ECONOMIC ANALYSIS OF BARLEY-FERTILIZER EXPERIMENTS AT DIFFERENT LOCATIONS IN THE WILLAMETTE VALLEY 1953-1955

by

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ECONOMIC ANALYSIS OF BARLEY-FERTILIZER EXPERIMENTS AT DIFFERENT LOCATIONS IN THE WILLAMETTE VALLEY 1953-1955

INTRODUCTION

Fertilizer trials were carried out on representative soil types in the Willamette Valley over a 3-year period to obtain information on the effect of different fertilizer treatments on the yield of Hannchen barley. Measurements of kernel-quality characteristics were also made. These measurements were used to study the effects of fertilizer on the malting quality of the grain.

To derive maximum benefit from these quantitative experimental data, concepts of production economics were applied to interpret them. These concepts were used in an attempt to estimate the fundamental physical relationships between inputs and outputs. With such basic information at hand, along with the prices of the factors and products and the risk and financial position of the farmer, more meaningful recommendations in the use of fertilizer to maximize returns from a given crop can be made.

The nature of the data made it possible to derive a general production function. The data were for three years at the same locations, and soil productivity rates were determined for each location from soil-test values. Thus the functions are general in that they are not limited to a particular year or location.

REASON FOR THE ECONOMIC ANALYSIS

Farmers apply fertilizer to a crop to obtain a greater yield. This practice is only justified if the cost of the fertilizer applied is more than paid for by the increase in yield. Hence, the farmer must know beforehand whether or not it will pay him to apply a nutrient to his crop. He also must decide whether the return from such an expenditure will return as much or more than if he had spent the money on some alternative input, such as livestock or machinery.

With his capital position, venture spirit, and alternative opportunities given, if the farmer decides to apply fertilizer, he is still confronted with a number of other decisions that he has to make. These are: where should it be applied, how should it be applied, what kind should be applied, and how much should be applied? To answer these questions the farmer has to know the basic physical relationship between inputs of fertilizer and yield, and the prices of the inputs and the output.

PURPOSE OF THIS STUDY

The objectives of this study are:

1. Estimate physical input-output relationships from the experimental data which permits the estimation of crop yields at different fertilizer levels;

2. Determine the optimum rates of nutrients to apply given the prices of factors and product, with unlimited capital;

3. Determine the effect of fertilizer on the malting quality of the grain.

An accurate estimation of the production surface would permit an efficient use of resources devoted to the fertilization of crops. However, because of a combination of factors, including soil characteristics, climate and a variety of management practices, a production surface applies only to those conditions that prevailed when the data were obtained.

THE CONCEPTS OF PRODUCTION ECONOMICS USED TO ANALYZE THE DATA

It is known that nutrients are substitutable one for the other within limits. If this were not so, nutrients would combine only in one way. That is, that a given yield could only be attained with a single combination of elements. Graphically this is shown in Figure 1. The nutrients are represented by X_1 and X_2. By changing the quantities of the nutrients, the series of curves (isoquants or equal product curves) 1, 2, and 3 are obtained. Points A, B, and C show the proper combination of the two nutrients to obtain different yields. The straight line EF joins these points together. This line is the isocline

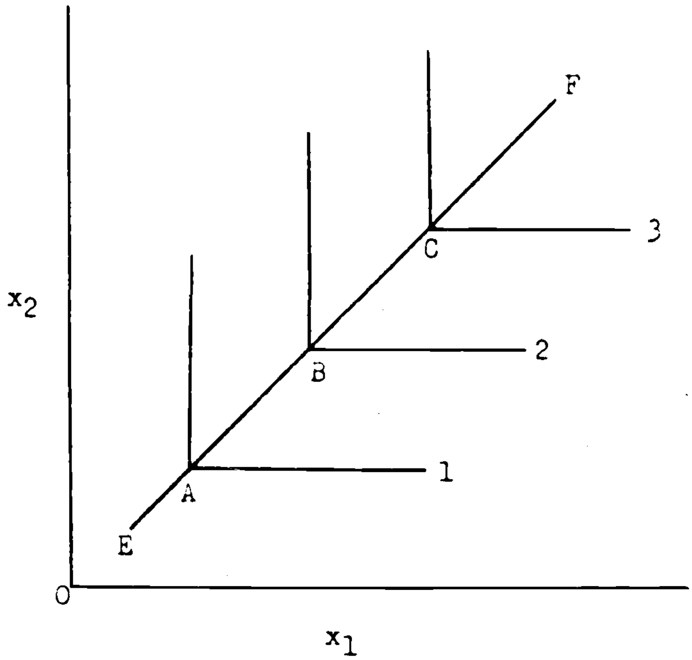

Figure 1. Perfect complementarity between nutrients

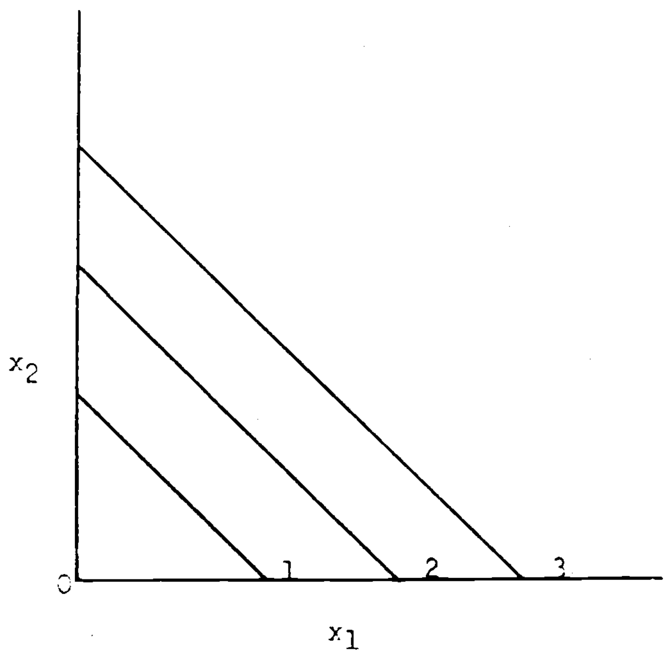

Figure 2. Perfect substitution between nutrients

least-cost line or expansion path. Under technical complementarity, where nutrients combine in fixed proportions, this line EF represents the convergence of all the isoclines to form one straight line.

The opposite of perfect complementarity is perfect supplementarity. In this case, one nutrient could completely substitute for another. Graphically, on a 2-dimensional chart, the isoquants would be represented by straight lines cutting both axes (Figure 2). With perfect substitutes there would be only two isoclines; these would coincide with the horizontal and vertical axes of the chart.

In both of these cases, one being technical complementarity and the other perfect substitutability, the economic limits are set by the isoclines and are bounded by the ridge lines. The relevant range of nutrient application lies between these two extreme cases, and because nutrients generally are not free, the ridge lines will not represent the proper nutrient combination. The appropriate combination will lie within the boundaries of the two ridge lines.

It is generally thought that an application of fertilizer usually causes the yield first to increase at an increasing rate, then at a decreasing rate until total yield begins to decline. In the area in which the yield increases at a diminishing rate, the isoclines will eventually converge. It is at the point of convergence that yield is a physical maximum. The estimated production surface reveals the relevant range of diminishing returns and makes it possible to determine the optimum combination of nutrients to apply when the prices of the nutrients and product are known.

With the prices of the inputs and outputs known and unlimited capital, the optimum combination of nutrients is where profit is maximized. Profit is maximized when marginal revenue equals marginal cost. That is, when the return from an additional unit of output just equals the cost of the additional inputs required to produce that extra unit of output. To reach a stable position, marginal cost will eventually have to increase faster than marginal revenue as inputs are increased. It will be at this point of equality that marginal revenue will be at a maximum.

Costs associated with fertilizer application, harvesting and storage of the crop are not included in the study. Net gain or net return as used in the study refer to units of barley multiplied by per unit price minus the cost of nutrients.

SOURCE OF DATA

The data consist of yield information for Hannchen barley from 25 experimental plots throughout the Willamette

Valley. Tests to determine the effect of the fertilizers on malting quality were run on the grain from 23 of the 25 plots. The characteristics studied were: kernel size, kernel weight, diastatic power, extract, bushel weight and protein content. The experiments were carried out in each of three years from 1953 to 1955.

Eighteen of the locations were on "Valley" soils and seven were on "Hill" soils. The "Valley" soils were: Willamette, Newberg, Amity and Chehalis. Carlton, Olympic, Melbourne and Aiken were the "Hill" soils.

The data were from a randomized block experiment with three replications. Nitrogen rates were 0, 30, 60 and 90 pounds per acre and rates for phosphorus were 0, 40 and 80 pounds. Sulphur as gypsum was applied to each plot at the rate of 20 pounds per acre. The source of nitrogen was ammonium nitrate and treble superphosphate was the source of phosphorus.

ANALYSIS OF DATA

"Hill" Soils Data

There were seven locations on "Hill" soils. Each plot at these locations had three replications. All locations received 0, 30, 60 and 90 pounds of N per acre. Some locations received 0, 40 and 80 pounds of P_2O_5, while others had only 0 and 40 or 0 and 80 P_2O_5 treatments. Each location had a top dressing of 20 pounds of gypsum. The average

Table 1. Hill Soils: Fertilizer Treatments and Average Yield*(Pounds) per Acre of Hannchen Barley Grown in Fertilizer Tests 1953-1955

Lbs. per Acre $N - P_2O_5 - S$	-- Location --							
	1	2	3	4	5	6	7	All Locations
0 - 0 - 20	2601	852	848	1076	700	860	994	1133
30 - 0 - 20	3461	1204	1278	1332	830	2305	1301	1673
60 - 0 - 20	3718	892	1344	1183	800	2773	1194	1701
90 - 0 - 20	4037	872	1249	1299	790	2731	1416	1771
30 - 40 - 20	--	--	--	--	--	--	--	--
60 - 40 - 20	--	--	--	1440	1100	3371	1495	1852
90 - 40 - 20	--	--	--	1299	950	3138	1425	1703
0 - 80 - 20	2853	717	--	--	--	--	1046	1539
30 - 80 - 20	3613	1497	1208	--	900	2364	1571	1859
60 - 80 - 20	3936	1464	1059	--	960	2932	1392	1957
90 - 80 - 20	4159	1366	1349	--	860	2836	1448	2003

*Based on three replications.

yields of three replications for each treatment at each location are shown in Table 1. The table shows that on the average N gave a greater response than P_2O_5 and interaction between N and P_2O_5 resulted in higher yields than either alone. Across the treatments, the average increase in yield over check plot from 30, 60 and 90 pounds of N per acre was 630, 743 and 753 pounds of barley respectively. The average increase in yield over check from 40 pounds per acre of P_2O_5 was 430 pounds of grain.

Results of the analysis of variance, computed for each location singly, showed N response to be significant in each case. Yield response from P_2O_5 was significant at all but two locations. Interaction between N and P_2O_5 was found also to be important to increased yields.

Table 1 also shows considerable difference in yields between locations. In recognition of these differences, a production index was included in the predicting equation. This index was based on the check-plot yield levels for each location.

Regression Analysis

A square-root transformation of a quadratic equation was fitted to the 183 observations included in Table 1. This form of equation was fitted because it explained more of the variation in yield than the quadratic, the other form of equation used. These two types of equations were tried because they "(1) allow specification of the one nutrient combination allowing maximum per-acre yields, (2) allow convergence of isoclines to the point of maximum yield and indication of changes in nutrient ratios required to attain higher yields, (3) do not require constant substitution rates between nutrients and (4) do not force constant elasticities of production" (3, p.808).

The equation was of the form:

$$\hat{Y} = a + b_1 N + b_2 \sqrt{N} + b_3 P + b_4 \sqrt{P} + b_5 \sqrt{NP} + b_6 \sqrt{\text{Prod } N} + b_7 \sqrt{\text{Prod } P},$$

where $\hat{Y}$ refers to yield in pounds per acre above check plot, N to available N per acre, P to available P_2O_5 per acre, NP to interaction between N and P_2O_5, Prod N to an interaction between the productivity level of the soil and the application of N, and Prod P to an interaction between the productivity level and the application of P_2O_5.

In the first equations tried for the "Hill" and "Valley" soils, the term P P_s was included. This term took into account the possible relationship between the phosphorus applied and that in the soil. It was found that this term did not aid in explaining the variation in yield. The reason was thought to be the high P_2O_5 soil-test readings for most of the locations. These locations were considered above the region of response and locations with low readings were too few.

For the "Hill" soils, the coefficient of determination of the square-root transformation was 0.24 and was significant at the 99 per cent level. The t values of the regression coefficients are shown in Table 2. It can be seen from this table that the coefficients for N are more important than the others. The N productivity level of the soil is highly significant.

Table 2. Hill Soils: Values for t for Coefficients of Regression

Independent Variables	Regression Coefficient	Values	Significance Level*
N	-8.1616	1.68	0.10
N	96.4573	1.95	0.05
P	-6.7060	0.92	0.36
P	82.3541	1.21	0.23
NP	2.1312	0.62	0.54
Prod N	11.9748	4.32	0.00004
Prod P	-3.5898	0.99	0.32

*Probability of obtaining as large or larger value of t by chance, given the hypothesis that the variables do not effect yield.

Production Surface

The yields for various combinations of N and P_2O_5 estimated from the production function are shown in

Table 3. The production function is

$$\hat{Y} = 12.7282 + 140.738 \sqrt{N} - 8.16156\ N$$

$$+ 69.0798 \sqrt{P} - 6.70597\ P + 2.13118 \sqrt{NP},$$

when the productivity terms take average values. The yields in Table 3 were predicted using this equation.

Table 3. Hill Soils: Predicted Increase in Yield of Hannchen Barley per Acre for Various Nutrient Combinations

Lbs. P_2O_5 Per Acre	-- Pounds N per Acre --				
	0	30	60	90	120
0	12.7	538.7	613.2	613.3	575.0
20	187.5	765.8	861.8	878.6	854.3
40	181.4	781.2	886.2	909.9	891.4
60	145.5	761.9	873.8	902.7	888.6
80	94.1	724.5	842.2	875.6	865.2

These yields are shown graphically in Figures 3 and 4. Figure 3 shows yield response curves to nitrogen at 0, 40 and 80 pounds of P_2O_5. The yield response curves in Figure 4 are for P_2O_5 at five levels of N: 0, 30, 60, 90 and 120 pounds.

Figure 3 shows large yield increases due to N and the existence of interaction between N and P_2O_5. The yield increases due to P_2O_5 are smaller, as shown by

Figure 4. Both figures also show eventually decreasing total product as the inputs of the nutrients are increased. The marginal physical products for both nutrients at higher levels become negative. Since there is interaction between N and P_2O_5, the marginal yields of N and P_2O_5 change as the combinations of these two nutrients are changed. The marginal physical products which result from various combinations of N and P_2O_5 are shown in Table 4. The figures indicate that larger marginal yields are attainable when the nutrients are used in combination and that N gives the greatest yield response.

Yield Isoquants and Isoclines

Both the isoquants and isoclines are derived from the predicting equation. The isoquants show the various combinations of the two nutrients that can be used to obtain a particular yield. The isoclines trace out the path of nutrient combinations to be used at a given ratio of prices. The isoquants and isoclines are shown in Figure 5.

Figure 5 shows isoquants for 300, 400, 500, 600, 700, 800 and 900 pounds of barley. As the yields are increased by 100 pounds, the isoquants become further apart, indicating diminishing returns. The different slopes of the isoquants show the change in the amount of P_2O_5 required to maintain a given yield when another unit of N is added. That is, the slope indicates the rate of substitution

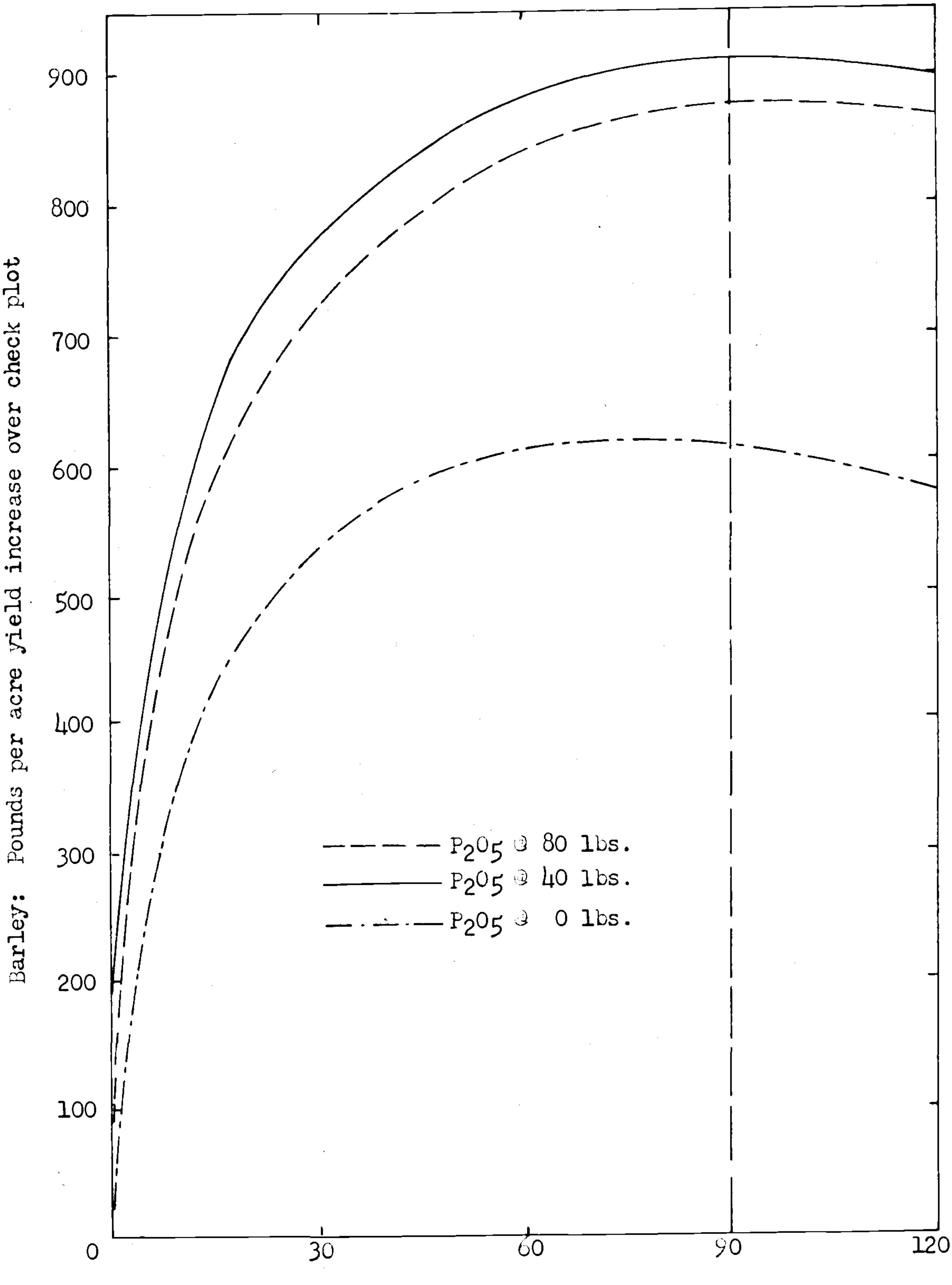

Figure 3. Hill Soils: Barley response to N at 0, 40 and 80 pounds of P_2O_5. (Dashed vertical line is limit of N in experiment)

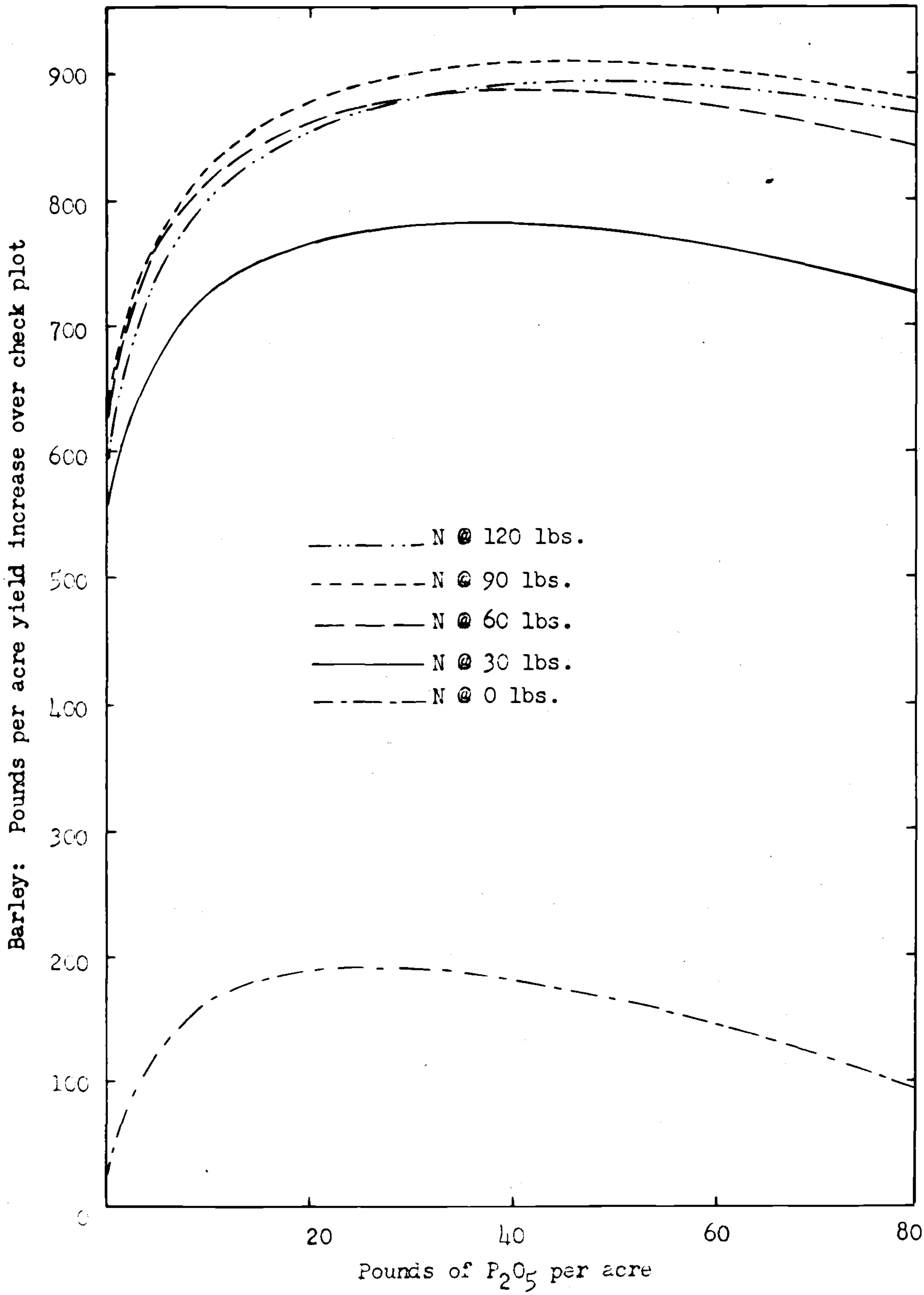

Figure 4. Hill soils: Barley response to P_2O_5 at 0, 30, 60, 90 and 120 pounds of N.

Table 4. Hill Soils: Marginal Physical Products of Hannchen Barley per Acre for Various Nutrient Combinations

Lbs. P_2O_5 Per Acre	-- Pounds N per Acre --					
	0	1	30	60	90	120
	-- Marginal Physical Product for N --					
0	70.4	62.2	25.7	7.2	-14.2	-19.0
20	75.1	66.9	30.4	11.9	-2.3	-14.3
40	77.1	68.9	32.4	13.9	-0.3	-12.3
60	78.6	70.4	33.9	15.4	1.2	-10.7
80	79.9	71.7	35.2	16.7	2.5	-9.6

Lbs. N Per Acre	-- Pounds P_2O_5 per Acre --					
	0	1	20	40	60	80
	-- Marginal Physical Product for P_2O_5 --					
0	34.5	27.8	4.5	-7.8	-17.5	-25.5
30	40.4	33.7	10.4	-2.0	-11.5	-19.6
60	42.8	36.1	12.8	0.4	-9.1	-17.1
90	44.6	37.9	14.7	2.2	-7.2	-15.3
120	46.2	39.5	16.2	3.8	-5.7	-13.7

between the two nutrients. For the lower yields, the isoquants are nearly horizontal beyond the 15-pound level of P_2O_5. This indicates that large amounts of P_2O_5 are required to replace small quantities of N. These lower equal product curves cut the N axis. These amounts of barley can be produced using all N. However, higher yields are only attainable by using both N and P_2O_5, illustrating the complementary relationships between N and P_2O_5.

Table 5 shows the changes in substitution rates for P_2O_5 and N for yield isoquants of 500 and 800 pounds. For the 500-pound yield, at 60 pounds of P_2O_5, an additional pound of P_2O_5 replaces one-quarter pound of N. Over most of the isoquant, additional units of P_2O_5 replace only small amounts of N.

Isoclines connect the points on successive isoquants that have the same slope. In Figure 5, the isocline labeled $P_n = 1.5\ P_p$, gives the proper combination of nutrients to use to obtain a particular yield when the price of N per unit is one and a half that of P_2O_5. This is the current price ratio; hence, the farmer should expand output along this path where one pound of N replaces one and a half of P_2O_5. This particular isocline is nearly straight; therefore, the same nutrient ratio could be maintained as yield was increased with little or no loss.

Table 5. Hill Soils: Isoquant Combinations of Nutrients for Producing Specified Yields and Corresponding Marginal Rates of Substitution

-- 500 Pounds --			-- 800 Pounds --		
Lbs. of P_2O_5	Lbs. of N	MRS of P_2O_5 for N	Lbs. of	Lbs. of N	MRS of P_2O_5 for N
10	7.14	-0.31	10	48.80	-1.24
20	5.71	-0.13	20	37.09	-0.43
40	5.57	0.09	40	33.39	0.06
60	6.80	0.25	60	37.01	0.38
80	9.00	0.40	80	45.32	0.73
100	12.24	0.55	100	60.68	1.39

This is not the case when the isocline is curved. For the isocline curve labeled $P_n = 2P_p$, to obtain the least-cost mix, the ratio of nutrients would have to be changed as output was increased.

Along any isocline in Figure 5, the marginal rate of substitution for the nutrients corresponds to the price ratio of P_2O_5 and N. If both nutrients were free, it would pay to apply 90.1 pounds of N and 44.3 pounds of P_2O_5 to reach the maximum yield of 910.6 pounds of barley. This maximum physical product is attained where the isoclines converge and intersect. Since nutrients are not usually free, production will take place somewhere below

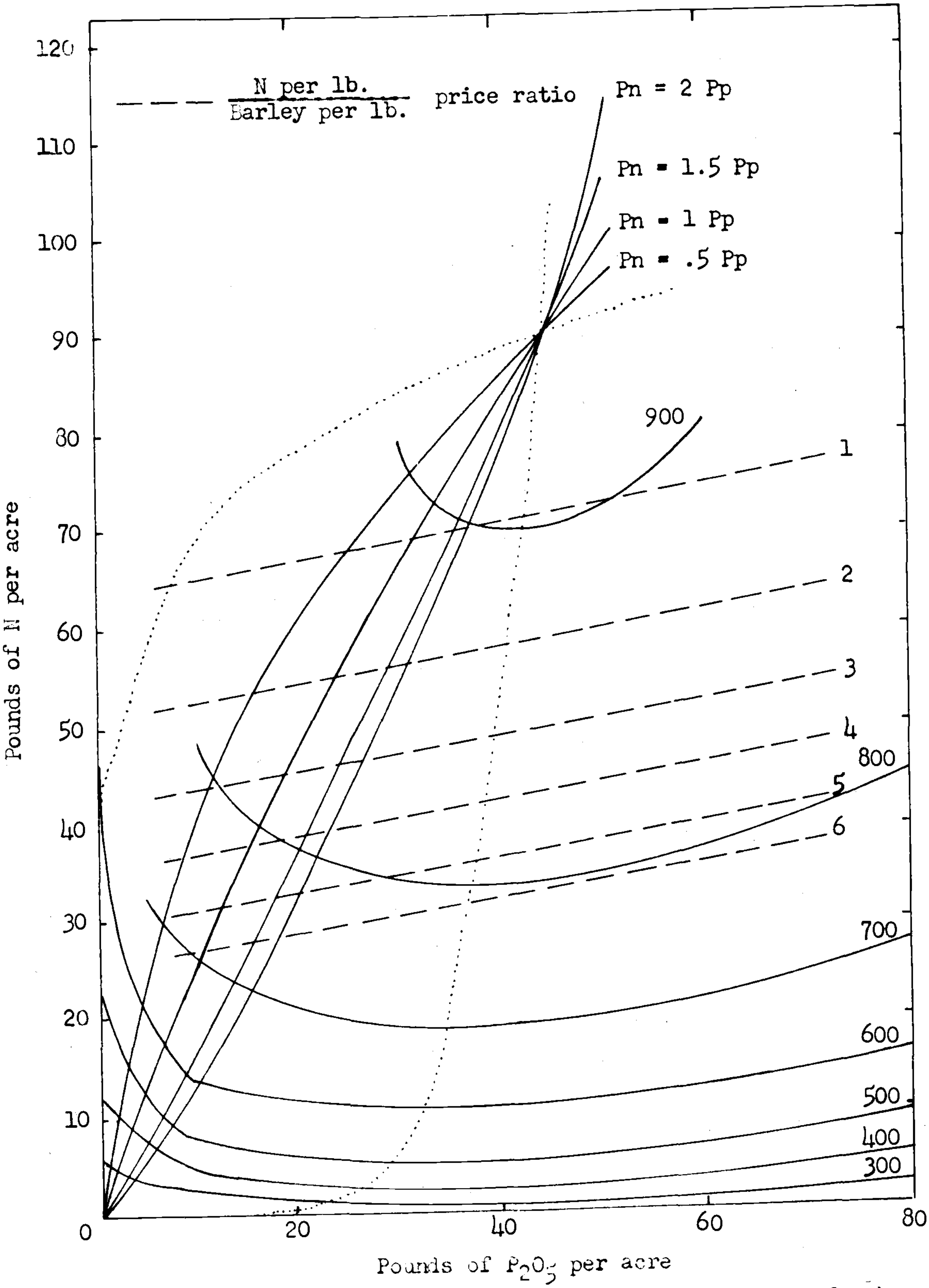

Figure 5. Hill soils: Increased yield isoquants and isoclines for barley with optimum rates indicated by dashed lines representing the N-barley price ratio. (Dotted lines are ridge lines)

the maximum. The combination of amounts of nutrients used will be governed by their price ratios. The technical limits of replacing one nutrient with another are indicated by the ridgelines. Along the ridgelines, the nutrients are technical complements. That is to say, it would not be profitable to use greater quantities than indicated by these lines, even if the nutrients were free.

Economic Optima

To determine the most profitable rate of fertilizer application, the prices of N, P_2O_5, and barley must be known. The optimum rate will vary, depending upon the ratio of these prices. Figure 5 shows isoclines for different price ratios for nutrients. By introducing the price of barley into the figure, the most profitable levels of N and P_2O_5 can be determined. Different barley prices are represented by the dashed lines. The most profitable combination of nutrients is found by choosing the isocline depicting the prevailing ratio of their prices and following along this isocline to where the current barley price line intersects it. Perpendiculars dropped from this point to the axes indicate the amounts of N and P_2O_5 to apply. For example, perpendiculars dropped from the intersection of the isocline labelled $P_n = 1.5 P_p$ and the price line marked $P_n/P_b = 6.00$ (P_n = \$.15, P_p = \$.10, P_b = \$.025), indicate 27.6 pounds of N and 14.0

pounds of P_2O_5 will give the best returns. If more than these amounts of nutrients are applied, at this price ratio, their additional cost will be greater than the return from the additional yield; hence, net return will be reduced.

The optimum rates of nutrient application along with the predicted yields and net returns under different price situations are shown in Table 6. At the prices specified, the nutrients are complementary. Nitrogen is consistently at a higher level than P_2O_5 under the different price situations, indicating it to be the more important nutrient. The ratio between N and P_2O_5 is fairly constant, though the change in quantity is greatest for N; hence, their substitution ratio is not one to one. As N becomes less profitable to apply because of its increased price, both estimated yield and net returns decrease. The additive effect of decreased barley return per pound and the increased cost per pound of N reduces net return from the use of fertilizer.

The economic importance of complementarity between the nutrients can be determined by calculating the estimated yield and net gain when only one nutrient is used. When the prices of N, P_2O_5, and barley are taken to be 15, 10 and 2 cents per pound respectively, the net gain is \$9.24. If no P_2O_5 is used, the net return is reduced by

Table 6. Hill Soils: Net Return and Increased Yield per Acre Obtained from Optimum Nutrient Application at Various Prices

Price per Pound			Optimum Inputs		Estimated Increased Yield	Net Return
Barley	N	P_2O_5	N	P_2O_5		
$	$	$	Lbs.	Lbs.	Lbs.	$
.03	.10	.10	42.3	17.1	811.1	18.39
.025	.10	.10	37.5	14.7	784.8	14.40
.0225	.10	.10	34.7	13.4	767.6	12.46
.0215	.10	.10	33.5	12.8	759.7	11.70
.02	.10	.10	31.7	12.0	746.6	10.56
.015	.10	.10	24.6	8.9	687.7	6.97
.03	.15	.10	32.2	16.3	767.1	16.55
.025	.15	.10	27.6	14.0	734.1	12.81
.0225	.15	.10	25.0	12.8	711.9	10.99
.0215	.15	.10	23.9	12.2	702.2	10.28
.02	.15	.10	22.3	11.4	686.3	9.24
.015	.15	.10	16.4	8.4	617.6	5.96
.03	.20	.10	25.3	15.8	725.5	15.12
.025	.20	.10	21.1	13.6	686.8	11.58
.0225	.20	.10	18.9	12.3	662.7	9.90
.0215	.20	.10	18.0	11.8	652.0	9.25
.02	.20	.10	16.6	11.0	634.6	8.28
.015	.20	.10	11.7	8.2	561.5	5.27

\$2.66 per acre to \$6.58. The yield and the amount of N needed for this net gain are also decreased. Nitrogen is reduced from 22.3 to 20.2 pounds and barley from 686.3 to 480.3 pounds. As N becomes cheaper and more of it is used without P_2O_5, the net gain from N alone becomes greater. At prices of \$0.10 for N and P_2O_5 and \$0.02 for barley, 28.6 pounds of N alone would produce 531.9 pounds of barley. The net gain per acre would be \$7.78; \$1.46 less than when P_2O_5 is also applied, and \$1.20 more than when N was \$0.15 per pound. These changes in yields and net returns demonstrate that the interaction between P_2O_5 and N is quite strong and indubitably important.

"Valley" Soils Data

There were 18 locations on "Valley" soils, nearly three times more than for the "Hill" soils. Fertilizer treatments were similar for both the "Hill" and "Valley" soils. The average yields of three replications for each treatment at each location are shown in Table 7. The yield figures show a considerable amount of variation between locations. The lowest check-plot yield was 851 pounds of barley per acre and the highest was 3483. On the average, N gave a much greater response than P_2O_5. The combined average increase over check-plot yield from the N treatments was 759, 931 and 891 pounds per acre for the 30-, 60- and 90-pound levels. Phosphorus gave an average yield response of 155 pounds at the 40-pound level.

An analysis of variance was computed for each location. The individual results showed that N produced a significant increase in yield at 15 of the locations. Phosphorus was significant at two locations and phosphorus x nitrogen interaction at five.

Regression Analysis

A square-root transformation of a quadratic equation best explained the variation in the 462 yield observations. It was of the form:

$$\hat{Y} = a + b_1 N + b_2\sqrt{N} + b_3 P + b_4\sqrt{P} + b_5\sqrt{NP}$$
$$+ b_6\sqrt{Prod\ N} + b_7\sqrt{Prod\ P} + b_8\sqrt{GsN} + b_9\sqrt{LgN} + b_{10}\sqrt{OVN}.$$

The terms from b_1 to b_7 are the same as for the "Hill" soil equation. Yield in pounds per acre above check plot is again denoted by $\hat{Y}$ and OVN, LgN and GsN refer to cropping history: barley following oats and vetch, legume, and grass seed respectively. The grain-cropping history is implicit in the function since only grain cropping is left after the other three cropping histories are deleted. This composite function explained slightly over half of the total variation in yield. The coefficient of determination was significant at the 99 per cent level. Values of t for each regression coefficient are shown in Table 8.

Table 7. Valley Soils: Fertilizer Treatments and Average Yield* (Pounds) per Acre of Hannchen Barley Grown in Fertilizer Tests 1953-1955

Lbs. per Acre	-- Location --**								
N -P_2O_5 -S	1	2	3	4	5	6	7	8	9
0 - 0 - 20	976	3291	1573	2445	1586	1726	2109	2918	851
30 - 0 - 20	2542	3955	2322	3675	2048	2605	2704	3694	2040
60 - 0 - 20	3456	4138	2760	4208	1770	2886	3334	4256	2528
90 - 0 - 20	3496	3912	3226	4280	1746	2974	3005	4011	2446
0 - 40 - 20	--	--	--	--	--	--	--	--	912
30 - 40 - 20	--	--	--	--	--	--	--	--	1957
60 - 40 - 20	--	--	--	--	--	--	--	--	2589
90 - 40 - 20	--	--	--	--	--	--	--	--	2458
0 - 80 - 20	813	3227	1008	2758	1571	1821	2002	2954	974
30 - 80 - 20	2790	3906	2619	3798	2442	2493	2984	4098	1858
60 - 80 - 20	3675	4240	3830	4235	2162	3102	3330	4102	2462
90 - 80 - 20	3483	3619	3728	4325	2326	3022	3259	4506	2856

Table 7 cont.

Lbs. per Acre $N-P_2O_5-S$	-- Location --									
	10	11	12	13	14	15	16	17	18	All Locations
0 - 0 - 20	3483	2157	963	3831	2126	2007	2455	2136	1477	2117
30 - 0 - 20	3629	2911	1742	4064	2722	3131	2546	2740	2322	2855
60 - 0 - 20	3789	2761	1845	3289	2233	3117	2459	2435	2422	2982
90 - 0 - 20	2739	2615	2173	2695	1895	2882	3432	2932	2661	2951
0 - 40 - 20	3134	--	--	--	--	--	--	--	--	2023
30 - 40 - 20	4195	2248	1783	4234	2618	3262	2409	2964	--	2852
60 - 40 - 20	3960	2571	2132	3401	2922	3072	3104	3064	2132	2895
90 - 40 - 20	3027	2646	2296	2987	2057	3094	3104	2562	2442	2667
0 - 80 - 20	--	--	--	--	--	--	--	--	--	--
30 - 80 - 20	3698	2379	1599	4028	2422	3246	--	--	--	2957
60 - 80 - 20	3302	2732	2275	3667	1465	3372	--	--	--	3197
90 - 80 - 20	3939	2954	2255	2785	2472	2848	--	--	--	3225

*Based on three replications.

**Location numbers by cropping histories were: 4, 6, 8, 11, 12, 14, 17 following grain; 1, 3, 9, 18 following grass seed; 10, 13 following legume; 2, 5, 7, 16 following oats and vetch.

The coefficients for N are more significant than the others, which was also the case on the "Hill" soils. The coefficient for barley following grass seed is positive and highly significant, indicating that nitrogen application after grass seed greatly increases yield. On the other hand, nitrogen application on barley following legumes will be less beneficial as indicated by the negative $\sqrt{LgN}$ coefficient. The coefficient for $\sqrt{LgN}$ is also very highly significant.

Production Surface

Using the production functions for each cropping history, barley yields for various combinations of N and P_2O_5 can be estimated. When the productivity terms take average values, the functions for barley following grain, grass seed, legume, and oats and vetch are as follows:

Grass Seed: $\hat{Y} = -1.03087 - 12.3606\ N + 279.899\ \sqrt{N} - 0.100299\ P - 1.34379\ \sqrt{P} + 2.17113\ \sqrt{NP}$

Grain: $\hat{Y} = -1.03087 - 12.3606\ N + 204.008\ \sqrt{N} - 0.100299\ P - 1.34379\ \sqrt{P} + 2.17113\ \sqrt{NP}$

Oats and Vetch: $\hat{Y} = -1.03087 - 12.3606\ N + 196.640\ \sqrt{N} - 0.100299\ P - 1.34379\sqrt{P} + 2.17113\ \sqrt{NP}$

Legume: $\hat{Y} = -1.03087 - 12.3606\ N + 96.5278\ \sqrt{N} - 0.100299\ P - 1.34379\sqrt{P} + 2.17113\ \sqrt{NP}$

Table 8. Valley Soils: Values for t
for Coefficients of Regression

Independent Variables	Regression Coefficient	t Values	Significance Level*
N	-12.3606	4.83	.00001
$\sqrt{N}$	235.4070	8.29	.00001
P	-0.1003	1.24	.22
$\sqrt{P}$	-2.2048	0.14	.89
$\sqrt{NP}$	2.1711	1.24	.22
$\sqrt{Prod\ N}$	-5.8457	2.62	.01
$\sqrt{Prod\ P}$	0.1603	0.08	.94
$\sqrt{GsN}$	75.8908	6.91	.00001
$\sqrt{LgN}$	-107.4800	8.22	.00001
$\sqrt{OVN}$	-7.3678	0.78	.44

*Probability of obtaining as large or larger value of t by chance, given the hypothesis that the variables do not effect yield.

The predicted yields are shown in Table 9. These yields show the importance of N, whereas the interaction between N and P_2O_5 is less important. The largest yield increases over the check plot are obtained when barley follows grass seed. A decreased total yield is not obtained until N is increased beyond 120 pounds per acre; well beyond the levels of the experiments. Yield increases of lesser magnitude are obtained following grain, legume, and oats and vetch. Diminished yields occur with 120 pounds or less of N. In the case of barley following legume,

Table 9. Valley Soils: Predicted Increase in Yield (Pounds) of Hannchen Barley per Acre for Various Nutrient Combinations and Cropping Histories

Lbs. P_2O_5 per Acre	-- Pounds N per Acre --			
	30	60	90	120
Following Grass Seed:				
0	1161.2	1425.4	1541.9	1581.8
20	1206.4	1492.6	1626.0	1680.2
40	1223.9	1519.3	1659.6	1719.7
60	1236.9	1539.3	1685.0	1749.6
80	1247.5	1555.8	1706.0	1774.5
Following Grain:				
0	745.6	837.6	821.9	750.5
20	790.7	904.8	906.0	848.8
40	808.2	931.4	939.7	888.4
60	821.2	951.4	965.0	918.3
80	831.9	968.0	986.1	943.2
Following Oats and Vetch:				
0	705.2	780.5	752.0	669.8
20	750.4	847.7	836.1	768.1
40	767.9	874.4	869.8	807.7
60	780.9	894.3	895.1	837.6
80	791.5	910.9	916.2	862.5
Following Legume:				
0	156.8	5.0	-197.7	-426.9
20	202.0	72.2	-113.6	-328.6
40	219.6	98.9	-80.0	-289.0
60	232.5	118.9	-54.6	-259.1
80	214.7	135.4	-33.6	-234.2

there is an absolute decrease in yield at higher levels of N. The effects of N and P_2O_5 can be perceived visually by referring to Figures 6 and 7. Figure 6 shows the yield responses to different levels of N at zero pounds of P_2O_5 for the four cropping histories. Yield responses from P_2O_5 with 30 pounds of N for the four cropping histories are shown in Figure 7. For the three cropping histories: grass seed, oats and vetch, and grain, P_2O_5 results in slightly increased yields at a decreasing rate for each level. Following legume, however, yield begins to decrease beyond the 60-pound level of P_2O_5.

The rates of change in yields for each cropping history are given in the tables of marginal physical products for N and P_2O_5 (Tables 10 and 11).

The marginal physical products for P_2O_5 are small and are the same for each history because the cropping histories were only in terms of N. The t values for P_2O_5 in Table 8 justify the exclusion of histories in terms of P_2O_5; P_2O_5 is only important in increasing yields in combination with N. Yields increase as greater amounts of both P_2O_5 and N are used in combination, up to the point where the marginal physical products become negative. The importance of N in influencing yields is illustrated by the large marginal physical products for N.

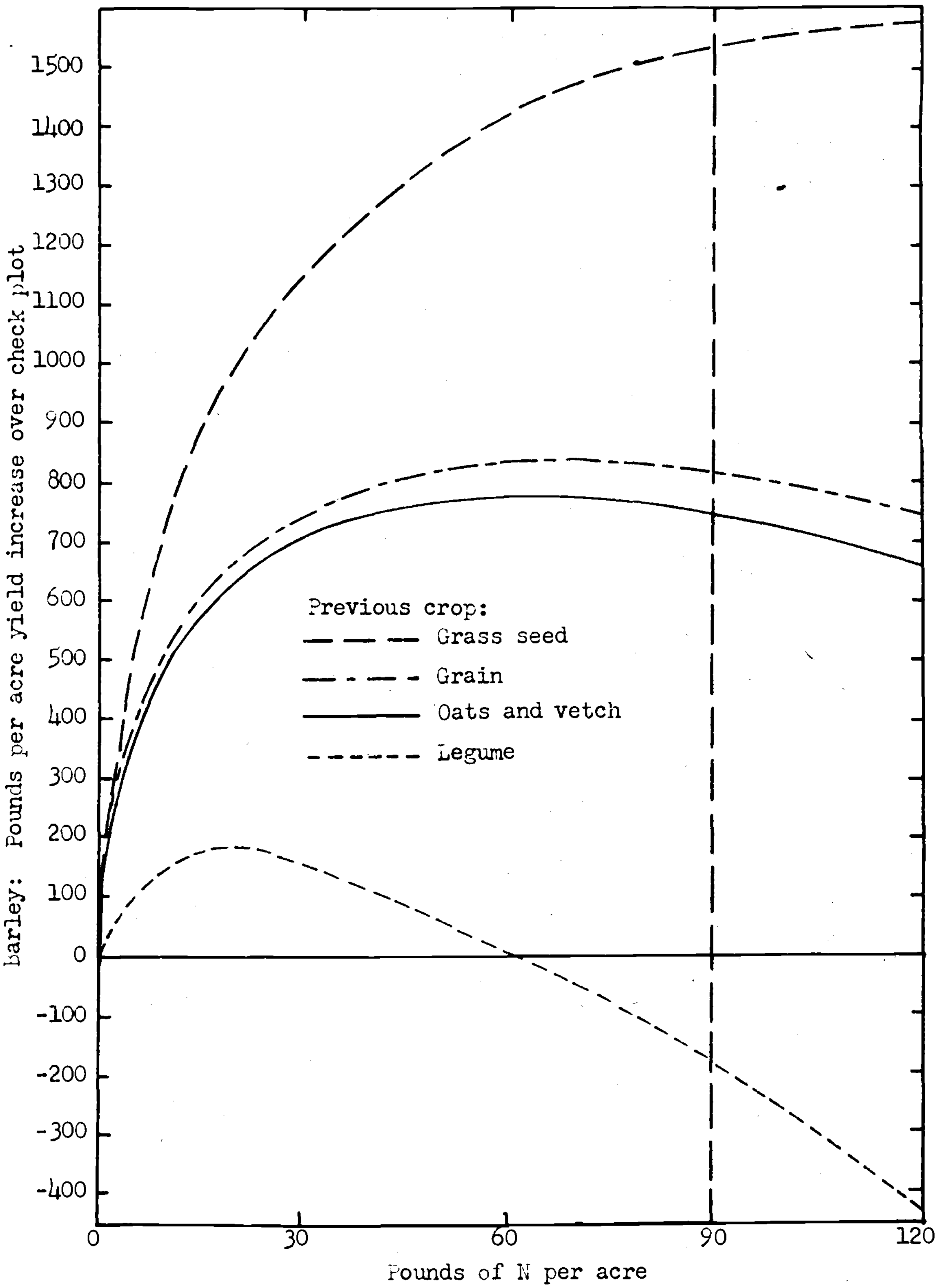

Figure 6. Valley soils: Barley response to N at 0 pounds of P_2O_5 for different cropping histories. (Dashed vertical line is limit of N in experiment)

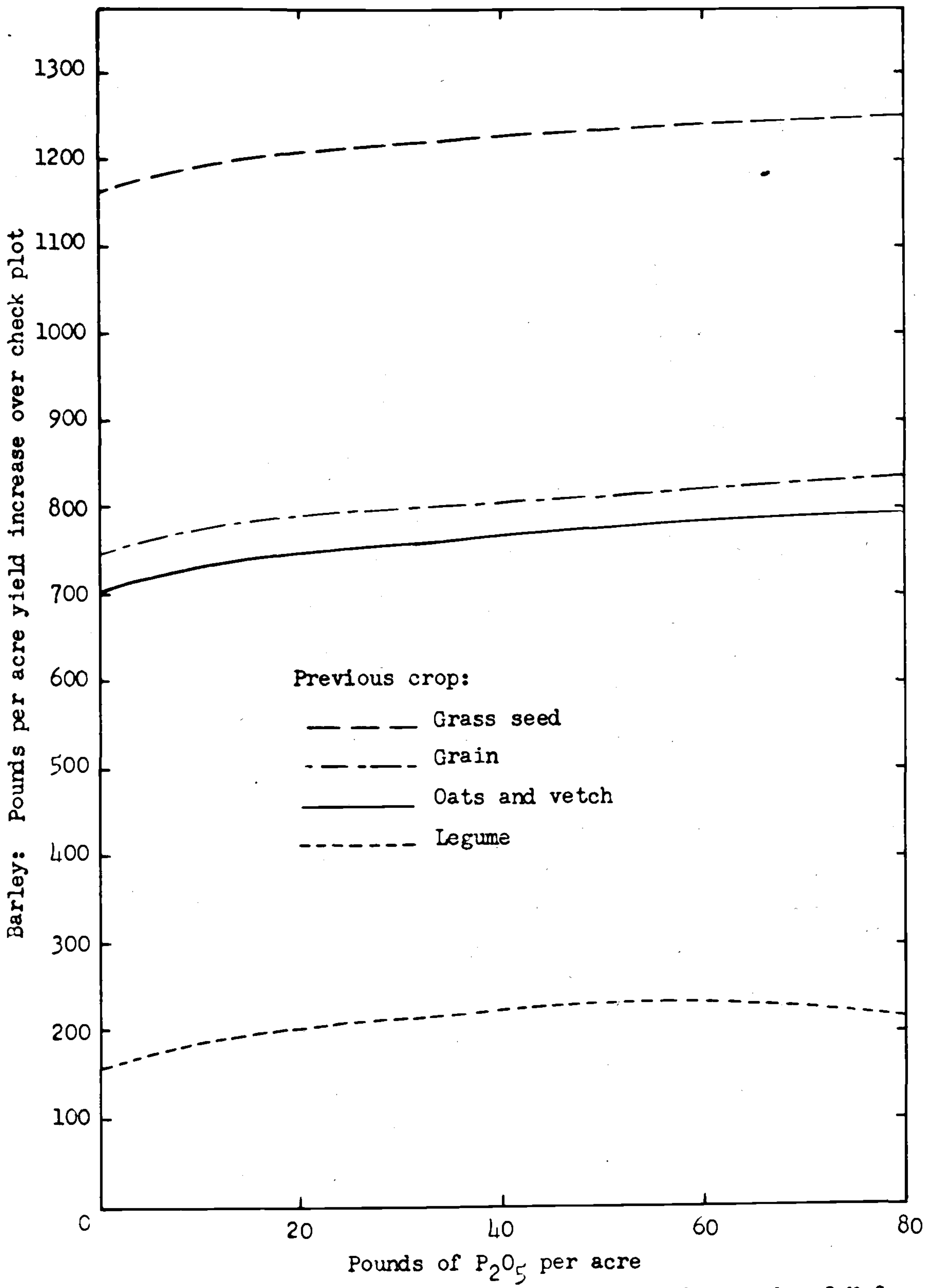

Figure 7. Valley soils: Barley response to P_2O_5 at 30 pounds of N for different cropping histories.

Economic Optima

To determine the optimum rate of fertilizer application, the prices of N, P_2O_5 and barley must be known. The most profitable combination of nutrients to use depends on the ratio of their prices. Optimum rates of nutrient application, predicted yields and net returns were calculated for various price situations under the different cropping histories. At the prices specified, the nutrients were found to be complementary. However, the interaction between N and P_2O_5 was slight. If it is assumed that a farmer would apply an additional nutrient only if it at least resulted in a return per acre above the cost of the nutrient, P_2O_5 would not be applied.

Table 10. Valley Soils: Marginal Physical Products of Hannchen Barley per Acre for Various Nutrient Combinations for All Cropping Histories

Lbs. N per Acre	-- Pounds P_2O_5 per Acre --					
	0	1	20	40	60	80
	-- Marginal Physical Products for P_2O_5 --					
All Cropping Histories:						
0	-0.7	-0.8	-1.1	-1.3	-1.4	-1.6
30	5.3	5.2	4.8	4.6	4.5	4.4
60	7.7	7.6	7.3	7.1	7.0	6.8
90	9.6	9.5	9.2	9.0	8.8	8.7
120	11.2	11.1	10.8	10.6	10.4	10.3

Table 11. Valley Soils: Marginal Physical Products of Hannchen Barley per Acre for Various Nutrient Combinations and Different Cropping Histories

Lbs. P_2O_5 per Acre	-- Pounds N per Acre --					
	0	1	30	60	90	120
	-- Marginal Physical Products for N --					
Following Grass Seed:						
0	139.9	127.6	72.2	44.2	22.7	4.5
20	144.8	132.4	77.1	49.1	27.5	9.4
40	146.8	134.4	79.1	51.1	29.6	11.4
60	148.4	136.0	80.7	52.6	31.1	13.0
80	149.7	137.3	82.0	53.9	32.4	14.2
Following Grain:						
0	102.4	90.1	34.8	6.7	-14.8	-33.0
20	107.3	94.9	39.6	11.6	-10.0	-28.1
40	109.3	97.0	41.6	13.6	-8.0	-26.1
60	110.9	98.5	43.2	15.1	-6.4	-24.5
80	112.2	99.8	44.5	16.4	-5.1	-23.2
Following Oats and Vetch:						
0	98.3	86.0	30.6	2.6	-19.0	-37.1
20	103.2	90.8	35.5	7.4	-14.1	-32.2
40	105.2	92.8	37.5	9.4	-12.1	-30.2
60	106.7	94.4	39.0	11.0	-10.5	-28.7
80	108.0	95.7	40.3	12.3	-9.2	-27.4
Following Legume:						
0	48.3	35.9	-19.4	-47.5	-69.0	-87.1
20	53.1	40.8	-14.6	-42.6	-64.1	-82.3
40	55.1	42.8	-12.6	-40.6	-62.1	-80.3
60	56.7	44.3	-11.0	-39.1	-60.6	-78.7
80	58.0	45.6	-9.7	-37.8	-59.3	-77.4

Using this criterion, the additional yield due to P_2O_5 did not warrant its use on barley following any cropping history. For this reason, Table 12 does not include P_2O_5. The unprofitableness of applying additional P_2O_5 is likely explained by the high P_2O_5 soil-test values for most of the 18 locations. The table shows the optimum quantity of N to apply and the predicted increased yields and net returns at various prices by cropping history.

Barley following legume has a low requirement for N compared to the other cropping histories. This is because the N level following legume was nearly adequate for maximum yield. The near adeouacy of N in the soil is indicated by its high production index value, which was based on the check-plot yields./1 Check yields with legume history averaged 3555 pounds per acre, as compared to 1234, 2061 and 2360 for barley following grass seed, grain, and oats and vetch respectively.

Though yield increases from N were greatest for non-legume cropping histories, total yields were highest following legume. At the price of $.0225 for barley and $.15 for N, total per-acre yields of barley following cropping histories are: Legume, 3719 pounds; oats and vetch, 3045; grain, 2805; and grass seed, 2623. Even without the

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/1 The location with the highest check-plot yield was given a production index value of 100 and the location with the lowest check-plot yield was given an index of zero. Locations with intermediate check-plot yield levels took intermediate values.

Table 12. Valley Soils: Net Return and Increased Yield per Acre Obtained from Optimum Nutrient Application at Various Prices by Cropping History

Price per Pound Barley	Price per Pound N	Optimum Input N	Estimated Increased Yield	Net Return
$	$	Lbs.	Lbs.	$
Following Grass Seed:				
.03	.10	79.5	1512.0	37.41
.025	.10	73.1	1488.8	29.90
.0225	.10	69.3	1472.7	26.21
.0215	.10	67.7	1465.0	24.73
.02	.10	65.0	1452.1	22.54
.015	.10	54.1	1389.0	15.42
.03	.15	65.0	1452.1	33.82
.025	.15	58.1	1414.3	26.65
.0225	.15	54.1	1389.0	23.14
.0215	.15	52.4	1377.2	21.75
.02	.15	49.6	1357.5	19.70
.015	.15	39.2	1266.6	13.12
.03	.20	54.1	1389.0	30.85
.025	.20	47.2	1338.9	24.02
.0225	.20	43.4	1306.2	20.71
.0215	.20	41.7	1291.3	19.41
.02	.20	39.2	1266.5	17.50
.015	.20	29.7	1156.8	11.42

Table 12 cont.

Price per Pound Barley	N	Optimum Input N	Estimated Increased Yield	Net Return
$	$	Lbs.	Lbs.	$
Following Grain:				
.03	.10	42.6	809.8	20.03
.025	.10	39.2	797.3	16.01
.0225	.10	37.2	788.7	14.03
.0215	.10	36.3	784.6	13.24
.02	.10	34.8	777.7	12.07
.015	.10	29.0	743.9	8.26
.03	.15	34.8	777.7	18.11
.025	.15	31.1	757.4	14.27
.0225	.15	29.0	743.9	12.39
.0215	.15	28.1	737.6	11.65
.02	.15	26.6	727.0	10.55
.015	.15	21.0	678.3	7.02
.03	.20	29.0	743.9	16.52
.025	.20	25.3	717.0	12.86
.0225	.20	23.2	699.5	11.09
.0215	.20	22.4	691.5	10.40
.02	.20	21.0	678.3	9.36
.015	.20	15.9	619.4	6.11

Table 12 cont.

Price per Pound Barley	N	Optimum Input N	Estimated Increased Yield	Net Return
$	$	Lbs.	Lbs.	$
Following Oats and Vetch:				
.03	.10	39.2	745.8	18.45
.025	.10	36.1	734.3	14.75
.0225	.10	34.2	726.3	12.92
.0215	.10	33.4	722.6	12.20
.02	.10	32.1	716.2	11.11
.015	.10	26.7	685.0	7.61
.03	.15	32.1	716.2	16.67
.025	.15	28.7	697.5	13.14
.0225	.15	26.7	685.0	11.41
.0215	.15	25.8	679.2	10.72
.02	.15	24.5	669.5	9.71
.015	.15	19.3	624.6	6.47
.03	.20	26.7	685.0	15.21
.025	.20	23.3	660.3	11.85
.0225	.20	21.4	644.2	10.21
.0215	.20	20.6	636.8	9.57
.02	.20	19.3	624.6	8.62
.015	.20	14.6	570.4	5.63

Table 12 cont.

Price per Pound Barley	N	Optimum Input N	Estimated Increased Yield	Net Return
$	$	Lbs.	Lbs.	$
Following Legume:				
.03	.10	9.5	178.9	4.42
.025	.10	8.7	176.2	3.53
.0225	.10	8.2	174.2	3.10
.0215	.10	8.0	173.3	2.93
.02	.10	7.7	171.8	2.67
.015	.10	6.4	164.3	1.82
.03	.15	7.7	171.8	3.99
.025	.15	6.9	167.3	3.14
.0225	.15	6.4	164.3	2.74
.0215	.15	6.2	162.9	2.57
.02	.15	5.9	160.5	2.33
.015	.15	4.7	149.7	1.55
.03	.20	6.4	164.3	3.64
.025	.20	5.6	158.3	2.84
.0225	.20	5.2	154.4	2.45
.0215	.20	5.0	152.7	2.29
.02	.20	4.7	149.7	2.06
.015	.20	3.5	136.7	1.34

use of fertilizer, a good yield of barley is obtained following legume. Most benefit is derived from fertilizer when applied to barley following grass seed. Fertilizer application is also important to increased yields and return following grain and oats and vetch.

Malting Characteristics

Hannchen malting barley is an important crop in the Willamette Valley. It is the main variety of barley grown, constituting a major portion of the total barley production in the Valley. For the 5-year period from 1950 to 1954, average harvested acres and production were 143,780 acres and 5,224,400 bushels respectively. In 1956, the production of 6,660,000 bushels was valued at about 7 million dollars (5). For the same year, a farmer producing malting barley was able to earn an average premium of $2.72 per ton. This average premium for malting barley has varied from $4.80 in the 1953-55 period (the period during which the basic experiments for this study were conducted) to $1.91 in 1957 (6, 7).

Physical and chemical factors were studied to evaluate the effect of N on the malting quality of Hannchen barley. The factors were bushel weight, kernel size and weight, extract, protein content and diastatic power. Measurements of these features were obtained for 16 of the "Valley" soils locations.

To meet the malting quality standards, the 2-row barley grown in Oregon has to conform to certain requirements. Test weight must be above 50 pounds per bushel. The kernel size has to be such that less than 10 per cent of the kernels will pass through a screen of specified size ($5\frac{1}{4}/64'' \times 3/4''$). Diastatic power, the measure of the ability of the malt to convert soluble starch to reducing sugar, should have a value of 100-125°L. Protein content should range between 9 to 13 per cent. Values around 80 per cent are desirable for extract, and kernel weight should have a value from 40 to 44 grams per 1000 kernels.

To estimate the effect of N application upon the malting quality factors, a linear equation was used. It was of the form:

$$\hat{Y} = a + b_1 N + b_2 OVN + b_3 GsN + b_4 LgN + b_5 OV + b_6 Gs + b_7 Lg.$$

Estimated values for the various malting factors are denoted by $\hat{Y}$. N refers to pounds of nitrogen applied per acre. The other terms from b_2 to b_7 refer to cropping history. OV means that oats and vetch preceded the barley, for Gs it was grass seed and for Lg a legume. The fourth history, barley following grain, is implicit in the function. It is the only history left when the other three are deleted from the equation. The variation in the different

Table 13. Valley Soils: Malting Factor Values for t for Coefficients of Regression and Coefficients of Determination

Independent Variables	Extract	Significance Level*	Bushel Weight	Significance Level*	Kernel Size	Significance Level*
N	7.86	.00001	4.28	.00006	5.09	.00001
OVN	0.85	.40	0.84	.40	0.47	.67
GsN	1.80	.07	0.86	.39	1.56	.12
LgN	0.90	.37	0.46	.65	0.56	.58
OV	1.53	.13	2.58	.01	1.14	.25
Gs	1.72	.09	0.95	.34	0.83	.39
Lg	3.49	.0007	1.57	.12	0.99	.32
R^2	0.66	**	0.28	**	0.36	**

Table 13 cont.

Protein Content	Significance Level*	Diastatic Power	Significance Level*	Kernel Weight	Significance Level*
9.12	.00001	6.48	.00001	4.47	.00002
1.66	.10	0.20	.84	0.005	--
2.45	.02	2.78	.006	1.49	.16
2.48	.02	1.38	.17	0.35	.76
0.54	.58	2.39	.02	1.52	.13
1.38	.19	0.59	.61	0.30	.76
3.35	.001	2.17	.04	0.69	.54
0.76	**	0.64	**	0.31	**

* Probability of obtaining as large or larger value of t by chance, given the hypothesis that the variables do not effect yield.
**Highly significant.

characteristics explained by this form of equation ranged from 28 to 76 per cent. All six coefficients of determination were highly significant. The coefficients of determination and the values of t for each regression coefficient for the different factors are shown in Table 13. For each characteristic, N is highly significant. The significance of the other terms varies over a wide range for a particular factor and between factors.

By using the predicting equations for each cropping history, estimates of the different malting characteristics can be made for various levels of N. The equations used to estimate the values shown in Table 14 were the following:

Extract:

Grass Seed: $\hat{Y} = 81.7812 - .024880\ N$

Grain: $\hat{Y} = 82.5326 - .038373\ N$

Oats and Vetch: $\hat{Y} = 81.8356 - .045002\ N$

Legume: $\hat{Y} = 80.4634 - .046999\ N$

Bushel Weight:

Grass Seed: $\hat{Y} = 54.1133 - .024562\ N$

Grain: $\hat{Y} = 54.8152 - .035507\ N$

Oats and Vetch: $\hat{Y} = 52.8548 - .024444\ N$

Legume: $\hat{Y} = 53.2972 - .028056\ N$

Kernel Size:

Grass Seed: $\hat{Y} = 3.27537 + .047948\ N$

Kernel Size cont.

Grain: $\hat{Y} = 1.95143 + .090507\ N$

Oats and Vetch: $\hat{Y} = 3.80548 + .103702\ N$

Legume: $\hat{Y} = 3.99722 + .070945\ N$

Protein Content:

Grass Seed: $\hat{Y} = 9.24063 + .021999\ N$

Grain: $\hat{Y} = 8.73200 + .037650\ N$

Oats and Vetch: $\hat{Y} = 8.93534 + .048572\ N$

Legume: $\hat{Y} = 10.3408 + .057817\ N$

Diastatic Power:

Grass Seed: $\hat{Y} = 62.3512 + .125823\ N$

Grain: $\hat{Y} = 65.8590 + 372456\ N$

Oats and Vetch: $\hat{Y} = 53.2068 + .354158\ N$

Legume: $\hat{Y} = 80.4555 + .530111\ N$

Kernel Weight:

Grass Seed: $\hat{Y} = 42.9369 -.024167\ N$

Grain: $\hat{Y} = 43.2297 -.049589\ N$

Oats and Vetch: $\hat{Y} = 42.0743 -.049677\ N$

Legume: $\hat{Y} = 42.3350 -.041900\ N$

When the values in Table 14 and the criteria values for the factors are compared, all factors meet the required standard except diastatic power. In the range of N called for to maximize net return, extract, kernel size, bushel weight, protein content and kernel weight show favorable values. Although diastatic power is low, it is improved by the application of N. However, this is a relatively unimportant factor in Hannchen barley since Hannchen barley is not used as a source for this malting factor. The predicted factor values indicate that the nutrient application estimated for optimum yield and net return by cropping history for the "Valley" soils also result in values that conform to the standards of malting barley. The actual malting characteristic values are shown in Table 15 of the Appendix.

Figures 8, 9 and 10 show the relationship between the factors. Bushel weight, kernel weight and extract values decrease as N is increased, whereas protein, kernel size and diastatic power values increase as N is increased. The increase in kernel size values means that there is a larger proportion of undersized kernels which fall through the screen, thus kernel size decreases.

Table 14. Valley Soils: Predicted Malting Factor Values for Hannchen Barley for Various Nitrogen Levels and Different Cropping Histories

Lbs. N per Acre	-- Malting Factors --					
	Extract	Bushel Weight	Kernel Size	Protein Content	Diastatic Power	Kernel Weight
	%	Lbs.	%	%	°L	gms/1000
Following Grass Seed:						
0	81.8	54.1	3.3	9.2	62.4	42.9
15	81.4	53.7	4.0	9.6	64.2	42.6
30	81.0	53.4	4.7	9.9	66.1	42.2
45	80.7	53.0	5.4	10.2	68.0	41.8
60	80.3	52.6	6.2	10.6	69.9	41.5
75	79.9	52.3	6.9	11.0	71.8	41.1
90	79.5	51.9	7.6	11.2	73.7	40.8
Following Grain:						
0	82.5	54.8	2.0	8.7	65.9	43.2
15	82.0	54.3	3.3	9.3	71.4	42.5
30	81.4	53.8	4.7	9.9	77.0	41.7
45	80.8	53.2	6.0	10.4	82.6	41.0
60	80.2	52.7	7.4	11.0	88.2	40.2
75	79.6	52.2	8.7	11.6	93.8	39.5
90	79.1	51.6	10.1	12.1	99.4	38.8
Following Oats and Vetch:						
0	81.8	52.8	3.8	8.9	53.2	42.1
15	81.2	52.5	5.4	9.7	58.5	41.3
30	80.5	52.1	6.9	10.4	63.8	40.6
45	79.8	51.8	8.5	11.1	69.1	39.8

Table 14 cont.

Lbs. N per Acre	-- Malting Factors -- Extract	Bushel Weight	Kernel Size	Protein Content	Diastatic Power	Kernel Weight
	%	Lbs.	%	%	°L	gms/1000
Following Oats and Vetch cont.						
60	79.1	51.4	10.0	11.8	74.4	39.1
75	78.5	51.0	11.6	12.6	79.8	38.3
90	77.8	50.6	13.1	13.3	85.1	37.6
Following Legume:						
0	80.5	53.3	4.0	10.3	80.4	42.3
15	79.8	52.9	5.1	11.2	88.4	41.7
30	79.0	52.4	6.1	12.1	96.4	41.1
45	78.3	52.0	7.2	12.9	104.3	40.4
60	77.6	51.6	8.2	13.8	112.3	39.8
75	76.9	51.2	9.3	14.7	120.2	39.2
90	76.2	50.8	10.4	15.5	128.2	38.6

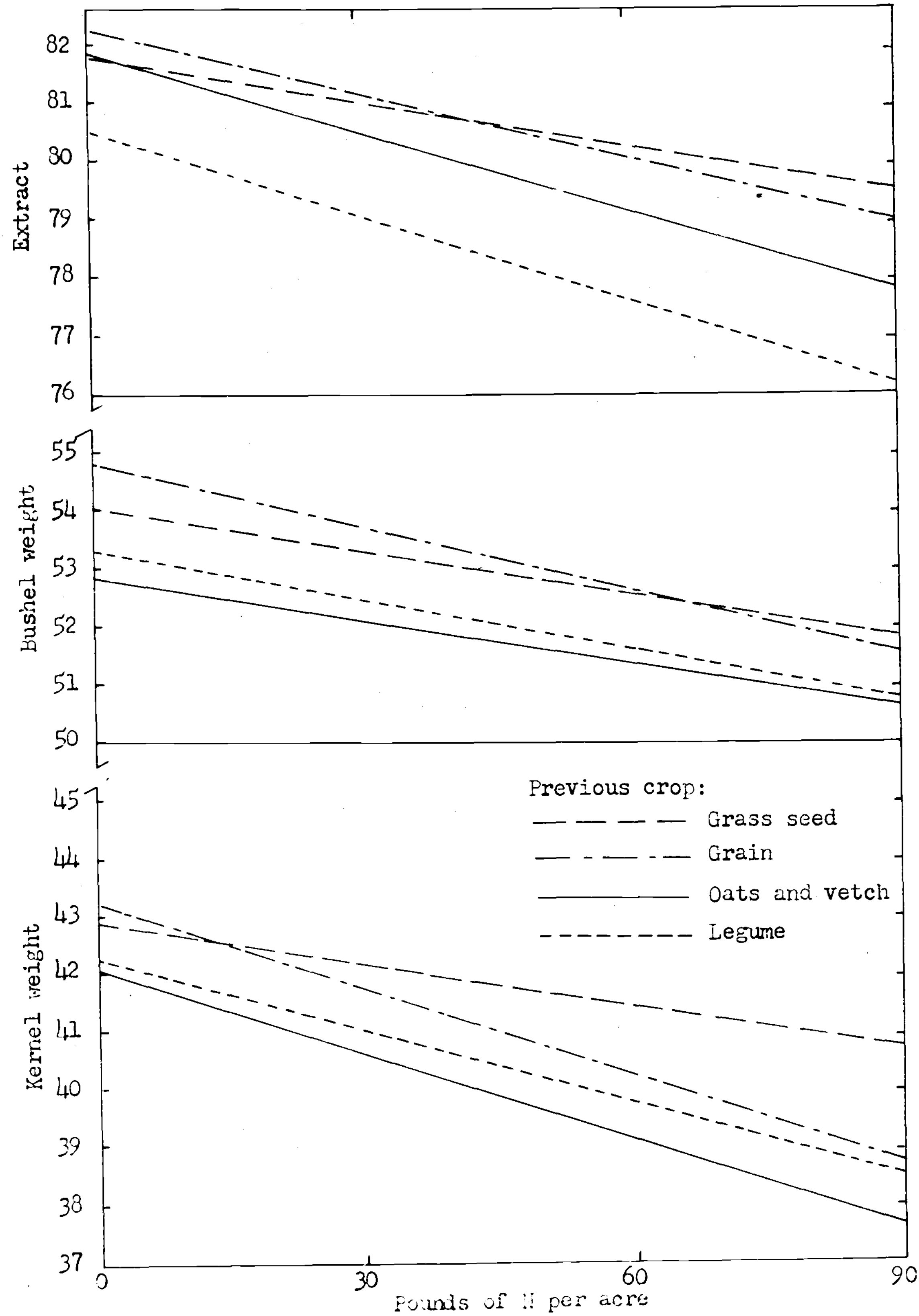

Figure 8. Valley soils: Malting factor values for Hannchen barley for various N levels and different cropping histories.

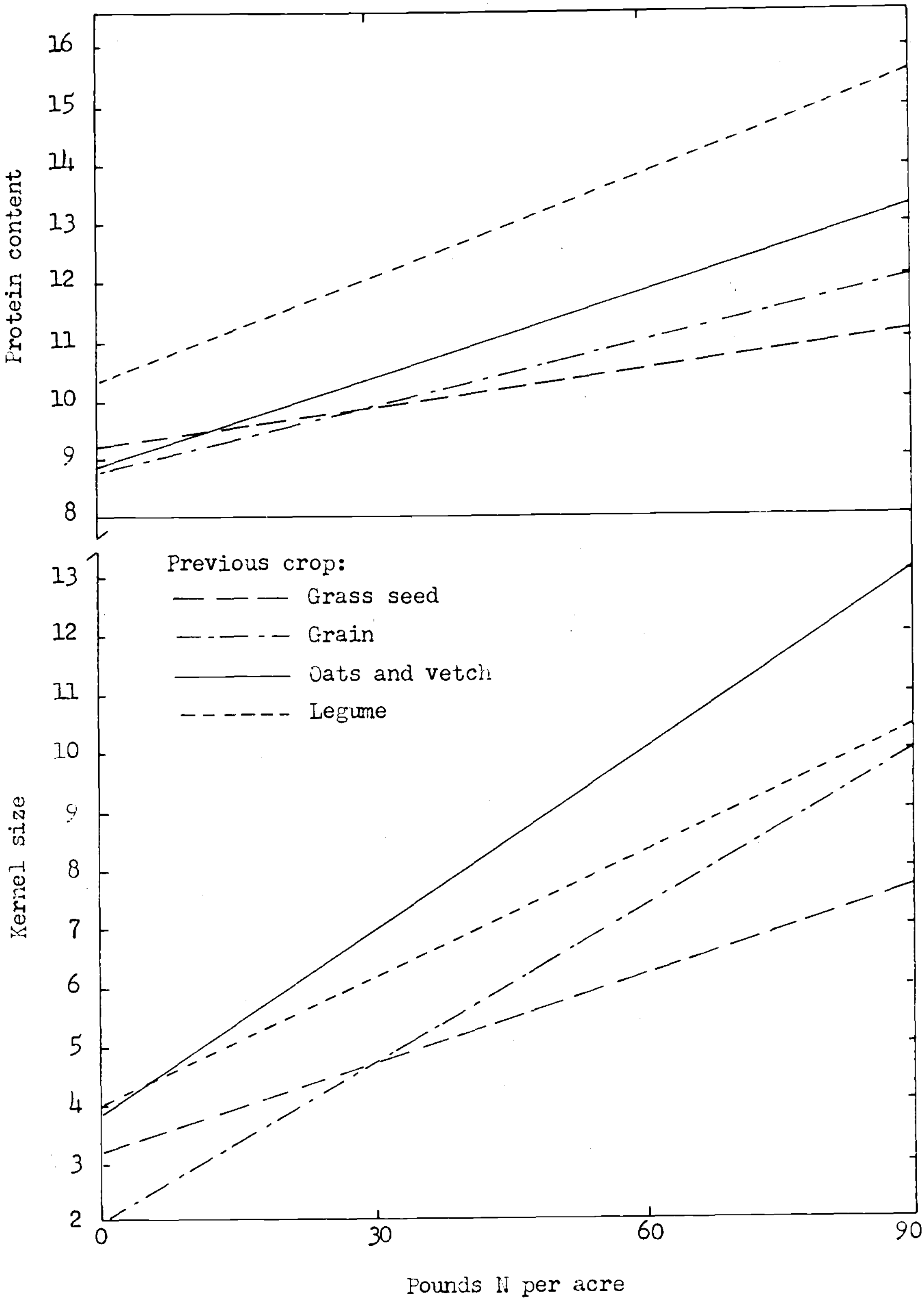

Figure 9. Valley Soils: Malting factor values for Hannchen barley for various N levels and different cropping histories.

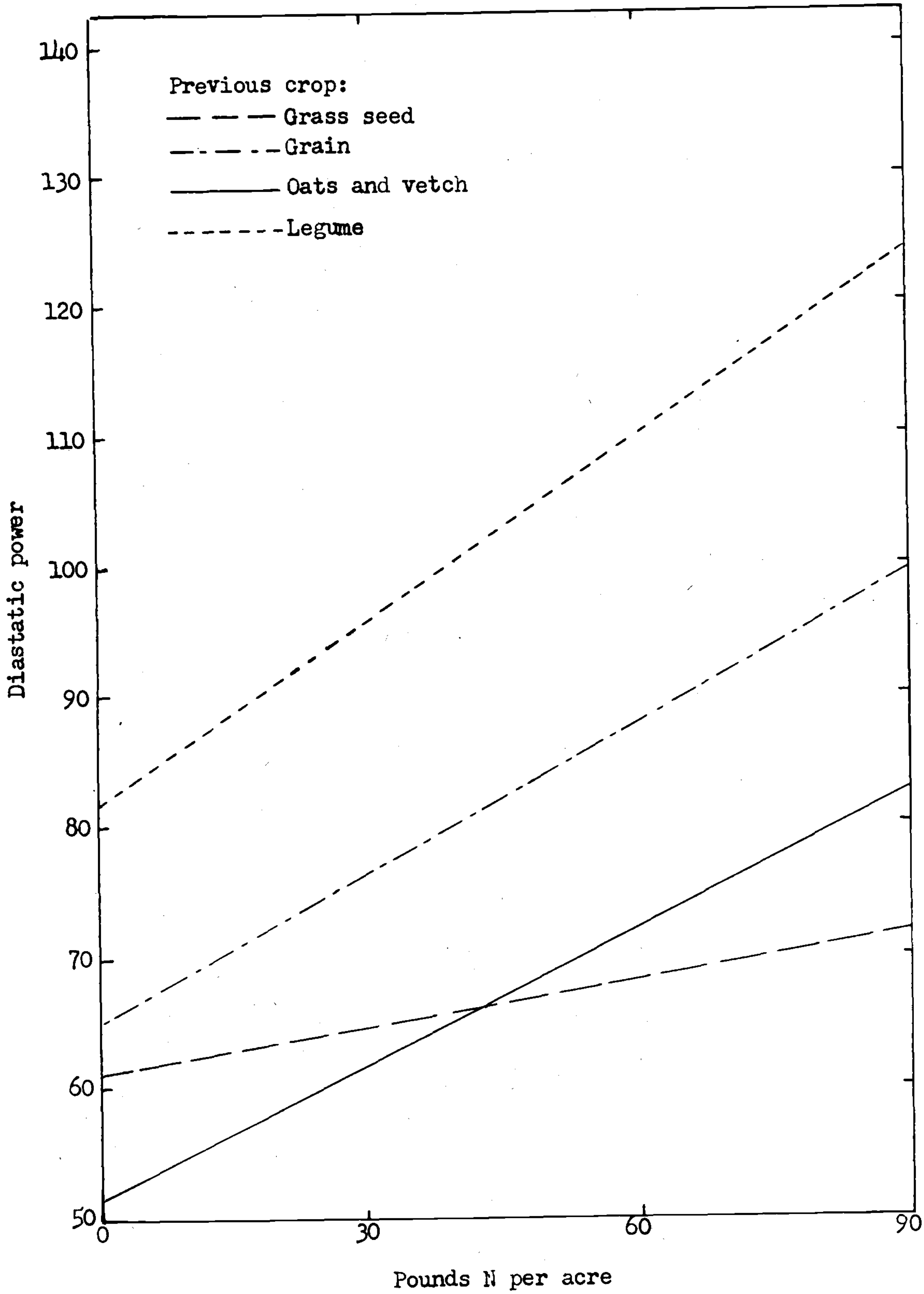

Figure 10. Valley Soils: Diastatic power values for Hannchen barley for various N levels and different cropping histories.

SUMMARY

Hannchen malting barley is an important crop in the Willamette Valley. It accounts for a major portion of the total barley production in the Valley. Fertilizer trials were carried out on representative soil types in the Valley over a 3-year period to obtain information on the effect of different fertilizer treatments on the yield of Hannchen barley. Kernel-quality measurements were also made so as to study the effect of fertilizer treatments on the malting quality of the grain. The soils were classed as either "Hill" or "Valley." Eighteen locations were on "Valley" soils and seven were on "Hill" soils.

To derive maximum benefit from these data, concepts of production economics were applied to interpret them. The nature of the data made it possible to derive a general production function; the function is not limited to a particular year or location.

Production functions permit: a) estimation of crop yields at different fertilizer levels, b) determination of the optimum rates of nutrients to apply given the prices of factors and product and c) determination of the effect of fertilizer on the malting quality of the barley.

The data were from randomized block experiments with three replications at each location. Nitrogen rates were

0, 30, 60 and 90 pounds per acre and rates of phosphorus were 0, 40 and 80 pounds. Sulphur as gypsum was applied to each plot at the rate of 20 pounds per acre. The source of nitrogen was ammonium nitrate and treble superphosphate was the source of phosphorus.

There was a considerable amount of variation in yield between the locations. For the "Hill" soils, the lowest check-plot yield was 700 pounds of barley per acre and the highest was 2601 pounds. Check-plot yields ranged from a low of 851 pounds to a high of 3483 pounds per acre on the "Valley" soils.

Predicting equations were derived for yield for both the "Hill" and "Valley" soils and for malting factors for the "Valley" soils. Isoquants, isoclines and economic optima for the fertilization of barley were predicted for the "Hill" soils.

A square-root transformation of a quadratic equation best explained the variation in the 183 yield observations for the "Hill" soils. The equation was of the form:

$$\hat{Y} = a + b_1 N + b_2\sqrt{N} + b_3 P + b_4\sqrt{P} + b_5\sqrt{NP}$$

$$+ b_6 \sqrt{\text{Prod } N} + b_7 \sqrt{\text{Prod } P},$$

where $\hat{Y}$ refers to yield in pounds per acre above check plot, N to available N per acre, P to available P_2O_5 per acre, NP to interaction between N and P_2O_5, Prod N to an interaction between the productivity level of the soil and the application of N, and Prod P to an interaction between the productivity level and the application of P_2O_5. The productivity level of the soil was determined by constructing a production index. Values of the index were determined by giving the location with the highest check-plot yield a value of 100 and a value of zero to the location with the lowest check-plot yield. Locations with intermediate check-plot yield levels were given intermediate values.

For the "Hill" soils, the coefficient of determination was highly significant. The t value for the N productivity level term was highly significant and significant for the linear N term. Yield response to N was strong. Interaction between N and P_2O_5 was also important to increased yields.

A square-root transformation of a quadratic equation best explained the variation in the 462 yield observations of the "Valley" soils. It was of the form:

$$\hat{Y} = a + b_1 N + b_2\sqrt{N} + b_3 P + b_4\sqrt{P} + b_5\sqrt{NP} + b_8\sqrt{Prod\ N}$$

$$+ b_7\sqrt{Prod\ P} + b_8\sqrt{GsN} + b_9\sqrt{LgN} + b_{10}\sqrt{OVN}.$$

The terms from b_1 to b_7 are the same as for the "Hill" soils equation. Yield in pounds per acre above check-plot yield is again denoted by $\hat{Y}$ and OVN, LgN and GsN refer to cropping history: barley following oats and vetch, legume, and grass seed respectively. The grain-cropping history is implicit in the function since only grain cropping is left when the other three cropping histories are deleted. This composite function explained slightly over half of the total variation in yield. The coefficient of determination was significant at the 99 per cent level. As was the case for the "Hill" soils, the regression coefficients for N were more significant than the others. The coefficient for barley following grass seed was positive and highly significant, indicating that nitrogen application after grass seed greatly increased yield. On the other hand, nitrogen application on barley following legume was less beneficial as indicated by the negative $\sqrt{LgN}$ coefficient. The coefficient for $\sqrt{LgN}$ was also highly significant.

Although the nutrients were found to be complementary at the specified prices for N, P_2O_5 and barley, it was not profitable to apply P_2O_5. The unprofitableness of applying additional P_2O_5 is likely explained by the high P_2O_5 soil-test values for most of the "Valley" soils locations.

Economic optima yields were predicted when only N was used. Barley following legume had a low requirement for N compared to the other cropping histories. This was because check-plot yields with legume history averaged 3555 pounds per acre, as compared to 1234, 2061 and 2360 for barley following grass seed, grain, and oats and vetch, respectively. Though yield increases from N were greatest for non-legume cropping histories, total yields were still highest following legume. Even without the use of fertilizer, a good yield of barley was obtained following legume. Most benefit was derived from fertilizer when applied to barley following grass seed. Fertilizer application was also important to increased yields and return following grain and oats and vetch.

Factors considered to evaluate the effect of N on the malting quality of Hannchen barley were bushel weight, kernel size and weight, extract, protein content and diastatic power. To meet the malting quality standards, these factors have to conform to certain values.

To estimate the effect of N application upon the various factors, a linear equation was used. It was of the form:

$$\hat{Y} = a + b_1 N + b_2 OVN + b_3 GsN + b_4 LgN + b_5 OV + b_6 Gs + b_7 Lg.$$

Estimated values for the various factors are denoted by $\hat{Y}$; N refers to pounds of nitrogen applied per acre. The other terms from b_2 to b_7 refer to cropping history. OV means that oats and vetch preceded the barley; for Gs it was grass seed and for Lg a legume. The fourth history, barley following grain, is implicit in the function. It is the only history left when the other three are deleted from the equation. The variation in the different characteristics explained by this form of equation ranged from 28 to 76 per cent. All six coefficients of determination were highly significant.

By using the predicting equations for each cropping history, estimates of the different characteristics were made for various levels of N. In the range of N called for to maximize net return, extract, kernel size, bushel weight, protein content and kernel weight met the required standards. Diastatic power, though low, was improved by N application. This factor, however, is relatively unimportant for Hannchen barley.

Bushel weight, kernel weight and extract values decreased as N was increased, whereas protein, kernel size and diastatic power values increased as N was increased. The increased kernel size values meant a larger percentage of kernels fell through the screen, hence kernel size decreased.

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APPENDIX

Table 15. Valley Soils: Fertilizer Treatments and Malting Factor Values* for Hannchen Barley Grown in Fertilizer Tests 1953-1955

Lbs. per Acre $N - P_2O_5 - S$	— Malting Factors — Extract	Bushel Weight	Kernel Size	Protein Content	Diastatic Power	Kernel Weight
Location 1**						
0 - 0 - 20	82.5	55.9	2.2	9.3	77.0	43.1
30 - 0 - 20	82.4	55.7	1.9	9.0	70.7	42.9
60 - 0 - 20	80.0	54.2	5.7	11.4	81.3	39.7
90 - 0 - 20	79.6	53.5	8.4	13.1	93.3	40.4
0 - 80 - 20	82.9	55.8	1.8	8.8	57.7	43.5
30 - 80 - 20	81.0	56.0	4.0	11.4	78.7	40.4
60 - 80 - 20	79.2	54.5	12.7	13.0	83.7	36.6
90 - 80 - 20	83.0	52.6	1.7	9.7	71.0	41.3
Location 2						
0 - 0 - 20	82.1	52.3	2.0	8.6	56.7	40.8
30 - 0 - 20	80.4	51.9	4.0	10.0	50.0	39.0
60 - 0 - 20	79.9	51.6	4.7	11.2	71.7	38.1
90 - 0 - 20	78.1	51.2	6.7	13.1	70.3	36.9
0 - 80 - 20	82.0	52.4	2.0	8.4	46.0	42.6
30 - 80 - 20	80.9	51.8	3.8	9.6	55.0	40.8
60 - 80 - 20	79.2	51.1	7.4	11.3	59.7	37.4
90 - 80 - 20	77.7	51.1	8.7	13.7	81.3	37.3
Location 3						
0 - 0 - 20	80.4	50.5	4.5	9.5	59.3	43.9
30 - 0 - 20	78.7	50.5	4.1	9.3	52.7	46.8
60 - 0 - 20	78.8	49.6	6.9	9.9	56.0	44.8
90 - 0 - 20	78.5	49.0	7.1	11.5	82.3	44.6
0 - 80 - 20	79.8	50.3	5.1	10.0	63.0	44.3
30 - 80 - 20	80.7	50.2	4.2	9.0	50.7	45.2
60 - 80 - 20	79.7	50.2	4.3	9.9	60.3	43.2
90 - 80 - 20	78.1	49.8	5.1	11.7	84.0	44.2
Location 4						
0 - 0 - 20	83.2	54.2	2.3	9.3	57.3	43.4
30 - 0 - 20	82.4	54.2	2.1	9.1	56.3	43.1
60 - 0 - 20	81.3	52.8	3.6	10.9	69.0	41.2
90 - 0 - 20	80.0	52.2	5.9	11.6	80.7	38.7
0 - 80 - 20	82.9	54.4	2.6	8.8	57.3	44.1
30 - 80 - 20	83.0	53.9	2.7	8.6	54.3	42.9
60 - 80 - 20	81.6	53.1	2.8	10.1	67.7	41.8
90 - 80 - 20	80.4	52.1	6.9	11.2	83.3	38.3
Location 5						
0 - 0 - 20	79.7	49.3	8.8	9.6	61.0	36.5
30 - 0 - 20	79.0	47.3	13.9	11.0	69.0	35.7
60 - 0 - 20	76.9	45.6	19.8	13.1	80.0	34.3
90 - 0 - 20	75.4	46.7	18.5	14.1	93.0	33.9
0 - 80 - 20	80.4	48.3	9.8	9.7	56.0	36.3
30 - 80 - 20	79.2	47.7	12.8	11.0	68.0	35.7
60 - 80 - 20	77.1	47.2	17.2	12.9	85.0	37.3
90 - 80 - 20	75.4	46.9	19.0	15.7	100.0	32.8
Location 6						
0 - 0 - 20	80.3	55.7	3.3	9.4	74.7	40.1
30 - 0 - 20	81.0	55.2	4.4	8.9	63.0	40.9
60 - 0 - 20	80.2	52.9	7.7	9.6	68.0	37.2
90 - 0 - 20	78.8	51.1	19.0	10.9	79.3	36.9

Table 15 cont.

Lbs. per Acre N - P_2O_5 - S	-- Malting Factors -- Extract	Bushel Weight	Kernel Size	Protein Content	Diastatic Power	Kernel Weight
Location 6 cont.						
0 - 80 - 20	80.6	56.0	2.6	9.4	69.3	43.2
30 - 80 - 20	81.3	55.5	3.2	8.7	67.7	41.3
60 - 80 - 20	79.8	53.7	8.3	9.5	66.0	38.4
90 - 80 - 20	78.6	51.7	18.6	10.9	82.0	35.2
Location 7						
0 - 0 - 20	82.5	55.4	2.7	9.4	62.3	43.5
30 - 0 - 20	81.5	53.9	6.3	10.6	65.7	39.6
60 - 0 - 20	79.9	52.3	13.1	11.9	73.7	36.9
90 - 0 - 20	78.7	51.2	18.0	12.8	74.7	35.3
0 - 80 - 20	82.4	55.8	2.9	9.8	66.3	43.5
30 - 80 - 20	82.0	54.4	4.8	9.8	62.0	41.0
60 - 80 - 20	79.8	52.6	12.8	12.4	83.3	37.3
90 - 80 - 20	78.6	50.3	25.0	13.7	90.3	33.4
Location 8						
0 - 0 - 20	82.6	55.0	2.3	9.2	70.7	42.2
30 - 0 - 20	82.6	55.1	2.4	9.8	68.7	42.6
60 - 0 - 20	80.3	53.7	6.1	11.2	89.0	40.6
90 - 0 - 20	79.4	52.8	10.0	12.6	100.7	36.4
0 - 80 - 20	83.4	54.8	2.8	9.0	65.7	42.4
30 - 80 - 20	80.7	55.2	2.7	10.5	72.7	42.1
60 - 80 - 20	80.9	53.9	5.4	11.4	89.3	41.3
90 - 80 - 20	79.8	52.9	9.4	13.0	102.7	37.4
Location 9						
0 - 0 - 20	82.0	55.6	2.5	9.8	73.0	43.1
30 - 0 - 20	82.5	54.6	3.4	8.5	57.3	43.2
60 - 0 - 20	81.6	54.3	4.4	9.0	60.3	42.3
90 - 0 - 20	80.9	53.6	7.2	10.5	69.0	40.9
0 - 40 - 20	83.6	55.5	2.5	9.9	66.0	43.0
30 - 40 - 20	82.5	54.7	3.2	8.4	58.7	42.7
60 - 40 - 20	81.5	54.0	4.5	9.6	64.3	42.0
90 - 40 - 20	80.3	53.3	6.5	10.3	67.0	42.5
0 - 80 - 20	81.6	55.5	2.2	9.7	79.3	43.3
30 - 80 - 20	82.7	54.1	2.5	8.4	58.3	43.3
60 - 80 - 20	82.0	54.3	4.0	8.9	59.3	43.0
90 - 80 - 20	80.8	52.7	6.4	9.8	71.3	40.2
Location 10						
0 - 0 - 20	79.7	53.6	5.5	10.8	80.7	41.9
30 - 0 - 20	78.2	52.5	6.8	11.7	81.3	40.1
60 - 0 - 20	77.1	51.4	11.3	12.8	92.7	38.7
90 - 0 - 20	75.0	50.1	15.8	15.0	96.7	36.7
0 - 40 - 20	80.5	53.5	4.3	9.9	73.3	43.2
30 - 40 - 20	79.4	53.0	6.2	10.8	81.7	40.9
60 - 40 - 20	78.3	52.2	8.5	11.5	84.0	39.1
90 - 40 - 20	75.8	50.4	17.2	14.9	113.0	35.8
Location 11						
0 - 0 - 20	82.0	52.5	4.0	8.7	66.7	39.9
30 - 0 - 20	81.7	52.2	4.2	9.4	68.3	40.7
60 - 0 - 20	80.3	51.5	6.3	10.8	84.7	40.8
90 - 0 - 20	78.7	50.6	9.0	12.6	100.0	39.3
30 - 40 - 20	81.0	52.0	4.8	9.8	75.0	40.8
60 - 40 - 20	81.1	51.9	5.5	10.1	82.0	40.2
90 - 40 - 20	78.8	50.7	8.1	12.3	104.3	39.4
30 - 80 - 20	81.4	51.9	5.6	9.4	71.0	40.8
60 - 80 - 20	79.3	51.8	5.9	10.9	74.7	40.4
90 - 80 - 20	78.8	51.6	7.5	12.6	100.3	39.3

Table 15 cont.

Lbs. per Acre N - P_2O_5 - S	-- Malting Factors -- Extract	Bushel Weight	Kernel Size	Protein Content	Diastatic Power	Kernel Weight
Location 13						
0 - 0 - 20	81.8	54.0	1.5	10.3	74.0	44.7
30 - 0 - 20	78.9	52.6	5.1	13.0	112.0	41.6
60 - 0 - 20	78.0	50.6	10.0	14.4	127.0	38.3
90 - 0 - 20	76.6	52.3	4.7	15.8	141.3	41.4
30 - 40 - 20	79.3	51.7	5.8	12.1	108.0	40.5
60 - 40 - 20	77.5	51.4	6.0	14.6	123.0	40.4
90 - 40 - 20	76.5	50.9	6.9	16.4	147.3	40.6
30 - 80 - 20	79.3	51.3	6.8	12.6	120.0	39.7
60 - 80 - 20	76.9	51.2	7.4	15.9	132.3	39.5
90 - 80 - 20	77.6	51.4	6.0	15.6	137.0	41.2
Location 15						
0 - 0 - 20	81.4	55.0	1.4	9.9	81.3	44.7
30 - 0 - 20	81.8	54.2	1.7	9.8	83.0	44.7
60 - 0 - 20	79.9	52.6	2.6	11.1	102.3	43.1
90 - 0 - 20	77.7	52.1	5.1	13.3	109.0	41.5
30 - 40 - 20	81.4	54.3	1.4	10.1	79.7	44.9
60 - 40 - 20	80.0	52.7	3.5	11.6	95.7	41.0
90 - 40 - 20	78.1	50.8	7.8	13.1	118.0	39.7
30 - 80 - 20	82.3	54.6	1.6	9.6	79.7	44.8
60 - 80 - 20	80.0	52.8	2.9	11.6	98.6	42.1
90 - 80 - 20	77.3	50.8	6.6	13.9	128.7	39.0
Location 16						
0 - 0 - 20	81.9	55.9	1.3	8.8	54.6	46.8
30 - 0 - 20	81.8	55.8	1.6	9.0	44.6	46.0
60 - 0 - 20	80.3	54.4	4.3	11.3	77.0	45.5
90 - 0 - 20	78.6	54.1	4.8	11.3	84.3	43.7
30 - 40 - 20	81.3	55.5	2.5	9.5	50.0	46.1
60 - 40 - 20	80.7	55.4	3.6	10.6	66.6	45.2
90 - 40 - 20	78.5	53.9	4.5	13.0	101.3	43.3
Location 17						
0 - 0 - 20	82.5	54.2	6.2	9.1	92.3	42.4
30 - 0 - 20	81.5	53.3	10.6	9.6	100.7	41.1
60 - 0 - 20	80.2	51.5	16.0	11.6	123.0	39.3
90 - 0 - 20	79.0	51.0	21.2	12.5	131.7	36.5
30 - 40 - 20	81.4	53.4	9.5	9.7	86.3	41.4
60 - 40 - 20	80.6	52.3	13.8	11.1	101.3	40.9
90 - 40 - 20	78.8	51.7	15.7	12.6	103.7	39.4
Location 18						
0 - 0 - 20	80.7	52.6	6.3	9.9	59.0	38.4
30 - 0 - 20	79.8	52.5	9.5	10.7	64.0	37.3
60 - 0 - 20	79.1	51.8	10.0	11.4	75.7	37.8
90 - 0 - 20	77.7	50.8	10.5	12.8	81.5	37.6
60 - 40 - 20	78.9	51.9	10.0	11.7	79.6	38.3
90 - 40 - 20	77.5	50.7	12.3	13.2	70.0	37.4

* Malting factor values were not obtained for locations 12 and 14.
**Location numbers by cropping histories were: 4, 6, 8, 11, 15, 17 following grain; 1, 3, 9, 18 following grass seed; 10, 13 following legume; 2, 5, 7, 16 following oats and vetch.