DO MIRACLE PRODUCTS WORK? A $5.50 PER ACRE TREATMENT

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Abstract

Articles containing experimental findings often appear in popular magazines or newspapers summarizing scientific work. Often, lack of understanding and/or employment of statistical rules can result in an oversimplification and misinterpretation of data. The objective of this study was to utilize the results from a series of experiments at which two pennies were randomly thrown on the "treated" plots to illustrate uses and misuses of statistics for the benefit of all those involved in agronomic research. The effect of the "two pennies" was significant in one of the 22 experiments. Statistical rules suggest that it is entirely possible since experiments were indeed designed to examine the effect of "nothing" at a 95 percent probability level. Hence, generalizing findings of one site-year only or averaging data from many site-years with no statistical significance leads to invalid conclusions.

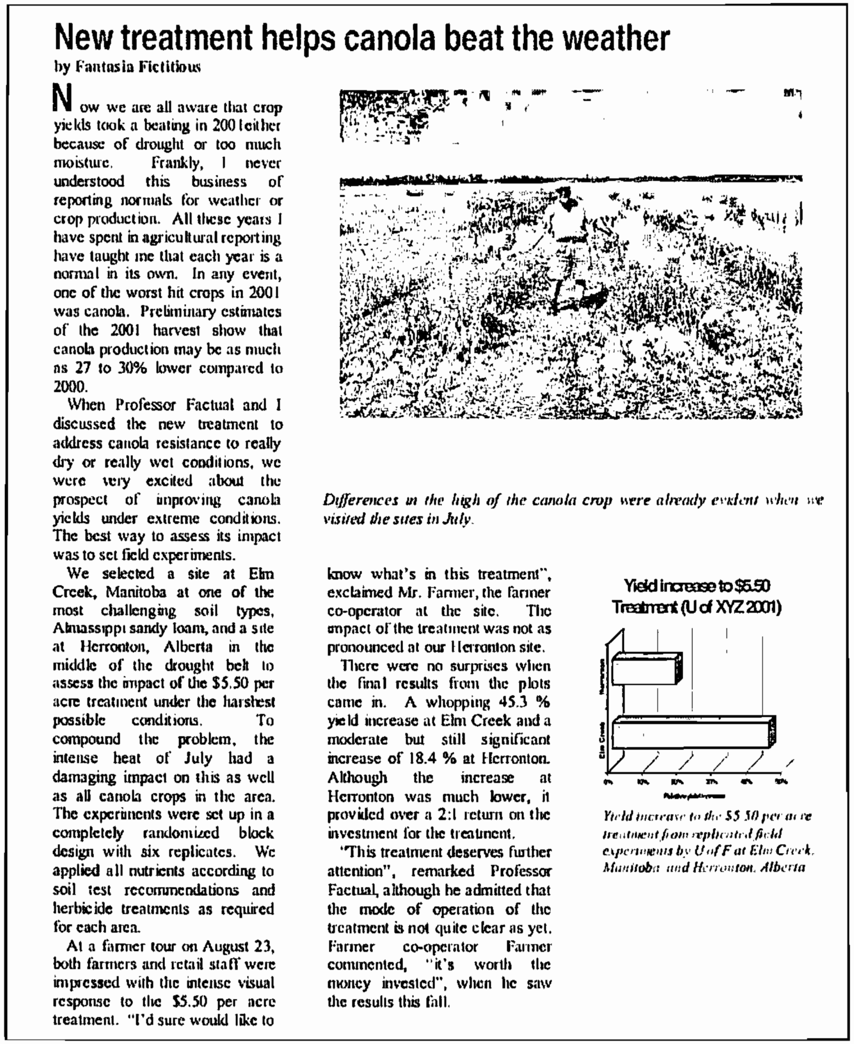
Introduction

Often articles communicating agronomic work in popular terms find their way into farm magazines or newspapers. Often, when results of experimental data are disseminated in popular magazines statistics take a back stage. Granted, the general public has no interest in statistics and inclusion of statistics can be confusing and cause the reader to abandon an otherwise interesting article. However, does this constitute a reason for omitting or misusing statistics? Can omission or misuse of statistical analysis lead to answers and conclusions that may be inconsistent or greatly different from what is apparently so obvious by just looking at the experimental results?

We are providing two examples of such articles that are presented in Figures 1 and 2. Although these two articles in are indeed fictitious stories, they are based on real field data. The articles appear as a credible encounter of a scientifically designed and executed set of experiments. An independent scientist (in this case a professor) is involved, and experimentation has been carried out with apparently a generally accepted and widely understood design. Normally, field experiments are designed to assess the impact of "something" on the yield and characteristics of crops. To illustrate the need for proper statistical treatment and interpretation of data, we designed a study to examined the impact of "nothing" (i.e., the null hypothesis) on the yield of various crops. Miracle products often do provide "nothing" as a treatment, yet they "work".

Approach

Eight experiments with SW Rider and one with Q2 canola (*Brassica napus* L.), five with AC Barrie wheat (*Triticum aestivum* L.), five with Harrington barley (*Hordeum vulgarae* L.) and four with Logan peas (*Pisum sativum* L.) were set in the three Prairie Provinces in 2001.



New treatment helps canola beat the weather

by Fantasia Fictitious

Now we are all aware that crop yields took a beating in 2001either because of drought or too much moisture. Frankly, I never understood this business of reporting normals for weather or crop production. All these years I have spent in agricultural reporting have taught me that each year is a normal in its own. In any event, one of the worst hit crops in 2001 was canola. Preliminary estimates of the 2001 harvest show that canola production may be as much as 27 to 30% lower compared to 2000.

When Professor Factual and I discussed the new treatment to address canola resistance to really dry or really wet conditions, we were very excited about the prospect of improving canola yields under extreme conditions. The best way to assess its impact was to set field experiments.

We selected a site at Elm Creek, Manitoba at one of the most challenging soil types, Almassippi sandy loam, and a site at Herronton, Alberta in the middle of the drought belt to assess the impact of the $5.50 per acre treatment under the harshest possible conditions. To compound the problem, the intense heat of July had a damaging impact on this as well as all canola crops in the area. The experiments were set up in a completely randomized block design with six replicates. We applied all nutrients according to soil test recommendations and herbicide treatments as required for each area.

At a farmer tour on August 23, both farmers and retail staff were impressed with the intense visual response to the $5.50 per acre treatment. "I'd sure would like to know what's in this treatment", exclaimed Mr. Farmer, the farmer co-operator at the site. The impact of the treatment was not as pronounced at our Herronton site.

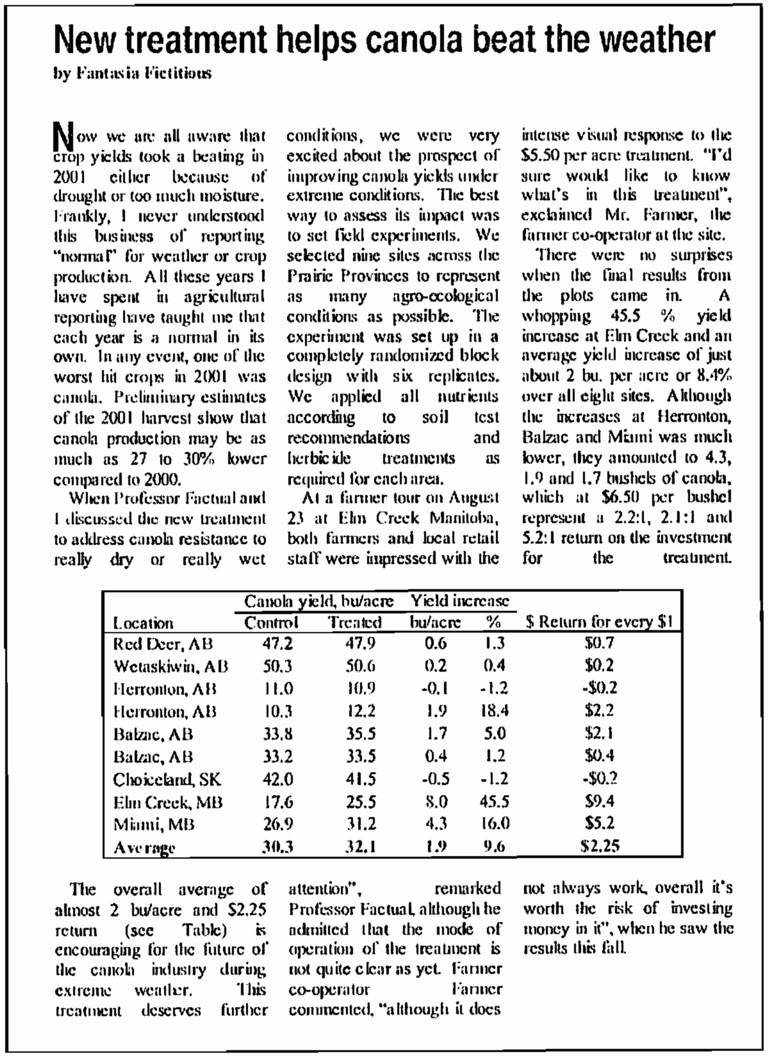
There were no surprises when the final results from the plots came in. A whopping 45.3 % yield increase at Elm Creek and a moderate but still significant increase of 18.4 % at Herronton. Although the increase at Herronton was much lower, it provided over a 2:1 return on the investment for the treatment.

"This treatment deserves further attention", remarked Professor Factual, although he admitted that the mode of operation of the treatment is not quite clear as yet. Farmer co-operator Farmer commented, "it's worth the money invested", when he saw the results this fall.

Differences in the high of the canola crop were already evident when we visited the sites in July.

Yield increase to the $5.50 per acre treatment from replicated field experiments by U of F at Elm Creek, Manitoba and Herronton, Alberta

Figure 1. Fictitious article A based on real data.



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Now we are all aware that crop yields took a beating in 2001 either because of drought or too much moisture. Frankly, I never understood this business of reporting "normal" for weather or crop production. All these years I have spent in agricultural reporting have taught me that each year is a normal in its own. In any event, one of the worst hit crops in 2001 was canola. Preliminary estimates of the 2001 harvest show that canola production may be as much as 27 to 30% lower compared to 2000.

When Professor Factual and I discussed the new treatment to address canola resistance to really dry or really wet conditions, we were very excited about the prospect of improving canola yields under extreme conditions. The best way to assess its impact was to set field experiments. We selected nine sites across the Prairie Provinces to represent as many agro-ecological conditions as possible. The experiment was set up in a completely randomized block design with six replicates. We applied all nutrients according to soil test recommendations and herbicide treatments as required for each area.

At a farmer tour on August 23 at Elm Creek Manitoba, both farmers and local retail staff were impressed with the intense visual response to the $5.50 per acre treatment. "I'd sure would like to know what's in this treatment", exclaimed Mr. Farmer, the farmer co-operator at the site.

There were no surprises when the final results from the plots came in. A whopping 45.5 % yield increase at Elm Creek and an average yield increase of just about 2 bu. per acre or 8.4% over all eight sites. Although the increases at Herronton, Balzac and Miami was much lower, they amounted to 4.3, 1.9 and 1.7 bushels of canola, which at $6.50 per bushel represent a 2.2:1, 2.1:1 and 5.2:1 return on the investment for the treatment.

	Canola yield, bu/acre		Yield increase		
Location	Control	Treated	bu/acre	%	$ Return for every $1
Red Deer, AB	47.2	47.9	0.6	1.3	$0.7
Wetaskiwin, AB	50.3	50.6	0.2	0.4	$0.2
Herronton, AB	11.0	10.9	-0.1	-1.2	-$0.2
Herronton, AB	10.3	12.2	1.9	18.4	$2.2
Balzac, AB	33.8	35.5	1.7	5.0	$2.1
Balzac, AB	33.2	33.5	0.4	1.2	$0.4
Choiceland, SK	42.0	41.5	-0.5	-1.2	-$0.2
Elm Creek, MB	17.6	25.5	8.0	45.5	$9.4
Miami, MB	26.9	31.2	4.3	16.0	$5.2
Average	30.3	32.1	1.9	9.6	$2.25

The overall average of almost 2 bu/acre and $2.25 return (see Table) is encouraging for the future of the canola industry during extreme weather. This treatment deserves further attention", remarked Professor Factual, although he admitted that the mode of operation of the treatment is not quite clear as yet. Farmer co-operator Farmer commented, "although it does not always work, overall it's worth the risk of investing money in it", when he saw the results this fall.

Figure 2. Fictitious article B based on real data.

Two experimental designs were used, namely, the simplest form of experimental design, i.e., two treatments, namely, a control and the $5.50 per acre treatment and rate experiments with eight rates, namely, 0, $2.75, $5.50, $8.25, $11.00, $13.75, $16.50, and $19.25 per acre. All treatments/rates were replicated six times at each site. Both control and treatment received the fertilizer rates described in Table 1, except two one cent (1¢) coins were randomly thrown on each of the six replicates of the treated plot prior to seeding for the $5.50 per acre treatment and 0, 1, 2, 3, 4, 5, 6 and 7 one cent (1¢) coins for the rate experiments.

Each site received all the weed control treatments that were necessary and appropriate for the area as recommended. Each plot was 6 feet (1.35 m) wide and 25 feet (7.6 m) long and crops were seeded with the implement indicated in Table 1 at 9 inch (22.5-cm) spacing. At maturity, the plots were harvested using a Wintersteiger Nurserymaster Elite experimental combine and the grain samples were dried at 60 °C by forced air and weighed to determine grain yield.

All data were subject to Basic Statistics or Analysis of Variance as appropriate using SYSTAT 8.0 (SPSS Inc. 1998).

Discussion

The articles in Figures 1 and 2 raise a number of issues. Some of them have been intentionally created for discussion sake; others were merely raised through the nature of this article. For example in article A, there is no mention of seven other experiments with canola or the experiments with wheat, peas and barley, although a number of experiments with these crops were also carried out. Observing responses to a treatment with one crop but not with others is not unusual. For example, certain crops (e.g., wheat) are more sensitive to a certain micronutrient (e.g., copper), while others (canola) are not. The choice of showing one crop is therefore probably justified; however, the choice of only the experiments where there was an "apparent" response is not. This also illustrates the danger of running an experiment once.

Response of Canola to the $5.50 per acre Treatment

The response of canola to the $5.50 per acre or "two penny" per plot treatment was statistically significant at Elm Creek (Table 2), however, the 18.4 % yield increased referred to in the article of Figure 1 is the $5.50 per acre rate of the rate experiment at the Herronton 2 site (Table 3). This difference apparently is not significant. Furthermore, separating a single rate out of a rate experiment is not appropriate.

Response of Wheat and Barley to the $5.50 per acre Treatment

There was no significant response of either wheat or barley to the $5.50 per acre treatment (Table 2). Normally, field experiments are designed to assess the impact of "something" on the yield and characteristics of crops. In this case, we examined the impact of "nothing" on the yield of various crops.

Statistical analysis of data is commonly expected to demonstrate the impact of something 18 to 19 out of 20 times (90 to 95 % probability). We, therefore, expected to obtain the same result for the impact of "nothing" on the yield of crops. Therefore, out of the eleven single rate experiments described above, only one produced a significant response. Should the remaining twelve rate experiments are included in this logic, then only one in twenty-three experiments produced a significant response.

Response of Canola, Barley and Peas to rates of SS's per acre
The results from the penny rate experiment are shown in Table 3.

Table 1. Location and brief plan of experimental sites of canola.

Test No.	Location	Province	Seeding date	Harvest date	Implement	Nutrient application rate. lb/ac N	P	K	S
				Canola					
C1	Herronton 1[a]	AB	May-01	Aug-28	Hoedrill	72	22	13	7
C2	Herronton 2[a]	AB	May-01	Aug-28	Hoedrill	72	22	13	7
C3	Balzac 1[a]	AB	May-10	Sept-06	Airseeder	72	22	13	7
C4	Balzac 2[a]	AB	May-10	Sept-06	Airseeder	72	22	13	7
C5	Red Deer	AB	May-04	Sept-17	Hoedrill	79	27	0	0
C6	Wetaskiwin	AB	May-04	Sept-26	DD Drill	79	27	0	0
C7	Choiceland	SK	May-10	Sept-05	Hoedrill	77	22	67	22
C8	Elm Creek	MB	May-25	Aug-22	Hoedrill	78	27	46	15
C9	Miami	MB	May-12	Aug-21	Hoedrill	77	22	80	27
				Wheat					
W1	Red Deer	AB	May-04	Sept-12	Hoedrill	79	27	0	0
W2	Smeaton	SK	May-09	Sept-06	Hoedrill	78	27	67	22
W3	Choiceland	SK	May-10	Sept-06	Hoedrill	78	27	67	22
W4	Elm Creek	MB	May-25	Aug-23	Hoedrill	78	27	46	15
W5	Miami	MB	May-12	Aug-21	Hoedrill	78	27	53	18
				Barley					
B1	Herronton 1[a]	AB	May-01	Aug-14	Hoedrill	67	22	21	0
B2	Herronton 2[a]	AB	May-01	Aug-14	Hoedrill	67	22	21	0
B3	Balzac 1[a]	AB	May-10	Aug-15	Airseeder	67	22	21	0
B4	Balzac 2[a]	AB	May-10	Aug-15	Airseeder	67	22	21	0
B5	Ellerslie	AB	May-03	Aug-29	DD drill	0	0	0	0
				Peas					
P1	Herronton 1[a]	AB	May-01	Aug-14	Hoedrill	5	22	0	0
P2	Herronton 2[a]	AB	May-01	Aug-14	Hoedrill	5	22	0	0
P3	Balzac 1[a]	AB	May-10	Aug-15	Airseeder	5	22	0	0
P4	Balzac 2[a]	AB	May-10	Aug-15	Airseeder	5	22	0	0

[a] Indicates sites where a rate experiment was carried out.

Yield Increase of 18.4% - Why is it not Real?
Looking at Figure 1 in Article A or the Table in Article B, the researcher has shown the two experiments with canola where he obtained the highest yields. Percent yield increases were obviously a convenient way to hide the fact that yields, especially at Herronton, were extremely low due to drought in this latter case. Nevertheless an 18.4% yield increase (1.9 bu/acre) in this case begs the question why it is not real (significant)?

A scientist will require all the individual data or the statistical analysis carried out on the results to ascertain whether the differences are real. A layman may argue that he/she don't care about the statistics. Just under two bushels is a good enough difference for them. Let's analyze this thinking.

Table 2. The effect of the $5.50 per acre treatment on canola

Location	Control	$5.50/acre	ANOVA (P) [a]	LSD
		Canola		
Red Deer	47.2	47.9	NS	5.5
Wetaskiwin	50.3	50.6	NS	7.1
Choiceland	42.0	41.5	NS	1.3
Elm Creek	17.6	25.5	*	6.7
Miami	26.9	31.2	NS	20.2
		Wheat		
Red Deer	50.4	49.2	NS	5.1
Smeaton	20.9	21.6	NS	2.1
Choiceland	29.4	28.5	NS	2.5
Elm Creek	29.8	30.2	NS	4.8
Miami	54.3	55.6	NS	5.3
		Barley		
Ellerslie	52.1	51.4	NS	3.6

[a] t,*,** Significant at $P \leq 0.10$, 0.05, and 0.01 respectively; NS, not significant

Suppose one uses the ruler in Figure 3 to measure the length of two golden chains, so they can decide which one to buy. The chains look pretty much the same length, but the buyer wants to make sure. Ten measurements of the each chain are taken (Table 4).

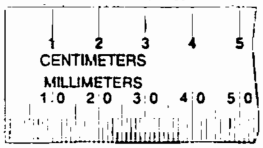

Figure 3. Portion of the metric ruler used to compare the length of two chains.

Can the buyer conclude that chain 1 was longer than chain 2 and, therefore, he/she should prefer to buy it? To a layman the answer is obvious: of course; it is 20 μm longer after all. However, to a scientist the answer is also obvious: the smallest unit we could measure is 1 mm or 1000 μm. Therefore, anything less than that cannot be seen and cannot be measured, although it can be mathematically calculated. The eye cannot see 20 μm differences anyway and we did use our eyes as an instrument to measure in addition to the ruler, therefore, the answer is no. The scientist has used the element of "uncertainty" in providing his/her answer. It is so easy to be out by one mm when we measure something so many times.

The above example begs the question: Is there an "eye" that allows us to see yield differences in experiments? The answer is, of course, yes and it is known as Variance. Although the intention of this paper is not to cover statistical analysis in detail, an example of determining the "experimental eye" is afforded in Table 5 in the form of the required replicates to detect a difference (Cochran and Cox 1992). The procedure to derive the number of replicates can be also found in Little and Hill (1978). Once an experiment has been carried out, the examples in Table 6 show the real "experimental eye".

Table 3. The effect of rates of $$'s per acre or pennies per plot on peas, barley and canola.

	$ Treatment per acre [c,d]								
Crop	$0.00	$2.75	$5.50	$8.25	$11.00	$13.75	$16.50	$19.25	crop means [a]
					Herronton 1				
Field Pea	14.3	14.0	15.8	14.5	15.8	16.1	14.7	15.1	15.0
Barley	37.2	39.2	39.5	36.4	36.6	38.8	38.4	39.0	38.1
Canola	11.0	11.0	10.9	9.9	11.2	9.7	10.3	11.0	10.6
$$ means [b]	20.8	21.4	22.0	20.3	21.2	21.6	21.1	21.7	26.6
					Herronton 2				
Field Pea	14.7	13.8	13.3	14.9	13.9	13.6	13.9	12.8	13.9
Barley	35.9	39.2	35.8	36.2	37.7	38.1	34.1	34.3	36.4
Canola	10.3	11.3	12.2	10.9	11.1	10.1	10.4	12.0	11.1
$$ means [b]	20.3	21.4	20.4	20.7	20.9	20.6	19.5	19.7	25.1
					Balzac 1				
Field Pea	46.7	49.4	51.2	49.0	48.5	44.5	46.9	47.6	48.0
Barley	91.9	93.5	92.4	90.0	90.8	95.8	94.3	93.9	92.8
Canola	33.8	36.4	35.5	34.4	34.7	34.2	34.5	35.6	34.9
$$ means [b]	57.5	59.8	59.7	57.8	58.0	58.2	58.5	59.0	70.4
					Balzac 2				
Field Pea	44.6	42.9	42.1	45.8	48.1	46.2	44.0	47.4	45.1
Barley	87.9	83.9	86.0	87.0	83.7	85.3	86.1	85.9	85.7
Canola	33.2	33.2	33.5	34.0	34.7	32.3	30.8	32.8	33.1
$$ means [b]	55.2	53.3	53.9	55.6	55.5	54.6	53.6	55.4	65.4

	Significance [e]			
Contrasts	Herronton 1	Herronton 2	Balzac 1	Balzac 2
Pea Yield vs Canola Yield (PC)	t	**	**	**
Barley Yield vs avg Pea & Canola Yield (B vs P & C)	**	**	**	**
Linear Response to Pennies (PL)	NS	NS	NS	NS
Quadratic Response to Pennies (PQ)	NS	NS	NS	NS
Cubic Response to Pennies (PCu)	NS	NS	t	NS
Residual Response to Pennies (PR)	NS	**	NS	**
PC x PL Interaction	NS	*	NS	*
PC x PQ Interaction	NS	NS	NS	NS
PC x PCu Interaction	NS	NS	NS	NS
PC x PR Interaction	NS	NS	NS	NS
(B vs P & C) x PL Interaction	NS	NS	t	NS
(B vs P & C) x PQ Interaction	NS	NS	NS	NS
(B vs P & C) x PCu Interaction	NS	NS	*	NS
(B vs P & C) x PR Interaction	t	NS	NS	NS

[a] LSD, 5%: between crop means, 4.8; [b] LSD, 5%: between penny rate means, 1.7; [c] LSD, 5%: between penny rate means at the same crop, 2.9; [d] LSD, 5%: between penny rate means at different crops, 5.5

[e] t,*,** Significant at P ≤ 0.10, 0.05 and 0.01 respectively; NS, not significant

Often scientists combine the results from a number of sites in support of the performance of a treatment. Analysis of the results of a series of experiments is quite a bit more complicated, so the reader is referred to Cochran and Cox (1992) for further information. An example of such analysis is demonstrated for the $5.50 per acre treatment with canola in Table 7. The analysis of variance is based on Cochran and Cox (1992) that includes all nine canola tests, in other words the $5.50 treatment from the rate experiments has been separated and included (Table 7).

Table 4. Measurement (in mm) of the length of two chains using the ruler in Figure 3.

	1	2	3	4	5	6	7	8	9	10	Average in mm	Difference in µm
Chain 1	20	20	19.9	20	20.1	20	20	20	20	20	20	+20
Chain 2	20	20	20	19.9	20	19.9	20	20	20	20	19.98	

Table 5. Examples of number of replicates required based on anticipated variance (two-tailed test with 4 treatments).

Parameter	Value	Explanation/Comments
		Example 1
Difference to be detected (% of mean):	5.0	This is the difference between the treatment mean and overall mean
Coefficient of Variation CV (% of mean):	5.0	This is the typical coefficient of variance associated with the test
Required probability:	0.95	This is a measure of the minimum certainty required to detect the difference inputted above (i.e., 5%)
Number of replicates required	27	

A Yield Increase of 9.6% - Is It Real?

Looking at the Table in Figure 1 the researcher has done what in the researcher's opinion was the honest thing to do, i.e., showed both the good and the bad. However, overall the yield increase of 1.9 bushels or 9.6% can be perceived as "quite impressive". The treatment applied when converted to on a per acre basis amounts to $5.50. However, in many instances other "cheaper" treatments or products find their way into the market, thus making the return on $1 much more attractive than the $2.25 in this case.

Table 6. Examples of differences that can be detected based on the experimental variance (two-tailed test at desired significance level of 5%).

Parameter	Example 1	Example 2	Example 3	Example 4	Example 5
Measured CV (% of mean)	10	15	15	15	15
Required probability	0.95	0.95	0.8	0.8	0.95
Number of treatments	5	5	5	5	2
Number of replicates	6	6	6	4	6
Difference that can be detected (% of mean)	±23%	±34%	±26%	±33%	±40%

Table 7. ANOVA for the series of nine experiments carried out with canola in 2001.

Rate	Test #									Averages
	1733	1734	1739	1740	1743	1752	1772	1795	1803	
0	11.0	10.3	33.8	33.2	47.2	50.3	42.0	17.6	26.9	30.3
$5.50	10.9	12.2	35.5	33.5	47.9	50.6	41.5	25.5	31.2	32.1
ANOVA (P) [a]	NS	NS	NS	NS	NS	NS	NS	*	NS	NS

[a] *,** Significant at $P \leq 0.05$, and 0.01 respectively: NS. not significant

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
PLACE	3343.031111	8	417.878889	115.118151	0.000000
TRT	15.125000	1	15.125000	4.166667	0.075528
Error	29.040000	8	3.630000		

There are many practical as well as scientific questions that have to be answered before the results of such an analysis are accepted.

Is the average relative yield increase calculated correctly? No. We cannot average the individual relative yield increases. Rather we need to average the control yield and the yield increase and then express the average yield increase as a percentage of the average control yield. The relative yield increase will then be 100* (1.9 / 30.3) =6.3%.

Are the yield increases real? A scientist will require all the individual data or the statistical analysis carried out on the results to ascertain whether the differences are real. A layman may argue that he/she don't care about the statistics. Just over two bushels is a good enough difference for them. The difference in the yield between the "two-penny" treatment and the control at one site (Elm Creek, Manitoba) was significant at 95% probability level ($P<0.05$). The difference in the remaining sites was not significant and overall the difference of 2.1 bu/acre of canola or 7.3% yield increase was below what our "experimental eye" could see.

The objective of many projects that employ agricultural field experimentation is to hopefully derive results that can be applied to practical farming. The results thus derived must be valid for at least several seasons and over a reasonably large farming area. It would be just as wrong to selectively present the data from the one experiment where the statistical significance was obtained and "bury" the rest as it would reporting all nine with the intention of proposing a new treatment without having the data statistically analyzed. A single experiment, however well conducted, supplies information for only one location and one season and in any event according to the statistical rules applied can represent the one case out of the twenty times that this experiment may be carried out (95 % probability) that results do not fit the overall conclusions.

Genetic and environmental variations are normally beyond the control of the experimenter and represent what is known as "experimental error". These will occur almost always in agricultural research. As Little and Hill (1978) observe "No matter how much scientists know about nutrition and physiology, they cannot predict precisely what will be the gain in weight of a steer or the yield of a plot of potatoes under given sets of conditions". The purpose of statistics according to Finney (1978) is to provide an objective basis for the analysis of problems in which the data depart from the laws of exact causality.

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PROCEEDINGS OF THE

THIRTY-FOURTH NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 20

November 17-18, 2004
Holiday Inn Airport
Des Moines, IA

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Published by:
Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
(605) 692-6280
Web page: www.ppi-ppic.org