VARIABILITY AND BIAS IN WHEAT GRAIN YIELDS DERIVED FROM PLOTS OF DIFFERENT WIDTHS AND LENGTHS

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ABSTRACT

The variability and bias in harvested wheat grain yields derived from plots of differing dimensions were investigated over two years. In field experiments with plotlets of width 3, 5, 7 and 9 drill-rows, and length 5, 10, 20 and 40 m, the basic experimental unit was a group of four adjacent identical plotlets. 'Variability' was defined as the variance within each group of four plotlets.

Where harvesting was done with an International F8-63 header mean grain yield and variability declined as either plotlet width or plotlet length increased. With a Wintersteiger header, results for plotlet width were similar to those obtained with the International F8-63 but for plotlet length, results differed.

INTRODUCTION

In New Zealand standard procedures for field experimentation with wheat and other small grain cereals were developed in the mid 20's (Hudson, 1926). Standard plots had seven 18 cm spaced drill rows and were 60 m long. Adjacent rows of neighbouring plots were separated by a 36 cm gap to make plot identification and harvesting easy.

In the 50's experimental procedures were reviewed and field studies carried out (Miller, 1954; Miller and Mountier, 1955). The inflationary effect of the vigorous outside rows on plot yields was documented, but no changes in procedure resulted.

In the early 70's Hall and Wallace (1975) carried out further field studies, comparing 3 row breeders' plots with the traditional 7 row drill strips. They found that the variability of the breeders' plots was considerably greater than that of the drillstrips. This meant that in terms of the area of land required to obtain a given level of precision, breeders' plots were no better than drillstrips.

The work reported in this paper is a continuation of the work on width of plot and extends also to an investigation of length of plot.

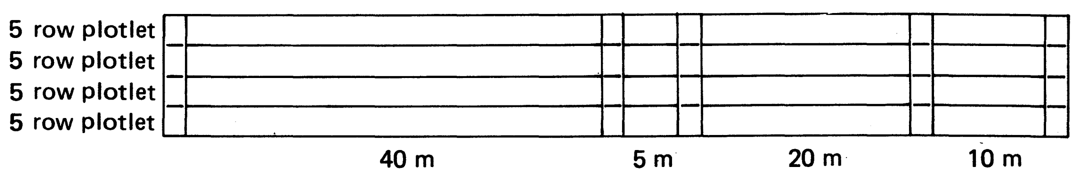
MATERIALS AND METHODS

Two field experiments were sown in June 1977 and a third in June 1978 using Kopara wheat at about 120 kg/ha, on deep fertile soils in the Methven district. The first and third experiments were on sites which had been continuously cropped for the previous five years. The second was on a site which had been in pasture for at least four years.

Each experiment consisted of 256 harvest areas, arranged in 64 "plots" each consisting of four drillstrips of a common width and length. Four such "plots" are shown in Fig. 1. Design was a splitplot, with plot width as the mainplot factor and plot length as the subplot factor. Plot widths were 3, 5, 7 and 9 drillrows, plot lengths were 5, 10, 20 and 40m. There were four replicates, with mainplots arranged in randomised blocks.

Sowing was done in groups of four 85m long drillstrips of width either 3, 5, 7, or 9 drillrows. Drill rows were 18cm apart and drillstrips were separated by 36cm. Immediately prior to harvest drillstrips were subdivided into the appropriate lengths by cutting out 2m strips by hand (Fig. 1). In the first experiment these hand samples were individually bagged and threshed.

Figure 1: A typical mainplot



Harvesting was with an International F8-63 header. In the third experiment a Wintersteiger header was also used, on two of the four replicates. All plots were headed in the same direction. With the F8-63 header it was necessary to let the machine stand for two minutes at the end of each harvest area. By this time the grain flow was down to a trickle. With the Wintersteiger header this prolonged wait was not necessary.

Statistical analyses were carried out using 64 data points, one from each "plot". Each "plot" consisted of four identical harvest areas (Fig. 1), and actually simulated a trial with plots of a particular width and length laid out in blocks of four.

Three variables were statistically analysed. The first variable was the mean of the four grain yields (kg/ha) from each "plot". The second variable was the standard error of the four grain yields from each "plot". The third variable was the (standard error) $\sqrt{n}$, where n was the number of plots of the given width and length which would fit into an area of $500m^2$. This last variable gives the precision for trials of a particular plot size given that trials must fit into a given area of land. The variable is the s.e. (mean) for a treatment mean from a trial of the particular plot size, assuming that each treatment occupies a standard area, taken to be $500m^2$. This is clarified by the examples given in Table 1.

Data from the individual row sampling in experiment one were bulked for each row within each main plot by averaging over the five 2m lengths and over the four drillstrips (Fig. 1). To find out whether outside rows were more variable than other rows, statistical analyses were performed on outside and other rows separately. The analysis for the outside rows was performed as four replicates of eight "treatments" = 2 outside rows × 4 widths in a randomised block design, and for the other rows using sixteen treatments.

TABLE 1: Calculation of variables in typical "plots".

(a) Small "plot", size 3 rows x 5m

e.g. basic data: 2.0, 1.4, 1.7, 1.5 kg
Area = 3 x 18 cm x 5 m = 2.7 sq.m.
Yields in kg/ha: 7407, 5185, 6296, 5556
Mean = 6111 kg/ha
Standard error = 980 kg/ha
S.e. (mean) = $980/\sqrt{185}$ = 72 kg/ha,
since 185 plots fit into 500 sq.m.

(b) Large "plot", size 9 rows x 40m

e.g. basic data: 34.7, 36.8, 35.4, 35.9 kg
Area = 9 x 18 cm x 40 m = 64.8 sq.m.
Yields in kg/ha: 5355, 5679, 5463, 5540
Mean = 5509 kg/ha
Standard error = 136 kg/ha
S.e. (mean) = $136/\sqrt{7.7}$ = 49 kg/ha,
since 7 or 8 plots fit into 500 sq.m.

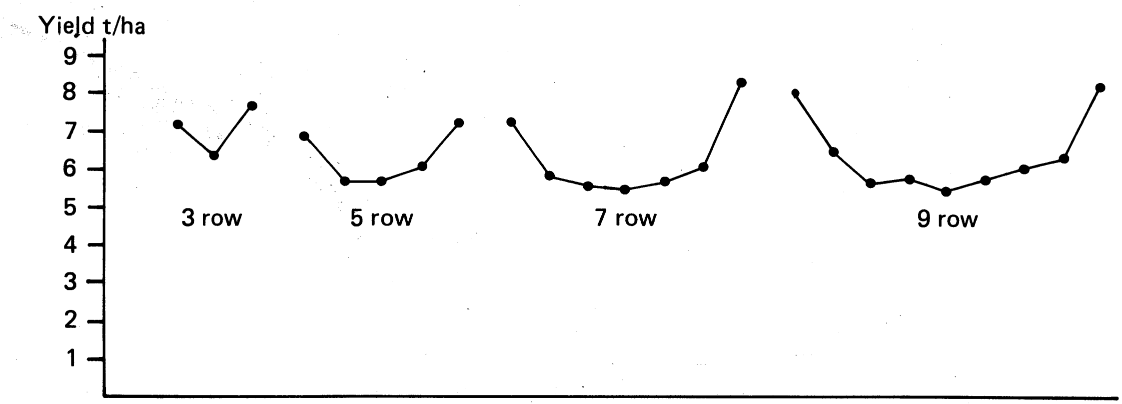
RESULTS AND DISCUSSION

The second trial in the series was in a paddock which had been in pasture, and was severely damaged by grassgrub *Costelytra zealandica* White. Damage was in the form of scattered circular patches on which the crop failed to establish. The first and third trials were not affected by pests or diseases.

Outside row effects:

Outside rows were reported by Miller and Mountier (1955) and Hall and Wallace (1975), to have higher yield and variability than other rows. This was confirmed directly in the first experiment by handsampling (Fig. 2). The s.e. (mean) from the analysis of outside rows was 415 kg/ha, as against 208 kg/ha for the other rows.

Fig. 2: Grain yield (t/ha) handsampled from individual rows.



Width main effects:

Main effects for plot width from the statistical analyses are given in Table 2. Yields were expected to decline with increasing width of plot as the inflationary effect of the outside rows became more and more diluted. The experimental data was in accordance with this expectation (Table 2 (a)).

Standard errors similarly were expected to decline with increasing width of plot, as found in the experiments (Table 2 (b)). Reasons for expecting this result were as follows:-

(i) The extra variability in the outside row yields is progressively diluted as plot width increases.

(ii) The plot yields are obtained from larger areas and hence are inherently less variable.

(iii) Weighing to the nearest tenth of a kilogram and then scaling to kg/ha adds variation which declines in magnitude as plot area increases.

Standard errors of the mean for $500m^2$ land area per treatment were no lower with the narrow plots than with the wider plots (Table 2(c)). That is, a few wide plots give as good a result as a greater number of narrow plots occupying the same area of land. This result is in accordance with the work of Hall and Wallace (1975).

TABLE 2: Width of plot main effects, International F8-63 harvester

(a) Mean grain yield (kg/ha)

	Trial 1	Trial 2 damaged	Trial 3	Average (1 & 3)
3 rows	7210	3040	5460	6340
5	6770	3650	5500	6130
7	6800	2760	5440	6120
9	6620	3010	4630	5620
se (mean)	176	215	202	
Linear trend	*	ns	ns	

(b) Standard error of grain yields (kg/ha)

	Trial 1	Trial 2 damaged	Trial 3	Average (1 & 3)
3 rows	1070	1060	520	800
5	460	680	370	420
7	350	530	370	360
9	350	310	280	320
se (mean)	118	226	138	
Linear trend:	**	*	ns	

(c) S.e. (mean) for trial of constant area ($500m^2$/treatment)

	Trial 1	Trial 2 damaged	Trial 3	Average (1 & 3)
3 rows	123	133	57	90
5	59	112	60	60
7	56	100	67	61
9	67	68	54	61
se (mean)	17.5	37.0	19.8	
Linear trend:	*	ns	ns	

Note: Spacings for the linear trend analyses were:
(a) 1/3, 1/5, 1/7, 1/9 checking for outside row effect.
(b) $1/\sqrt{3}$, $1/\sqrt{5}$, $1/\sqrt{7}$, $1/\sqrt{9}$ checking for an inverse relationship to plot area.
(c) 3,5,7,9 (no theory)

TABLE 3: Length of plot main effects, International F8-63 harvester

(a) Mean grain yield (kg/ha)

	Trial 1	Trial 2 damaged	Trial 3	Average (1 & 3)
5m	7250	3510	5750	6500
10	6860	3310	5370	6120
20	6690	2900	5290	5990
40	6610	2740	4620	5610
se (mean)	206	183	328	
Linear trend:	*	**	ns	

(b) Standard error of grain yields (kg/ha)

	Trial 1	Trial 2 damaged	Trial 3	Average (1 & 3)
5m	890	680	610	750
10	650	800	350	500
20	450	560	340	400
40	240	540	230	240
se (mean)	130	99	106	
Linear trend:	**	ns	*	

(c) S.e. (mean) for trial of constant area (500 m^2/treatment)

	Trial 1	Trial 2 damaged	Trial 3	Average (1 & 3)
5m	83	65	59	71
10	78	103	49	63
20	83	104	64	74
40	61	142	66	63
se (mean)	15.4	18.8	15.0	
Linear trend:	ns	**	ns	

Note: Spacings for the linear trend analyses were:
(a) 1/5, 1/10, 1/20, 1/40 checking for constant bias in bag weight.
(b) $1/\sqrt{5}$, $1/\sqrt{10}$, $1/\sqrt{20}$, $1/\sqrt{40}$ checking for an inverse relationship to plot area.
(c) 5, 10, 20, 40 (no theory).

Length main effects:

Main effects for plot length from the statistical analyses are given in Table 3.

Yields declined with increasing plot length (Table 3 (a)). The data suggest that a constant had been added to the weight of each bag, with the constant being scaled up by different amounts in the conversion to kg/ha (for example, a 0.5 kg bias is a 25% bias in a 2.0 kg bag, but only a 2.5% bias in a 20 kg bag). An obvious explanation is that the scales were in error by a constant amount. However, this was not the case. Another possible explanation is that grain lodged in the F8-63 header and that more was released during the harvest of short lengths than of long lengths.

Standard errors also declined with increasing plot length (Table 3 (b)). The decline was substantial enough for short plots to have no advantage over long plots in terms of precision for a given area of land (Table 3 (c)).

Width by length of plot interactions:

The statistical analyses, the main effects of which have been presented, used the very simplest of mathematical models, and can be criticised on several counts. For this reason, and for completeness of presentation, it is necessary to give some information on the interaction between width of plot and length of plot. This is done by presenting the interaction tables for "mean" and "standard error", averaged over trials 1 and 3 (Table 4).

TABLE 4: Width of plot by length of plot interaction tables, F8-63 machine, averaged over trials 1 and 3.

(a) Mean yield (kg/ha)

	3 row	5	7	9
5m	6920	6200	6340	5880
10	6640	6170	5860	5880
20	6910	6370	5650	5570
40	5520	5740	6110	5130

(b) Standard error of yields (kg/ha)

	3 row	5	7	9
5m	1240	860	700	380
10	570	520	390	200
20	700	280	210	240
40	490	350	280	130

Wintersteiger harvester:

For plot width, the results obtained with the Wintersteiger harvester were very similar to those obtained with the International F8-63 harvester (Table 5 (i)).

For plot length results were quite different (Table 5 (ii)). With the Wintersteiger harvester yields increased with increasing plotlength, standard errors remained constant, and standard errors of the mean increased.

The increase in yield with increasing plot length was inexplicable because the Wintersteiger is a selfcleaning machine specifically designed for experimental work. However, it was further evidence to suggest that a constant bias in the scales was not the explanation for the reverse trend in the F8-63 yield data.

The constancy of the standard errors with increasing plot length was not surprising, since the Wintersteiger harvester was expected to do a better job of harvesting the plots than the older F8-63 machine. It is interesting that for all plot lengths the Wintersteiger standard errors were as low as the best of the F8-63 standard errors, achieved with a 40m long plot. This suggests the high standard errors of the 5m plots harvested with the F8-63 were attributable more to the harvester than to variation in the ground or variation due to rounding and scaling of data.

TABLE 5: Wintersteiger harvester results, trial 3

(i) Main effect of plot width

	Mean grain yield	Std error of yields	S.e. (mean) for 500m²/treatment
3 row	5830	390	52
5	6030	200	29
7	5170	230	47
9	5200	180	45
se (mean)	142	67	10.8
Linear trend:	*	ns	ns

(ii) Main effect of plot length

	Mean grain yield	Std error of yields	S.e. (mean) for 500m²/treatment
5m	5020	230	22
10	5310	290	38
20	6010	260	49
40	5900	240	65
se (mean)	142	57	10.4
Linear trend:	**	ns	*

The decline with increasing plot length in the standard error of the mean for 500m² land area per treatment means that with the Wintersteiger machine short plots may be more economical than long plots.

It should be reiterated that the comparison between machines was only done in the last experiment and that the differences in trend between machines were not statistically significant for the variables standard error and standard error of the mean.

CONCLUSIONS

The following statements apply only to trials in which a uniform gap is left between adjoining plots, and in which the entire plots are harvested for yield:

1. Narrow plots are no more economical in trial area required to obtain a given level of precision, than are wide plots. Also, grain yields from narrow plots suffer a proportionately higher bias from the effect of the outside rows than do wider plots. Therefore the use of wide plots is recommended.
2. The results for plot length are not so clearcut, and vary with type of harvester.

With the F8-63 harvester, long plots are just as economical in terms of variability per unit area, as are short plots. Furthermore, grain yields from the short plots appear to be biassed upwards. Therefore long plots are recommended over short plots for trials harvested with an F8-63 machine.

With the Wintersteiger harvester, results are tentative in that they are based on only one trial. In terms of variability per unit area, the 40 m long plots were inferior to the shorter plots. However, grain yields from the 5 and 10 m plots appeared to be biassed downwards. This leaves 20 m appearing the most satisfactory plot length for trials harvested with a Wintersteiger machine.

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