring stand 100% for all plots.

of rod row equivalent plots respectively. The C.V.'s for oats, barley, and wheat hill plots for yield were 1.4, 1.5, and 1.1 times that of hill rows respectively. The great difference between yield C.V.'s of hill plots and hill rows on the one hand and rod row equivalent plots and drill strips on the other with oats can be explained by the extreme variability among hills for spring stand. The greater C.V.'s of hill plots and hill rows with oats, barley, and wheat yields would be expected because of more error associated with changing plot yield to kg/ha with the smaller plots. When a small error is made with a small plot its effect would be greater than the same size error with a larger plot.

The C.V.'s for plant height and 100 kernel weight were relatively low and showed no pattern for all plot types with oats, barley, and wheat. These are characters that are measured on small samples of the plot and hence error caused by small plot size would not have a chance to influence results.

Correlation Coefficients

Correlation coefficients between plot types give a measure of association between those plot types for measuring various characters. Correlation coefficients between plot types at the 0.05 probability level for date headed, date ripe, plant height, percent lodging, and yield are in Tables 3, 4, 5, 6, and 7 respectively for data from oats, barley and wheat combined. These show the degree to which two plot types measure a character similarly.

All correlation coefficients between plot types were significant for date headed and date ripe. They were very high and positive.

Table 3. Correlation Coefficients Between Plot Types for Date Headed on Combined Data from Small Grains.

	Plot Type			
Plot Type	Hill	Hill Row	Rod Row Equivalent	Drill Strip
Hill	1.00*	.95	.93	.93
Hill Row		1.00	.96	.92
Rod Row Equivalent			1.00	.95
Drill Strip				1.00

*All coefficients are significantly different from zero at the 5% level of probability.

Table 4. Correlation Coefficients Between Plot Types for Date Ripe on Combined Data from Small Grains.

	Plot Type			
Plot Type	Hill	Hill Row	Rod Row Equivalent	Drill Strip
Hill	1.00*	.96	.95	.95
Hill Row		1.00	.95	.90
Rod Row Equivalent			1.00	.91
Drill Strip				1.00

*All coefficients are significantly different from zero at the 5% level of probability.

Table 5. Correlation Coefficients Between Plot Types for Plant Height on Combined Data from Small Grains.

	Plot Type			
Plot Type	Hill	Hill Row	Rod Row Equivalent	Drill Strip
Hill	1.00*	.59	.66	.63
Hill Row		1.00	.69	.60
Rod Row Equivalent			1.00	.79
Drill Strip				1.00

*All coefficients are significantly different from zero at the 5% level of probability.

Table 6. Correlation Coefficients Between Plot Types for Percent Lodging on Combined Data from Small Grains.

	Plot Type			
Plot Type	Hill	Hill Row	Rod Row Equivalent	Drill Strip
Hill	1.00*	.78	.82	.81
Hill Row		1.00	.91	.87
Rod Row Equivalent			1.00	.89
Drill Strip				1.00

*All coefficients are different significantly from zero at the 5% level of probability.

Table 7. Correlation Coefficients Between Plot Types for Yield on Combined Data from Small Grains.

	Plot Type			
Plot Type	Hill	Hill Row	Rod Row Equivalent	Drill Strip
Hill	1.00*	.60	.65	.61
Hill Row		1.00	.78	.84
Rod Row Equivalent			1.00	.84
Drill Strip				1.00

*All coefficients are significantly different from zero at the 5% level of probability.

Correlations for date headed ranged from .92 to .96 and from .90 to .96 for date ripe. All correlation coefficients between plot types for plant height were significant and ranged from .59 to .79. Correlation coefficients for percent lodging ranged from .78 to .91. Correlation coefficients between plot types for yield ranged from .60 to .84.

Date headed and date ripe are highly correlated with each other for all plot type comparisons because the size sample they were measured from would not cause much variability in their measurement. The correlations for the other characters were all significant and positive which shows a degree of association between the plot types for evaluating those characters. The correlation coefficients had larger ranges for the characters yield and plant height indicating the correlations between various plot types are not as close with those characters. Yield was measured by increasing sample size as plot size increased. This would result in differences in variability for measurement of yield as plot size varied, which would give a larger range of correlations between plot types. The greater range for correlations between plot types for plant height could possibly be explained by differences in plant spacing of the four plot types.

Analyses of Variance

Analysis of variance was calculated for each crop as a randomized complete block design with plot types as treatments for spring stand, date headed, date ripe, plant height, percent lodging, yield, and 100 kernel weight. F-tests for differences among plot types are given in Table 8 for oats, barley, and wheat. Duncan's New Multiple Range Test

Table 8. Plot Type and Error Mean Squares of Spring Stand, Date Headed, Date Ripe, Plant Height, Percent Lodging, Yield, and 100 Kernel Weight with Oats, Barley, and Wheat.

Crop and Mean Square	Spring Stand	Date Headed	Date Ripe	Plant Height	Lodging	Yield	100 Kernel Weight
	%	Days after April 1	Days after May 1	cm.	%	kg/ha	gm.
Oats							
Plot Type	3940.8*	47.137*	31.409*	98.00	158.84	1709765.9	0.67116*
Error	532.5	5.225	1.859	56.11	65.08	698217.2	0.08511
Barley							
Plot Type	-----	11.278	4.889*	272.16*	1080.13	2288446.3*	0.14038*
Error	-----	4.157	0.813	31.94	523.24	422159.0	0.03252
Wheat							
Plot Type	-----	3.1389	0.1875	41.639*	1142.4*	900795.8*	0.11408*
Error	-----	1.5479	0.7481	6.699	373.6	161288.6	0.02696

*F-test for differences among plot types is significant at the 0.05 level of probability.

was used for mean separation where F-tests indicated differences among plot types at the 0.05 probability level. Means for the various characters are presented for oats, barley and wheat in Tables 9, 10, and 11 respectively. A combined analysis for the three experiments was calculated over crops for the various characters. Tests of significance for crop by plot type interactions were conducted at the 0.05 probability level.

The hill row, rod row, and drill strip measured spring stand higher than the hill plot with oats. The rod row equivalent measured spring stand higher than the hill row. The hills were more susceptible to winterkilling and more erratic in their results. Thus, the measures of experimental error (ranges and C.V.'s) were much greater for hill plots and hill rows than with rod row equivalent plots and drill strips. This casts doubt on the effectiveness of these techniques to differentiate winterhardiness.

Due to the hill plots and hill rows of oats having a significantly smaller spring stand than the rod row equivalent and drill strip, and that their ranges and C.V.'s of spring stand were much greater; individual degree of freedom treatment comparisons for yield were performed using individual error terms for F-tests of significance. This method did not result in any difference among treatments for measurement of yield with the comparisons used (hill plot vs. rod row equivalent; hill row vs. rod row equivalent, and hill plot vs. hill row). Yield for barley was measured the same by the hill plot, hill row, and rod row equivalent. Yield in the hill plot and hill row was higher than in the drill strip.

Table 9. Means for Spring Stand, Date Headed, Date Ripe, Plant Height, Percent Lodging, Yield, and 100 Kernel Weight of Cumberland Oats Grown on Four Plot Types.

Plot Type	Spring Stand	Date Headed	Date Ripe	Plant Height	Lodging	Yield	100 Kernel Weight
	%			(cm)	%	(kg/ha)	(gm)
Hill Plot	55 c*	5-11 a	6-16 a	99**	0**	2949**	3.45 b
Hill Row	74 b	5-9 a	6-15 a	98	0	2320	3.33 b
Rod Row Equivalent	95 a	5-7 b	6-13 b	103	7	3174	3.55 b
Drill Strip	90 ab	5-7 b	6-13 b	103	6	2566	3.88 a

*Numbers followed by the same letter are not significantly different at the 0.05 level of probability using Duncan's New Multiple Range Test.

**F-test for differences among plot types is not significant at the 0.05 level of probability.

Table 10. Means for Date Headed, Date Ripe, Plant Height, Percent Lodging, Yield, and 100 Kernel Weight of Volbar Barley Grown on Four Plot Types.

Plot Type	Date Headed	Date Ripe	Plant Height	Lodging	Yield	100 Kernel
			(cm)	%	(kg/ha)	(gm)
Hill Plot	4-23**	6-4 b*	111 b	67**	5373 a	3.97 a
Hill Row	4-24	6-3 b	113 b	64	5195 a	3.98 a
Rod Row Equivalent	4-22	6-3 b	121 a	83	4814 ab	3.80 b
Drill Strip	5-22	6-5 a	119 a	62	4389 b	3.78 b

*Numbers followed by the same letter are not significantly different at the 0.05 level of probability using Duncan's New Multiple Range Test.

**F-test for differences among plot types is not significant at the 0.05 level of probability.

Table 11. Means for Date Headed, Date Ripe, Plant Height, Percent Lodging, Yield, and 100 Kernel Weight of Arthur Wheat Grown on Four Plot Types.

Plot Type	Date Headed	Date Ripe	Plant Height	Lodging	Yield	100 Kernel
			(cm)	%	(kg/ha)	(gm)
Hill Plot	4-21**	6-6**	105 b*	50 b	3894 b	3.73 a
Hill Row	4-22	6-6	107 a	64 ab	3625 b	3.67 ab
Rod Row Equivalent	4-22	6-6	109 a	69 a	4286 a	3.76 a
Drill Strip	4-22	6-6	108 a	50 b	3861 b	3.54 b

*Numbers followed by the same letter are not significantly different at the 0.05 level of probability using Duncan's New Multiple Range Test.

**F-test for differences among plot types is not significant at the 0.05 level of probability.

The hill plot, hill row, and drill strip measured wheat yields equivalent and lower than the rod row equivalent. The erratic nature of hill plots and hill rows in winterkilling affected the results of the oat yield analysis. Ranges and C.V.'s were much greater for hill plots and hill rows for yield of oats. This high experimental error did not allow any differentiation of yield among plot types with oats. The hill plot and hill row of barley and wheat yielded the same as the rod row equivalent or drill strip which are the standards used in small grain research.

No differences among plot types were observed for date headed for barley and wheat, but the hill plots and hill rows of oats were two or three days later than the rod row equivalent and drill strip. This might have been due to hill plots and hill rows being more susceptible to winterkilling which caused a delay in plant heading. The hill plot and hill row ripened the same time as the rod row equivalent with barley and wheat. The oat hill plots and hill rows ripened later than the rod row equivalent plots and drill strips due to their later heading date.

The hill plots and hill rows were equally effective for measuring lodging as the drill strip with all crops. All plot types measured lodging the same for oats and barley. Thus, hill plots and hill rows compare favorably with the rod row equivalent and drill strip for measurement of lodging.

There were no differences among plot types for plant height of oats. Plant height was less with the hill plot than with the rod row equivalent and drill strip with barley and wheat. This may have been caused by different plant spacing of the plot types.

One hundred kernel weight of oats was greater with the drill strip than the hill plot, hill row, or rod row equivalent. Weight per 100 kernels was higher in the hill plot and hill row than with the rod row equivalent and drill strip with barley. One hundred kernel weight was the same for the hill plot, hill row, and rod row equivalent with wheat but higher than the drill strip. The differences among plot types showed no consistent pattern over the three crops.

Plot by crop interactions were not significant for plant height or lodging but were for date headed, date ripe, yield, and 100 kernel weight. Yield of wheat was lower with the hill plot and hill row than with the rod row equivalent, but all three were the same with oats and barley. The hill plot and drill strip measured yield the same with oats and wheat but different with barley. Date headed was the same with barley and wheat for all plot types but the hill plot and hill row were earlier than the rod row equivalent and drill strip with oats. No differences were measured by plot types for date ripe with wheat. The hill plot and hill row were earlier for date ripe than the drill strip with barley but later with oats. The rod row equivalent and drill strip measured date rip the same with oats but different with barley.

Relative Efficiencies

Relative efficiencies were calculated for all plot types with all crops for the various characters by the formula in Chapter III. Relative efficiencies for the various characters of the four plot types with oats, barley, and wheat are shown in Table 12. The relative efficiencies are a relative measure of the number of replications of the plot type which would

Table 12. Relative Efficiencies of Four Plot Types Compared to the Rod Row for Spring Stand, Date Headed, Date Ripe, Plant Height, Percent Lodging, Yield, and 100 Kernel Weight of Oats, Barley and Wheat.

Plot Type	Spring Stand	Date Headed	Date Ripe	Plant Height	Lodging	Yield	100 Kernel Weight
Oats							
Hill Plot[1]	21.3	43.0	71.9	45.9	----	29.0	43.3
Hill Row[1]	36.3	55.5	81.2	57.9	----	59.5	69.8
Rod Row Equivalent	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Drill Strip	153.3	177.0	115.3	68.3	257.9	163.7	189.7
Barley[2]							
Hill Plot	----	104.4	55.7	63.5	59.3	41.0	95.2
Hill Row	----	125.7	77.5	74.1	70.6	62.4	197.2
Rod Row Equivalent	----	100.0	100.0	100.0	100.0	100.0	100.0
Drill Strip	----	82.5	30.8	108.8	100.9	144.6	204.2
Wheat[2]							
Hill Plot	----	113.5	190.0	118.1	71.4	43.5	74.7
Hill Row	----	128.7	162.0	113.3	81.1	51.2	75.2
Rod Row Equivalent	----	100.0	100.0	100.0	100.0	100.0	100.0
Drill Strip	----	104.6	164.5	143.2	106.0	121.1	75.9

[1]No lodging observed for this plot type in this species.

[2]Spring stand 100% for all plots.

be required to detect the same difference at the same probability level as a certain number of replications of rod row equivalent plots. For example, if a plot type had a relative efficiency of 20% it would take 10 replications of it to equal two replications of rod row equivalent plots, or 20 replications to equal four replications, etc.

The R.E. for spring stand of oats with hill plots and hill rows were 21.3% and 36.3% respectively while the drill strip had one of 153.3%. The hill plot presents the problem of low efficiency as compared to the rod row equivalent for winterhardiness evaluation. The winterkilling with hills causes more erratic results. The small size of a hill gives more chance for greater variation for winterkilling.

Relative efficiencies for date headed with barley and wheat hill plots and hill rows were greater than those of the rod row equivalent. The R.E.'s for date headed of hill plots and hill rows were approximately half that of rod row equivalent plots. Date headed and date ripe for the hill plot and hill row compare favorably with the rod row equivalent and drill strip. The larger R.E.'s for date headed of oat hill plots and hill rows can be accounted for by the variability of spring stand with oats.

Hill plots and hill rows were more efficient than rod row equivalent plots for measuring plant height in wheat. Efficiencies ranged from 45.9 to 74.1% as efficient as rod row equivalent plots with oats and barley. Relative efficiencies of hill plots for 100 kernel weight varied from 43.3% with oats to 95.2% with barley. They varied from 69.8% to 197.2% with hill rows. Lodging was measured with a favorable efficiency with hill plots and hill rows of barley and wheat. One hundred kernel weight and plant height efficiencies were better or favorable when compared to rod row equivalent plots. These would be consistent with expectations for plant height and 100 kernel weight since they are measured on the same size sample for all size plots.

Hill plots and hill rows had R.E.'s for yield of barley and wheat from 41.0 to 62.4%. The R.E.'s of hill plots and hill rows for oats were 29.0% and 59.5% respectively. The erratic results with spring stand for oats adversely affected the efficiency of hill plots and hill rows in evaluating yield. The R.E.'s for yield with barley and wheat are consistent with other measures of variability for yield. The smaller efficiency of hill plots and hill rows would be expected since the effect of any error would be greater as the plot size decreased. This is shown by the greater efficiency of drill strips for yield compared to rod row equivalent plots.

Further Research

A study with several varieties of diverse expression of each crop grown on the plot types would give more information on the plot type performances. The plot types could be compared for each crop in a factorial arrangement of treatments in a randomized complete block design for each crop. Plot types would be one factor and varieties another one. Tests could be performed for differences among plot types and differences among varieties. Variety by plot type interactions could be tested. Duncan's New Multiple Range Test could be used for mean separation by varieties and plot types. This could be used to compare the same variety's performance on the plot types against other varieties. Rankings of the varieties could be compared with the various plot types this way using Duncan's New Multiple Range Test for mean separations. This would also have the advantage of comparing plot types where they occur as treatments within the same experiment as opposed to the current literature where comparisons have been made when the different plot types occurred in different experiments.

CHAPTER V

SUMMARY AND CONCLUSIONS

Winterkilling in oats presented the problem of erratic results for winterhardiness evaluation with hill plots. Percent spring stand with hill plots was significantly lower than that of rod row equivalent plots and drill strips. Hill plots were much more variable than rod rows equivalent plots and drill strips for measurement of spring stand by all measures of variability. The problem of winterkilling affected the yield evaluation to a great extent. Hill plots of oats had much greater variability for yield. The problem of winterkilling in hill plots of oats affected date headed and date ripe evaluations to a lesser extent. Lodging was not different among plot types of oats.

Where winterkilling did not occur (with barley and wheat) hill plots reacted more favorably for yield, date headed, and date ripe evaluation. For all characters, except yield, two replications of hill plots would have been as or more efficient than one replication of rod row equivalent. For yield 2.5 replications of hill plots would have been as or more efficient as one replication of rod row equivalent.

The hill row did not measure any character differently than the hill plot with the single exception of plant height for wheat. It did not have enough advantage over the hill plot in reducing variability to justify its use due to the increased effort involved in seed preparation.

Although conducted at only one location for one year this study raises serious doubts on the feasibility of hill plots for use in winter small grains research when winterkilling occurs and is a factor to be evaluated.

More information would be gained on the relative performance of the plot types by use of several varieties of each crop in a factorial arrangement of treatments in a randomized complete block design for each crop. Plot types would be one factor and varieties another. Rankings could be made by variety and plot type. Rankings of varieties by plot types could be compared using Duncan's New Multiple Range Test for mean separations.

LITERATURE CITED

LITERATURE CITED

1. Baker, R. J., and D. Leisle. 1970. Comparison of hill and rod row plots in common and durum wheats. Crop Sci. 10:591-583.

2. Bonnett, O. T., and W. M. Bever. 1947. Head-hill method of planting head selections of small grains. J. Amer. Soc. Agron 39:442-445.

3. Cochran, W. G., and G. M. Cox. 1964. Experimental Designs. John Wiley & Sons, Inc., New York.

4. Frey, K. J. 1965. The utility of hill plots in oat research. Euphytica 14:196-208.

5. Hall, A. D., and A. R. Wallace. 1975. Suitability of breeder's plots for evaluation of spring barley. N.Z.J. Agric. Res. 18:280-285.

6. Hayes, H. K., and A. C. Arny. 1917. Experiments in field technic in rod row tests. J. Agric. Res. 11:399-419.

7. Hayes, H. K., H. K. Wilson, and E. R. Ausemus. 1932. An experimental study of the rod-row method with spring wheat. J. Amer. Soc. Agron. 24:950-960.

8. Hendriksen, A. J. TH. 1956. The maintenance of the winter wheat variety Alba in the Netherlands. Euphytica 5:1-7.

9. Jellum, M. D., C. M. Brown, and R. D. Seif. 1963. Hill and row plot comparison for yield in oats. Crop. Sci. 3:194-196.

10. Jensen, N. F., and D. S. Robson. 1969. Miniature plots for cereal testing. Crop Sci. 9:288-289.

11. Khadr, F. H., A. A. Kassem, and A. A. El Khishen. 1970. Hill versus row plot for testing wheat lines. Crop Sci. 10:449-450.

12. Kiesselbach, T. A. 1919. Experimental error in field trials. J. Amer. Soc. Agron. 11:236-241.

13. Kiesselbach, T. A. 1919. Plat competition as a source of error in crop tests. J. Amer. Soc. Agron. 11:242-247.

14. Kiesselbach, T. A., R. J. Garber, S. C. Salmon, H. M. Steece, C. A. Mooers, L. J. Stadler, and J. W. White. 1933. Standardization of field experiments. J. Amer. Soc. Agron. 25:803-828.

15. Klages, K. H. W. 1933. The reliability of nursery tests as shown by correlated yields from nursery rows and field plats. J. Amer. Soc. Agron. 25:464-472.

16.. Love, H. H. 1919. The experimental error in field trials. J. Amer. Soc. Agron. 11:212-216.

17. Love, H. H., and W. T. Craig. 1918. Methods used and results obtained in cereal investigations at the Cornell station. J. Amer. Soc. Agron. 10:145-157.

18. Norton, J. B. 1907. Notes on breeding oats. Amer. Breeders Assoc. Rep. 4:280-285.

19. Patanothai, S., L. J. Michel, and M. D. Simons. 1975. Comparison of hill-plot designs for evaluating quantitative response to oat crown rust. Crop. Sci. 15:803-806.

20. Ross, W. M., and J. D. Miller. 1955. A comparison of hill and conventional yield tests using oats and spring barley. Agron. J. 47:253-255.

21. Slinkard, A. E. 1957. The relationships in two barley crosses between F_2 plants and their progrenies grown in hills. Ph.D. Thesis. Univ. Minnesota (Libr. Congr. Card No. Mic. 58-1141). Univ. Microfilms. Ann Arbor, Mich. (Diss. Abstr. 18:1200-1201).

22. Smith, O. D., R. A. Kleese, and D. D. Stuthman. 1970. Competition among oat varieties grown in hill plots. Crop. Sci. 10:381-384.

23. Taylor, F. W. 1908. The size of experimental plots for field crops. Proc. Amer. Soc. Agron. 1:56-58.

24. Wiancko, A. P., S. C. Salmon, and A. C. Arny. 1921. Report of the committee on standardization of field experiments. J. Amer. Soc. Agron. 13:368-374.

25. Wiancko, A. P., S. C. Salmon, and F. S. Harris. 1918. Report of the committee on standardization of field experiments. J. Amer. Soc. Agron. 10:345-354.

VITA

Larry Douglas Robertson was born on January 11, 1952, in Knoxville, Tennessee. He is the son of Mr. and Mrs. Bill O. Robertson of Midland, Michigan. He graduated from Lincoln East High School, Lincoln, Nebraska, in July, 1970. He attended Central Michigan University where he received his Bachelor of Science Degree in Biology in May, 1973. His Master of Science program in Plant Breeding was begun in September, 1974, at the University of Tennessee, Knoxville. He plans to receive said degree in August, 1976.

He is a member of Phi Theta Kappa, the American Society of Agronomy, and the Crop Science Society of America. He plans to begin work toward the Doctor of Philosophy degree in September, 1976, at Iowa State University on a Predoctoral Research Associateship with the Agronomy Department.