SIZE OF PLOT AND NUMBER OF REPLICATIONS NECESSARY FOR VARIETAL TRIALS WITH WHITE PEA BEANS.

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THESIS

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Many experiments have been conducted with different field crops to determine what size of plot and how many replications are necessary to give reliable results. Economical administration of funds requires that the plots be small and repeated a minimum number of times. However, efficient plot technique requires that the plots be of sufficient size and repeated often enough to make the results reliable. That information obtained for one crop under certain conditions can not be applied to another is clearly shown by articles on the subject. A complete bibliography (1) of articles dealing with plot technique in general was reported by a committee of the American Society of Agronomy, for the standardization of field experiments. Additional articles (2) were recently reported. A search of this literature fails to reveal any experiments of this nature with white pea beans (Phaseolus vulgaris, L.). Odland and Garber (4) in their work with soybeans, which comes nearest to this particular subject, concluded that under conditions existing where their experiment was conducted, a 16-foot plot one row wide replicated three times was the most satisfactory when both accuracy, and economy of land and of labor were taken into consideration.

The object of the study reported in this paper was to find the proper size of plot and the number of replications of this size necessary for varietal trials with white pea beans when the trials are conducted under conditions similar to those prevailing in this experiment. Due consideration should be given to the amount of land to be used and to the convenience of handling the plots in all field operations.

MATERIAL AND METHODS

The Robust variety of white pea beans is used as a standard of comparison in variety trials at the Michigan Agricultural Experiment Station and is grown extensively throughout the state. Consequently, it was used in this experiment. An area of Conover soil of approximately one and three-quarters' acres, located in one of the regular plant-breeding sections, was chosen for the planting. The beans were planted in rows twenty-eight inches apart on June 15, 1932, and so spaced that the plants were approximately one to two inches apart. To insure a good stand sixty pounds of beans were planted to the acre instead of the usual rate of forty-five pounds. After the last cultivation, an area 210 feet long and 210 feet wide was chosen from the center of the field for the experiment. A total of 1890 plots was obtained by dividing this area into twenty-one ten-foot series, each ninety rows wide. A count of the number of plants in each ten-foot plot was made shortly before harvest. At maturity the plants were pulled by hand and allowed to cure. The ten-foot plots were threshed and the beans air dried in a warm room before weighing. Fortunately, the season was favorable for beans and all plots had a good stand without any skips although a fairly wide range in the number of plants per row occurred. The coefficient of correlation between stand and yield was found to be $.10 \pm .01$. This coefficient was too small to make any correction in the yields for variations in stand.

The statistical constants used to study the problem were obtained by making use of the "analysis of variance" as used by Immer (3). The principles of the method as stated by Immer are:

> If the total variability of the observations on all the plots is given in suitable term (sum of squares) it may legitimately be apportioned to various known causes, leaving a remaining portion ascribable to uncontrolled or unknown causes. The latter will then serve as a basis for the calculation of the error of the experiment. The variance (standard deviation squared) due to any of the known causes or to the uncontrolled or unknown causes may then be found by dividing the sum of squares by the appropriate number of degrees of freedom. The term "degrees of freedom" is here used in the sense of "independent comparisons". With N quantities whose mean is fixed, there are in general N-1 independent comparisons or degrees of freedom.

The assumption was made that five varieties or treatments were to be tested by the analysis and that the arrangement of the plots within each replication was at random. Thus, variation between blocks could be removed legitimately from the total variation, by subtracting the sum of squares due to variation between blocks from the total sum of squares of all of the plots. The remainder is due to variation within blocks. The standard error, calculated from this remainder, was used as the error of the experiment. This error will be smaller than the standard error as calculated from the total population only when the variation between blocks is greater than that within blocks.

Example of Analysis of Variance for Entire Plot

An example of the analysis of variance as applied to yields of the 1,890 plots ten feet long and one row wide is given in Table 1.

TABLE 1 - Analysis of Variance of Yield of Beans in Plots Ten Feet Long, One Row Wide, for 21 Series.

Variation	Degrees of Freedom	Sum of Squares	Variance or Mean Square	Standard Deviation	F*	Error in % of Mean Yield
Between blocks	377	6,967,077.18	19,678.48	140.28		
Within blocks	1512	4,879,158.20	3,226.96	56.80	6.10	12.67
Total between plots	1889	11,846,235.38	6,271.16	79.20		

Mean (M) = 448.38

*The ratio of the larger mean square to the smaller.

The formula used to obtain the total sum of squares was $S(X^2) - S(X)M_x$ where X represents a variate and M_x the mean of the population. This formula is briefed to $S(X^2) - C$, where C (correction) represents $S(X)M_x$. The formula for the sum of squares between blocks was $\frac{S(B^2)}{5} - C$ in which B was the sum of the five plots in a block and C was the correction term $S(X)M_x$. The sum of B^2 was divided by 5 to place the value on a single plot basis.

The total sum of squares 11,846,235.38 was obtained by subtracting C or 379,966,062.62 from $S(X^2)$ or 391,812,298.00. The sum of squares between the 378 blocks of the five adjacent plots added sidewise of the series was obtained in a similar way except the summation was divided by five, to place values on the basis of a single plot, before subtracting the correction factors. Thus $\frac{S(B^2)}{5} - C$ became $\frac{1,934,665,699.00}{5} - 379,966,062.62$ which gave 6,967,077.18. The sum of squares due to variation within blocks was the difference between the total sum of squares and that portion due to variation between blocks. Since the total of 1890 plots was considered, there were 1889 (N-1) degrees of freedom attributable to the total sum of squares. There were 378 blocks (of five plots each) and consequently 377 (N-1) degrees of freedom due to blocks. The difference of 1512 was the number of degrees of freedom due to variation between the five plots within each of the 378 blocks. Each sum of squares was divided by its respective number of degrees of freedom to give the mean square. The standard error is the square root of the mean square, and, calculated from the remainder was 56.80 grams or 12.67 per cent of the mean yield of 448.38 grams.

The significance of the difference between the variance between blocks and that within blocks was determined by the F-test developed by Snedecor (5). The values of F in these tables are given for two different levels of significance, the five per cent and the one per cent points for selected numbers of degrees of freedom. The former is expected to be exceeded in random sampling from a homogeneous population five times in one hundred trials, the latter only once. The five per cent point is taken as a convenient minimum level of significance. In Table 1 the observed value of F exceeds the one per cent point and it can be concluded that removal of the variation between blocks was worthwhile.

Example of Analysis of Variance for Center Rows of Plot

The standard error of a three-row plot was determined, with the outer rows discarded to eliminate possible competition from other plots. The center values were used from each three-row plot. The analysis of variance is given in Table 2.

TABLE 2 - Analysis of Variance of Yield of Beans in Three-Row Plots, Ten Feet Long, of which only the Center Row was Used, for Twenty-one Series.

Variation	Degrees of Freedom	Sum of Squares	Variance or Mean Square	Standard Deviation	F	Error in % of Mean Yield
Between blocks	125	2,277,829.65	18,222.64	134.99		
Within blocks	504	1,887,275.60	3,744.59	61.19	4.87	13.40
Total between plots	629	4,165,105.25	6,707.64	81.90		

M = 456.73

The number of degrees of freedom attributable to total variation was 629, since there were 630 three-row plots in the entire field of 1890 single rows, ten feet long. Each block of five then required fifteen rows. The 630 three-row plots subdivided into blocks of five contributed 125 degrees of freedom, leaving 504 degrees of freedom attributable to variation between plots within blocks.

The observed value of F exceeded the one per cent point and it was concluded that the removal of the variation between blocks was worthwhile.

The standard error of a single plot was 61.19 grams or 13.40 per cent of the mean yield (456.73 grams) of all the central rows in the three-row plots in the field.

RESULTS AND DISCUSSION

The weights in grams of cleaned beans for the 1890 plots are given in Table 3. Analyses were made of the fields of plots 1, 2, 3, 4, 5, 6, 9 and 18 rows wide and 10, 20, 30, 40 and 50 feet in length, respectively. A total of 108 different sizes and shapes of plots were studied, 72 of these involved the entire plot while the other 36 used only the center rows, the outside or border rows being discarded to eliminate competition between plots. Certain of these combinations could not be based on the entire area of 21 series and 90 rows wide. This was partially due to the original assumption involving five varieties or treatments. The four-row and five-row plots could not use all 90 rows because 90 is not divisible by four, nor could the 18 plots five rows wide be subdivided into blocks containing five plots each. Also, 21 series could not be subdivided into plots 20, 40, or 50 feet in length, but could be divided into plots 30 feet in length. To overcome these limitations, values were calculated for areas 21 and 20 series in length containing 90, 80, and 75 rows in width. In order to compare the values obtained with plots four and five rows wide with those 1, 2, 3, 6, 9, and 18 rows wide, the standard errors were also calculated for the areas 21 and 20 series long, and 80 and 75 rows wide, respectively. The same conditions hold true for the plots having the border rows discarded. Similar calculations were made whenever necessary.

TABLE 3 - Yield of Beans in grams from 1890 Single-Row Plots, Each Ten Feet Long.

Series ↓ / Plot Number →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
	361	334	343	373	433	468	365	467	430	446	474	470	384	438	407	312	304	390	370	382	3.
	353	465	502	376	500	468	387	490	600	347	488	482	510	425	435	435	438	425	602	557	531
3	330	340	416	438	450	527	333	485	530	450	538	605	487	440	410	440	386	433	516	430	582
4	381	398	540	430	520	417	467	481	533	511	470	590	555	418	614	570	270	348	470	467	600
5	418	225	538	430	450	480	490	530	465	505	473	602	545	485	520	415	416	440	360	515	540
6	412	405	455	443	498	438	381	480	462	404	520	550	626	433	516	320	413	381	425	315	465
7	370	367	476	470	470	520	440	456	440	545	585	562	670	478	516	495	417	460	435	460	430
8	305	351	605	435	465	556	465	440	557	457	504	586	491	460	551	395	295	528	457	420	502
9	373	425	518	484	535	488	440	506	590	415	438	510	542	425	431	465	410	475	435	560	550
10	334	387	613	490	575	532	472	530	490	482	432	444	490	424	528	450	425	402	482	446	488
11	385	400	619	564	550	480	480	481	519	376	480	498	460	405	525	453	455	475	461	557	530
12	390	415	590	567	617	612	430	465	415	432	535	522	432	421	535	437	486	448	483	509	485
13	381	378	565	488	588	457	492	486	450	364	554	426	410	420	485	468	419	423	575	570	550
14	456	482	546	482	535	500	450	471	485	477	523	494	512	431	600	535	462	536	552	560	556
15	420	495	475	448	593	406	516	445	470	370	408	554	445	440	440	364	488	530	445	565	525
16	390	473	445	521	479	470	458	515	380	443	565	360	378	460	575	560	323	490	470	470	405
17	402	495	570	455	498	520	518	570	540	432	519	494	414	441	450	415	470	498	495	630	523
18	388	507	431	562	476	432	480	359	515	334	424	524	449	426	548	456	496	437	490	480	415
19	362	523	448	455	478	500	474	425	478	464	474	488	381	400	562	495	307	400	410	435	366
20	360	470	512	457	466	598	443	470	385	464	420	533	480	515	476	558	456	442	535	640	455
21	405	598	441	425	495	437	579	474	432	389	410	431	375	470	545	360	555	518	505	525	445
22	339	483	452	450	465	420	500	505	512	490	540	400	390	360	475	468	450	480	418	440	462
23	398	470	406	452	468	583	507	572	420	526	460	458	473	385	618	474	507	472	525	530	458
24	287	443	451	444	389	612	508	424	573	515	505	394	338	438	577	485	512	550	517	463	400
25	517	445	458	450	530	561	494	585	492	504	486	410	463	448	656	446	620	560	405	385	400
26	467	472	440	510	540	525	484	555	545	475	505	400	374	354	634	488	490	450	557	452	445
27	386	492	449	506	495	512	495	474	645	399	457	399	462	480	425	591	390	490	454	512	400
28	475	445	410	560	450	565	490	556	509	453	513	445	485	520	521	605	485	545	512	415	370
29	450	455	460	519	537	504	425	540	505	534	483	430	505	474	535	612	304	473	376	447	380
30	404	412	412	393	414	540	452	481	460	470	430	460	479	473	621	530	498	506	400	410	414
31	475	435	458	586	525	520	453	500	482	685	430	485	525	450	500	550	485	515	438	497	462
32	392	431	410	572	568	583	530	520	470	625	606	485	505	422	465	565	497	439	445	443	380
33	394	455	412	256	440	535	505	458	570	603	438	465	435	417	512	544	476	480	454	377	444
34	396	440	385	508	660	515	415	521	475	547	555	456	453	380	640	470	435	494	350	365	435
35	390	425	355	420	610	405	558	465	560	556	510	540	419	455	538	520	570	457	470	360	450
36	385	445	340	455	560	510	516	484	505	451	596	475	438	393	430	430	465	430	375	407	417
37	352	360	395	519	548	557	587	600	485	486	505	532	365	455	654	488	488	495	494	396	420
38	388	425	335	414	645	625	518	620	605	475	507	564	638	495	545	590	544	521	562	384	430
39	368	440	410	448	580	600	500	568	390	480	440	608	402	415	517	481	437	563	525	400	403
40	387	485	420	558	575	460	478	492	478	555	445	588	458	405	575	555	690	597	550	495	334
41	336	446	380	488	545	540	645	414	570	472	440	560	557	476	596	590	662	557	562	456	455
42	324	465	421	390	596	630	507	419	390	535	486	457	352	376	572	600	555	468	575	420	452
	423	392	408	482	490	620	492	450	555	476	468	550	385	334	426	557	615	556	507	405	368
	370	490	447	460	645	577	626	445	682	470	526	584	377	432	605	532	466	455	385	364	
	78	413	418	535	609	492	530	362	586	479	530	466	395	640	615	507	458	505	580	4	

TABLE 3 - (continued)

	350	608	390	355	410	565	462	305	605	550	534	385	386	472	445	490	372	402	505	557	
/	348	452	405	587	565	475	546	390	555	487	330	345	373	430	545	505	400	470	447	385	365
48	330	404	325	468	507	660	463	360	440	392	417	465	383	429	502	437	342	420	458	302	437
49	417	386	402	421	614	566	548	350	485	556	450	380	460	400	530	560	425	555	440	371	396
50	510	405	360	550	570	703	375	345	485	580	468	446	402	412	530	515	462	425	360	357	385
51	405	345	370	495	541	567	470	320	382	513	474	503	483	410	563	340	426	446	420	320	298
52	265	411	414	392	548	505	450	420	424	450	415	498	385	466	532	410	324	437	370	350	300
53	461	394	355	510	455	545	410	437	368	445	500	427	435	351	512	466	348	393	356	425	300
54	340	392	315	446	520	391	531	315	440	392	516	360	318	290	448	402	401	385	420	354	328
55	348	445	370	343	580	470	451	343	400	395	395	435	370	318	444	412	305	390	439	366	386
56	364	420	318	422	520	453	487	390	534	410	490	400	419	217	434	375	286	378	395	370	260
57	335	335	314	332	578	437	468	370	435	388	434	450	373	345	415	419	270	303	350	365	315
58	353	392	350	432	500	461	425	425	475	353	365	352	448	366	430	415	387	375	393	500	422
59	375	367	350	405	484	418	384	400	435	384	377	354	265	355	541	450	250	310	377	431	392
60	295	296	377	300	335	430	375	392	473	389	344	440	340	386	455	350	260	373	393	480	440
61	302	330	285	267	434	437	344	365	373	373	306	332	367	290	420	335	240	312	420	400	465
62	252	330	404	570	400	410	345	375	377	411	395	422	325	407	508	430	345	383	613	487	420
63	372	390	394	555	565	400	405	458	368	338	466	442	350	403	440	445	357	354	540	483	350
64	310	450	380	448	340	455	462	335	466	360	334	314	405	481	452	358	374	358	450	362	365
65	341	320	388	490	448	440	399	435	455	364	332	420	365	392	470	426	338	434	426	555	300
66	287	268	425	485	480	444	370	466	590	435	292	332	334	384	405	428	380	436	442	355	352
67	368	332	382	490	456	545	444	567	390	474	358	400	388	344	446	427	274	325	312	386	356
68	310	337	406	524	475	510	560	530	540	522	335	425	517	463	387	415	410	335	340	310	475
69	300	325	358	475	515	432	382	490	458	440	356	440	436	430	455	392	352	226	310	352	453
70	352	354	325	540	405	478	429	420	465	345	425	415	555	503	415	440	410	373	290	400	470
71	375	354	388	482	555	426	468	506	465	418	345	571	437	420	485	430	376	228	260	398	492
72	306	320	432	417	475	512	475	440	436	500	456	438	516	445	564	534	348	337	329	365	555
73	375	387	242	390	458	431	363	455	438	520	509	551	494	485	660	407	404	329	331	487	406
74	355	365	444	348	440	483	419	377	460	530	490	460	525	552	540	473	455	367	294	409	523
75	345	425	395	370	436	556	515	492	525	511	571	523	454	467	575	435	441	319	340	345	531
76	370	420	415	371	377	425	481	415	473	420	595	511	510	509	416	492	468	370	339	385	534
77	414	366	325	400	401	367	416	370	550	425	485	413	515	454	570	470	331	451	374	258	528
78	316	287	311	312	305	364	431	407	483	509	404	408	550	444	525	420	400	372	275	380	464
79	289	286	376	345	400	452	392	366	540	380	533	355	407	452	458	460	485	335	270	276	385
80	335	336	343	325	375	442	351	338	475	533	460	425	435	470	512	490	565	316	528	456	435
81	395	335	336	424	365	532	420	432	520	485	467	388	400	430	610	440	405	408	398	355	428
82	323	394	355	420	405	450	458	443	625	570	548	475	450	375	515	490	490	414	475	350	395
83	400	380	280	460	473	450	530	370	498	565	435	510	405	362	586	500	395	331	371	380	390
84	370	410	260	402	470	525	456	292	565	524	451	435	339	386	610	548	410	412	483	405	290
85	354	390	246	415	534	473	568	475	473	440	390	440	408	468	590	495	365	329	452	404	295
86	365	406	380	344	435	505	449	510	525	438	453	432	485	505	603	532	450	400	375	365	450
87	350	357	357	320	435	573	520	460	562	393	414	439	452	543	635	530	402	376	334	410	475
88	300	278	325	350	375	495	470	545	543	509	451	524	583	462	645	520	445	427	440	350	465
	335	256	348	381	468	474	542	492	445	470	464	495	498	562	627	452	376	420	392	396	407
	387	314	340	395	352	506	574	438	485	330	416	400	387	413	430	480	540	548	535	427	

STANDARD ERRORS IN PER CENT OF MEAN

The standard deviations, as obtained by analysis of variance for the plots of varying lengths and widths, were expressed in percentage of their respective means and are shown in Tables 4 and 5. Before these tables and all subsequent tables can be discussed, it is necessary to determine whether the values obtained for the plots four and five rows wide can be compared with those obtained for other widths. The values are considered to be comparative in this and in all future tables because similar calculations from 1, 2, and 3-row plots for the areas of 80 and 75 rows in width, respectively, are in close agreement with those calculated for the entire area of 90 rows. These values are also shown in Tables 4 and 5.

Considering the entire plots, the standard error in per cent of the mean, decreased as the length of the plot was increased. The greatest reductions come when the plots were increased from 10 to 20 feet in length. Considerable further reduction in percentage error occurs when the plots were increased to 30 feet in length, but when the length of the plot was increased to 40 or 50 feet, further reduction does not compensate for the increase in land used.

Increasing the width of the plot from one row to two rows shows a great reduction in percentage error, compara-

TABLE 4 - Standard Errors of Single Plots in Percentage of the Mean, of Yields of Plots Varying in Size and Shape, when Entire Plot was Used.

Length of Plot in Feet.	Number of Series of Plots Used End to End Across the Field.	Width of Plots in Rows							
		1	2	3	4	5	6	9	18
10	21	*90 12.67	45 9.98	30 9.74			15 10.30	10 9.25	5 9.83
		80 12.94	40 10.03		20 10.18				
		75 12.88		25 9.73		15 8.15			
	20	90 12.11	45 9.93	30 9.71			15 10.25	10 9.13	5 9.75
		80 12.27	40 9.99		20 10.23				
		75 12.25		25 9.73		15 8.93			
20	10	90 9.38	45 7.83	30 8.03			15 9.09	10 7.94	5 8.99
		80 9.43	40 7.82		20 8.73				
		75 9.36		25 7.99		15 7.45			
30	7	90 7.89	45 6.60	30 6.90			15 8.14	10 7.07	5 8.48
		80 7.96	40 6.72		20 7.94				
		75 7.90		25 7.04		15 6.22			
40	5	90 7.28	45 6.51	30 6.63			15 7.75	10 6.18	5 7.92
		80 7.23	40 6.24		20 7.47				
		75 7.20		25 6.62		15 5.72			
50	4	90 6.72	45 5.66	30 6.25			15 7.59	10 6.12	5 7.91
		80 6.78	40 5.81		20 7.20				
		75 6.74		25 6.44		15 5.53			

*Small figures in each compartment of Tables 4 and 5 indicate the number of plots side to side across the field.

TABLE 5 - Standard Errors of Single Plots, in Percentage of the Mean, of Yields of Plots Varying in Size and Shape, when Border Rows were Removed.

Length of Plot in Feet.	Number of Series of Plots Used End to End Across the Field.	Width of Plot in Rows. / Number of Rows Used.	3 / 1	4 / 2	5 / 3	6 / 4	9 / 7
10	21		30* 13.40			15 11.12	10 10.06
				20 12.09			
			25 13.42		15 9.93		
	20		30 13.42			15 11.01	10 9.97
				20 12.09			
			25 13.46		15 9.81		
20	10		30 10.26			15 9.47	10 8.59
				20 9.84			
			25 10.34		15 8.00		
30	7		30 8.67			15 8.36	10 7.61
				20 8.72			
			25 8.77		15 6.63		
40	5		30 8.06			15 8.11	10 6.64
				20 7.73			
			25 8.01		15 6.33		
50	4		30 7.36			15 7.77	10 6.47
				20 7.72			
			25 7.44		15 6.01		

*Small figures in each compartment of Tables 4 and 5 indicate the number of plots side to side across the field.

ble to increasing the length from 10 to 20 feet. Increasing the width of plots to three rows reduces the percentage error slightly while further increases in width change the results but very little.

When the border rows are discarded and only the center rows used in the calculations, the results are similar to those obtained when the entire plot is used. A great reduction in percentage error was noted when the length of plot was increased from 10 to 20 feet and a still further reduction when increased to 30 feet, but very little difference was noted beyond that. Increasing the width of the plot from three rows to four rows resulted in a slight decrease in the percentage error but when the width was increased to five rows a considerable reduction was observed. Increasing the width of the plot to six and nine rows showed very little change one way or the other. The standard error was in all but one case greater than when all the rows of the same sized plots were used in the calculations. Increasing the size of plot to allow for the discarding of the border rows resulted in some increase in the percentage of the standard error in all but three cases where a corresponding number of rows were harvested. This means that there was greater variability between the plots of a block when only the center rows were harvested than when the entire plot of the same number of harvested rows was used.

NUMBER OF REPLICATIONS

The theoretical number of replications required by any given size of plot to reduce to four per cent the standard error of the mean of that number of replications may be obtained by dividing the standard error percentages, as given in Table 4 and Table 5, by four and squaring these quotients. The values thus obtained are given in Tables 6 and 7. The value of four per cent was chosen because normally this is the approximate size of the standard error of nine replications of bean plots at the Michigan Station.

The theoretical number of replications for the entire plot tended to decrease as the length of the plot was increased. The greatest difference in number was observed when the plot was increased from 10 to 20 feet, the number of replications for the 20-foot plots being nearly one-half of that for the 10-foot plot in the two narrowest width plots. There was a further noticeable decrease when the length of the plot is increased from 20 to 30 feet but scarcely any when increased beyond that.

When the width of the plot was increased from one row to two rows there was also a decided decrease in the number of replications required but further increase in the number of rows per plot made very little change in the theo-

TABLE 6 - Theoretical Number of Replications Needed to Reduce the Standard Error of the Mean to Four Per Cent, when Entire Plot was Used.

Length of Plot in Feet.	Number of Series of Plots Used End to End Across the Field.	Width of Plots in Rows							
		1	2	3	4	5	6	9	18
10	21	10.0	6.2	5.9			6.6	5.3	6.0
		10.5	6.3		6.5				
		10.4		5.9		4.2			
	20	9.2	6.2	5.9			6.6	5.2	5.9
		9.5	6.2		6.5				
		9.4		5.9		5.0			
20	10	5.5	3.8	4.0			5.2	3.9	5.0
		5.6	3.8		4.8				
		5.5		4.0		3.5			
30	7	3.9	2.7	3.0			4.1	3.1	4.5
		3.9	2.8		3.9				
		3.9		3.1		2.4			
40	5	3.3	2.6	2.7			3.8	2.4	3.9
		3.3	2.4		3.5				
		3.2		2.7		2.0			
50	4	2.8	2.0	2.4			3.6	2.3	3.9
		2.9	2.1		3.2				
		2.8		2.6		1.9			

TABLE 7 - Theoretical Number of Replications Needed to Reduce the Standard Error of the Mean to Four Per Cent when the Border Rows were Removed.

Length of Plot in Feet.	Number of Series of Plots Used End to End Across the Field.	Width of Plot in Rows.	3	4	5	6	9
		Number of Rows Used.	1	2	3	4	7
10	21		11.2			7.7	6.3
				9.1			
			11.3		6.2		
	20		11.2			7.6	6.2
				9.1			
			11.3		6.0		
20	10		6.6			5.6	4.6
				6.0			
			6.7		4.0		
30	7		4.7			4.4	3.6
				4.8			
			4.8		2.7		
40	5		4.0			4.1	2.8
				3.7			
			4.0		2.5		
50	4		3.4			3.8	2.6
				3.7			
			3.4		2.3		

retical number of replications necessary to reduce the standard error of the mean to four per cent.

Practically the same thing is true when the border rows were discarded and only the center rows used in the calculations. The greatest decrease was noted in the three-row plots when the length of the plot was increased from ten to twenty feet. Increasing the length of the plots to thirty feet tended to reduce the number still more but when increased to forty and fifty feet the reduction in theoretical number of replications was small.

When the two center rows of the four-row plots or the three center rows of the five-row plots were used instead of the center one of the three-row plots, the theoretical number of replications was appreciably decreased, but a further increase in number of rows to six and nine did not reduce the number greatly.

COMPARATIVE LAND EFFICIENCY

Tables 6 and 7 indicate that as the plot was increased in length and, to some extent, in width the number of replications needed to put the standard error to the common basis of four per cent of its mean was reduced. However, the larger plots required more land. To determine, then, which size and shape of plot used the land most effectively the comparative land efficiency values for the 108 sizes and shapes of plots were obtained. It was assumed that a plot ten feet long and one row wide had an efficiency of 100.0 per cent. According to Table 6, a plot ten feet long and two rows wide required 6.2 replications to reduce the standard error of the mean to four per cent. Since the plot was two rows wide, 6.2 was multiplied by two and this product divided into 10.0 (the theoretical number of replications needed for a plot ten feet long and one row wide), then multiplied by 100 to give per cent. Thus

$$\frac{10.0 \times 100}{6.2 \times 2} = 80.6 \text{ per cent.}$$

Values for land efficiency calculated in this way are given in Tables 8 and 9.

It will be noted in Table 8 that when the length of the plot was increased from ten to twenty feet the percentage of land efficiency was materially decreased but when the length of plot was increased from twenty to thirty feet the land efficiency percentage value did not decrease. When the length of plot was increased still further there was a considerable decrease in the percentage of land efficiency. An increase in the number of rows per plot from one to two caused a decrease in percentage of land efficiency. Still further decreases in land efficiency were noted when the number of rows per plot was increased to three, to five and so on to eighteen.

TABLE 8 - Percentage Efficiency in Use of Land of Plots Varying in Size and Shape, when Entire Plot was Used.

Length of Plot in Feet.	Number of Series of Plots Used End to End Across the Field.	Width of Plots in Rows							
		1	2	3	4	5	6	9	18
10	21	100.0	80.5	56.4			25.2	20.8	9.2
		100.0	83.2		40.4				
		100.0		58.4		49.9			
	20	100.0	74.4	51.8			23.2	19.5	8.6
		100.0	75.4		36.0				
		100.0		52.8		37.7			
20	10	83.4	59.7	37.8			14.8	12.9	5.0
		84.6	61.5		24.7				
		85.7		39.2		27.1			
30	7	85.9	61.4	37.4			13.4	11.9	4.1
		88.1	61.9		22.2				
		88.7		37.2		28.9			
40	5	69.1	43.3	27.8			10.2	10.6	3.2
		71.9	48.3		16.8				
		72.4		28.5		22.9			
50	4	64.8	45.8	25.0			8.5	8.7	2.6
		65.5	44.6		14.5				
		66.2		24.1		19.6			

TABLE 9 - Percentage Efficiency in Use of Land of Plots Varying in Size and Shape when the Border Rows were Removed.

Length of Plot in Feet.	Number of Series of Plots Used End to End Across the Field.	Width of Plot in Rows.	3	4	5	6	9
		Number of Rows Used.	1	2	3	4	7
10	21		29.8			21.6	17.6
				28.6			
			30.7		33.6		
	20		27.3			20.2	16.4
				25.7			
			27.6		31.2		
20	10		23.2			13.6	11.0
				19.4			
			23.4		23.5		
30	7		23.7			12.7	10.3
				18.3			
			23.9		25.1		
40	5		18.8			9.3	9.2
				15.2			
			19.5		18.7		
50	4		18.0			8.1	7.8
				12.6			
			18.1		16.6		

In Table 9 are given the comparative land efficiency values for the plots when the border rows were discarded and only the center rows were used. As in Table 8, the shorter plots were the more efficient ones. Unlike the results from the entire plots, it is seen that the land efficiency values for the three center rows of the five-row plots 10-20-and 30-feet long were slightly higher than the efficiency values for the center rows of plots three and four rows wide of similar length.

A comparison of Tables 8 and 9 shows that harvesting the entire plot is more efficient than using only part of the plot and that the differences in efficiency are much greater in the narrower widths of plot.

SUMMARY

Summarizing the results which have been obtained it can be said that for this field of beans:

The standard errors in per cent of their respective means were greater in nearly all cases when only the center rows of a plot were used than when the entire plot was harvested. This was true whether the comparison was between equal numbers of rows harvested or equal numbers of rows per plot.

The standard error in percentage decreased as the area of the plot increased, except as noted in the preceding paragraph. The decreases were consistent with increases in length, but were not entirely consistent with increases in width.

Rather large decreases in magnitude of per cent standard error occurred when the plot length was increased from ten to twenty and on to thirty feet. Comparatively small decreases were found when the plot length was increased beyond thirty feet.

Rather large decreases in magnitude of per cent standard errors were observed as the plot width was increased to two rows but variable results were obtained as the plot width was increased beyond two rows.

On the whole, increasing the size of the plot by increasing its length proved much more effective in reducing the standard error in per cent of its mean than making a similar increase in plot size by increases in width.

The number of replications needed to reduce the standard errors to the same comparable basis of four per cent followed the same trends as did the standard errors. This is not to be wondered at as the number of replications was dependent on the magnitude of the standard error.

An increase in the theoretical number of replications decreases the standard error more rapidly than an equivalent increase in the size of plot. This is especially true when the plot is increased in width.

The comparative land efficiency values bring out, more strongly than the standard errors alone, the greater desirability of harvesting entire plots in comparison to harvesting only the center rows of the plot.

When the entire plot was harvested, plots one row wide and thirty feet long were slightly more efficient than plots the same width and twenty feet long and much more efficient than plots two rows wide and only ten feet long.

Although the comparative land efficiency values indicate that the ten-foot, one-row plots were the most efficient in the use of land, yet there are several other factors not considered under standard error and land efficiency values which must be considered. These are ease of planting, of harvesting, of threshing and subsequent laboratory determinations.

It is much easier, less time consuming, and subject to less mistakes to plant four replications (see Table 6) of plots thirty feet long, one row wide than to plant ten replications of plots ten feet long, one row wide. Harvesting, threshing and other procedure would all be in favor of the larger of these two sizes of plots with their respective numbers of replications.

CONCLUSIONS

The data obtained from 1890 ten-foot plots of white pea beans studied by the variance method indicates that plots thirty feet long and one row wide replicated four times were more efficient in the use of land for the reducing of the standard error in per cent of its mean than all of the other 107 shapes and sizes studied, except the original ultimate units ten feet long and one row wide.

Field operations, such as planting, harvesting and threshing, and subsequent laboratory determinations indicate that the use of the plots thirty feet long, one row wide, which require but four replications is more desirable than that of the more land-efficient but smaller plots, ten feet long, one row wide, which require ten replications.

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