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The Fertilization Of Potatoes In Peru

I. A Summary and Interpretation of Data From Field Experiments Completed From 1959 Through 1964 in the Sierra

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Soil fertility research in the Peruvian Andes is fraught with difficulties of a magnitude seldom encountered by agricultural scientists in the United States or in other so-called "developed" nations. Few permanent research stations exist, and soil scientists have access to little land area that is subject to their direct supervision. Most of the field work is therefore dependent on cooperative agreements between the researcher and the private land owner. Farmer cooperation on a year-to-year basis is relatively easy to obtain, but long-time commitments to desirable experimental sites are difficult to maintain.

Poor roads over long distances of extremely rough terrain prohibit the transport of heavy farm equipment from research centers, and farmer-owned tractor power is a rarity. Most of the routine cultural operations must therefore be done with animal or human power. Poor transportation facilities also restrict the use of delicate scientific instruments in the field. Other systems of rapid communication (telephone, radio, etc.) are either inadequate or non-existent, and the passage of vital information between the cooperator and the researcher is frequently too slow for appropriate and timely action.

Under these conditions, the so-called "team approach" to field research problems is not onlv desirable but essential. As currently organized, the national research program in soils is directed from the *Estacion Experimental Agricola* at La Molina (Lima), but crucial members of the team are scattered throughout the sierra. These members consist of (1) farmers who provide land and labor for field experiments and (2) local technicians *(Ingenieros Agronomos)* who conduct the field work and maintain liaison between the program administrator and the farmer-cooperator.

It would scarcely be possible here to cite all of the participants who have contributed to this report; and to those who must remain anonymous, the authors wish to express their appreciation. A special note of recognition is extended to the following individuals who in their various capacities have made vital contributions to this endeavor.

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The Fertilization of Potatoes in Peru
I. A Summary and Interpretation of Data from Field Experiments Completed from 1959 Through 1964 in the Sierra

Introduction

In Peru, as in most of the world, agriculture is a highly satisfying enterprise. In Peru, as elsewhere, it is also a profitable enterprise when all of the known factors of production are brought to bear in the provision of a favorable environment for plants and animals. Subsistence farming results when one or more of these production factors is omitted or inappropriately applied.

In the production of crops as food, clothing, or shelter for either humans or animals, the factors or practices in the following list repeatedly have been proven important in obtaining profitable yields.

1. The selection of high-yielding, adapted varieties or species.
2. A productive soil adequately supplied with plant nutrients, water, and oxygen.
3. Proper seed-bed or land preparation.
4. Timely seeding.
5. Adequate sunlight and temperature to support optimum vegetative growth or seed development.
6. Control of competitive weeds.
7. Timely and effective control of destructive insects and diseases.
8. Timely and efficient harvesting.
9. Facilities for storing and preserving the marketable product.

In the Peruvian sierra, the potato is the most important food crop, with some 230,000 hectares seeded annually. Unit yields are quite low, however. Yearly average yields are about 5,500 kg. per hectare with no evidence of any upward trend during the period 1948 to 1960. These years encompass a period of rapid technological development in agriculture, but the absence of any significant upward trend in potato yields indicates that these advances in technology are not being applied to this important Andean crop.

For both practical and economic reasons, all of the modern farming methods are not presently available to every farmer in the sierra. Many of the more important practices are within his reach, however, and recent research data indicate that their efficient application could more than double the unit yields of potatoes immediately. The purpose of this bulletin is to review the potato fertility program of SIPA and to present representative data illustrating the importance of balanced fertilization on potato yields. It is hoped that this information will induce more farmers to adopt not only the fertilization practices suggested by the data but also the other improved practices available to them.

Climate and Soils of the Andean Sierra

The climate of a region is of course not subject to practical human control, and much of the sierra is liable to climatic extremes of devastating magnitude. Because of its altitude and geographic position, drought, frost, and hail are constant hazards throughout much of the potato-producing area.

Climate, along with time, topography, and vegetation is also a major factor in the formation of soil from its geological parent material, and the interacting effects of these factors in the Sierra have resulted in soils with a wide range in chemical and physical properties as well as in their adaptability to modern agricultural technology. Few soils maps of the area exist. Detailed studies of isolated areas on a scale suitable for operational planning have been made, but essentially none of them have been published for mass distribution. Perhaps the best example to date is the soils map of the Mantaro Valley (Mapa de suelos del Valle del Mantaro. Ministerio de Agricultura, SIPA, and Point Four. 1960). Six more or less distinct groups of soils (soil associations) have been recognized and described (4). These associations were separated primarily on the basis of topography and elevation and are recognized as follows:

1. Lithosols of the western slopes (Lithosoles de las Pendientes occidentales).
2. Soils of the Andean Valleys (Asociación de valles Andinos).
3. Soils of the Interandean Slopes (Asociación Puna).
4. Titicaca Association (Asociación Titicaca).
5. Lithosols and hydromorphic soils of the high mountain (Lithosols e hidromorphicos de las montanas altas).
6. Frigid zone soils (Suelos de la Region Frigida).

For further description of these associations, the reader is referred to the cited publication. Suffice it to point out here that groups 2-4 above are best adapted both climatically and topographically to intensive cultivation. In many areas, however, population pressure is so intense that essentially every accessible acre is used for cultivated crops with considerable regularity.

The inherent fertility status of these soils is quite variable, but they are generally low in plant available nitrogen and phosphorus. Although the content of organic matter is frequently quite high, climatic conditions are such that it is relatively stable. For this reason, organic matter content as a fertility index is perhaps less useful than it would be under a more moderate climate.

Evolution of the Research Program in Soil Fertility

Historically, soil fertility research in Peru has been based upon the use of *guano de islas*, the manurial deposits of some three species of birds which inhabit the off-shore islands of Peru. This was logical for two reasons. In the first place, it is a local product which can be mined and marketed economically without alteration. Secondly, it is a carrier of the three major plant nutrient elements (nitrogen, phosphorus, and potas-

sium). The approximate N-P_2O_5-K_2O analyses of the two types marketed (guano rico and guano pobre) are 12.5-9-2 and 4-14-2, respectively.

Exportation and increased local demand have resulted in the depletion of the initial deposits, however, and annual depositions are diminishing. A frequently-mentioned cause of this decline in annual production is the enormously expanded fishing industry, which is believed to have resulted in a decreased food supply for the birds and hence a diminishing bird population. While there is little doubt that the bird population has declined, the evidence in support of the above conclusion is beyond the scope of this presentation.

In any event, it has become increasingly evident that guano alone cannot continue to fill the ever-increasing demand for fertilizers in an expanding agriculture. Agricultural scientists recognized this fact early in the last decade, and they began to shift their research efforts toward the evaluation and use of chemically synthesized fertilizer materials.

Scientifically, these materials offer several advantages over guano in soil fertility research. Not only does guano vary considerably in the major nutrients but also it contains undetermined quantities of other essential elements which may at times influence experimental results. The chemical forms of the nitrogen and phosphorus in guano are also quite variable, depending upon its age and degree of decomposition. The rate at which these elements become available to plants under different soil and climatic conditions is therefore difficult to predict. Finally, since guano is a mixture of nutrient elements, it is impossible to evaluate the effect on one nutrient independently of all others.

Chemical fertilizers, on the other hand, are essentially pure materials. Their chemical forms are known, and their reactions with different soils can be predicted with considerable accuracy. In addition, these pure, single nutrient carriers permit either the study of only one element at a time or an evaluation of the combined effects of several elements varied independently.

The present soil fertility program, not only in potatoes but other crops as well, may therefore be said to have evolved in three stages: (1) *an early stage*, in which the total effect of all of the nutrients contained in *guano de islas* was evaluated; (2) *a transitional stage*, during which guano was supplemented with chemical fertilizers; and (3) *the current stage*, which is based on the premise that foreseeable demands for plant nutrients can only be satisfied through an increasingly wider use of chemical fertilizers. The research summarized below deals with the latter two stages in this evolution.

Experiments With Guano or Barnyard Manure Supplemented With Chemical Fertilizers

During the decade 1950-1960, a large number of experiments of this type were carried out throughout the sierra. Summaries of some of this work have been published. For example, Calzada Benza *et al.* (1) reported that 100 Kg/Ha* each of N,

*Metric system abbreviations with appropriate conversion factors for converting yields to U.S. units: Kg=Kilogram=2.2046 lbs.; Ha=hectare=2.471 acres; M.T.=metric ton=1000 Kg=22.046 cwt.; (Kg/Ha)0.892=lbs./A.; (M.T./Ha) 8.92=cwt/A.

P_2O_5 and K_2O gave a 62 percent increase over the check (12,800 vs 7,950 Kg/Ha) for 10 experiments conducted, at six different locations (two each in Junin, Puno, Cusco, and Ayacucho, with one in Huanuco and one in Ancash) during the years 1952-54. Guano de Islas, applied at a rate to provide 100 Kg of N per hectare (App. 100-75-12) gave equally good yields. In a later publication (2), some 44 experiments involving applications of guano, barnyard manure, and chemical fertilizers, both singly and in various combinations, were summarized. The consistently high-yielding treatments were those receiving about 100 Kg/Ha of both nitrogen and phosphorus with a more modest amount of potassium.

Whether these nutrients originated in guano, manure, or chemical fertilizers made little difference. Based upon these results, the authors recommended 100, 60 and 30 Kg of N, P_2O_5, and K_2O, respectively, per hectare for potatoes in the sierra.

The most recent experiments of this type were completed during the years 1959 and 1960. The experimental approach used and the data obtained are representative of some 10 years of experimentation in potato fertility. Since the results of this work have not been widely publicized, a brief summary here will perhaps illustrate the general conclusions permissable from experiments of this type and establish the philosophy upon which the current soil fertility program is based.

Experimental Approach

During the crop-year 1958-59, nine three-factor (N - P - K) experiments were superimposed upon uniform applications of guano (7). Seven similar experiments were completed in 1959-60. Nine different sections of the sierra were represented (Junin, 4 expts.; Puno, 3; Huanuco, 2; Ancash, 2; and one each in Cusco, Cajamarca, Arequipa, Apurimac, and Ayacucho). Guano was applied uniformly at the rate of 560 Kg/Ha (approximately 70, 56 and 8 Kg of N, P_2O_5 and K_2O, respectively). Nitrogen, P_2O_5, and K_2O from chemical sources were superimposed factorially on the guano at the following rates per hectare: 0, 50 and 100 Kg. of N; O, 60, 100 Kg of P_2O_5; 0 and 60 of K_2O. Additional treatments, consisting of a check plot and a series of plots with N, P_2O_5, and K_2O additions from chemical sources but no guano were included at each location.

The experiments were conducted on state-owned lands or in cooperation with local hacienda owners by government technicians stationed in the various areas. Land preparation and cultivation practices common to the area were used. Although irrigation water was available in some locations, the moisture regime was determined by natural precipitation in most instances. Specific rainfall data for each location are not available, however.

In a similar approach, three experiments using barnyard manure in place of guano were completed in 1960 (9). These were located in the departments of Junin, Cuzco, and Ancash. Nitrogen, P_2O_5 and K_2O from chemical sources were superimposed factorially upon a uniform application of 5,000 Kg of manure per hectare. It was estimated that this quantity of manure provided 60, 25 and 45 Kg, respectively, of N, P_2O_5, and K_2O. To evaluate the effectiveness of the nitrogen source, additional treatments of guano supplemented with superphosphate and potash to provide formulas equivalent to 75-75-75, 75-150-75, and 150-150-75 were included at each location. Phosphorus from natural and synthetic sources were

similarly compared by using *guano de islas pobre* (App. 18% P_2O_5) and simple superphosphate. Prior to the initiation of each experiment, soil samples were taken and analyzed for pH, organic matter, and available phosphorus and potassium by routine laboratory methods.

Results

Guano-N-P-K Experiments. Average yields of pertinent treatments for 1959 and 1960 are summarized in Figures 1 and 2, respectively. Yield data for each location are given in Appendix Tables 1 and 2. As the data show, yield levels for the two crop years were quite different, and there was considerable variation among locations. Significant yield responses were recorded for all but three of the 16 locations, however, and the highest average yields in both years were obtained from the treatment receiving the highest total amount of plant nutrients (treatment GN_2P_2K). This treatment supplied a total of 170, 156, and 68 Kg of N, P_2O_5 and K_2O per hectare, respectively; and in both years, it essentially doubled the yield of the check treatment. Guano alone (treatment G) produced 64 and 71 percent of the maximum yield for 1959 and 1960, respectively. It should be pointed out, however, that near-maximum yields were produced by other treatments which provided smaller quantities of the three nutrients studied. For example, the yield increase from the second increment of N and P_2O_5 from chemical sources was seldom significantly different from the first (GNPK vs GN_2P_2K). Furthermore, in nine of the 16 experiments, a double application of guano was included (providing a total of 140, 100, and 22 Kg of N, P_2O_5 and K_2O per hectare), and yields from this treatment averaged about 83 percent of the maximum.

Manure-N-P-K Experiments. Mean yields from three experiments of this type are tabulated in Appendix Table 3. To illustrate the possible influence of soil properties on the response to manure and/or chemical fertilizer, the data from two locations are further summarized in Figure 3. Only the nitrogen and phosphorus effects are shown in the graph because the response to potassium was not statistically significant. It is worth pointing out, however, that the highest yields at all locations were obtained from plots receiving at least 75 Kg of K_2O/Ha.

Although they differ in magnitude, the nitrogen response curves for the two locations have similar shapes. All of them reach a maximum at 150 Kg of N per hectare in addition to that supplied by the manure, and in each case, the yields level off or decrease as nitrogen is increased to 300 Kg. At both locations, the N-P combination giving the highest yields was at 150 Kg each of N and P_2O_5, but the main effects for phosphorus and the N X P interaction were quite different among sites. In Junin, the direct effect of phosphorus, though statistically significant, was small in magnitude; and there was no significant N X P interaction. In Ancash, on the other hand, the direct effect of phosphorus was quite striking and the N X P interaction was highly significant. The combined effect of 150 Kg/Ha each of N and P_2O_5 was nearly a two-fold yield increase over manure alone. In the absence of additional phosphorus, however, there was a negative response to N beyond the 75 Kg level. This phenomenon illustrates the principle of nutrient interaction in plant growth and the importance of a balanced fertility program in crop production.

The relative response to both manure and chemical fertilizers at the

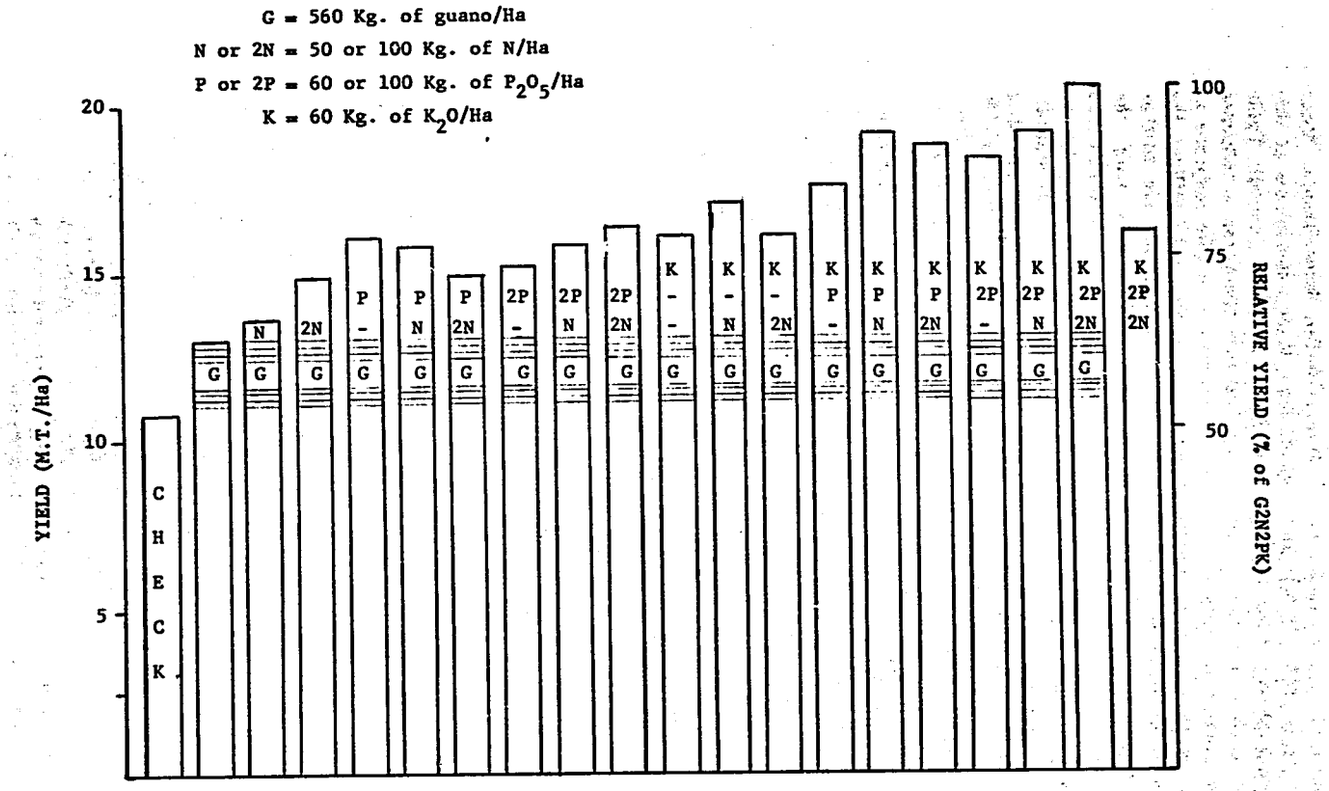

Fig. 1. Potato yields as affected by applications of N, P_2O_5, and K_2O from chemical sources superimposed upon a uniform application of *guano de islas* (Average of 9 sierra locations during crop-year 1958-59). From Rodriguez, L. M. *et al.* (4).

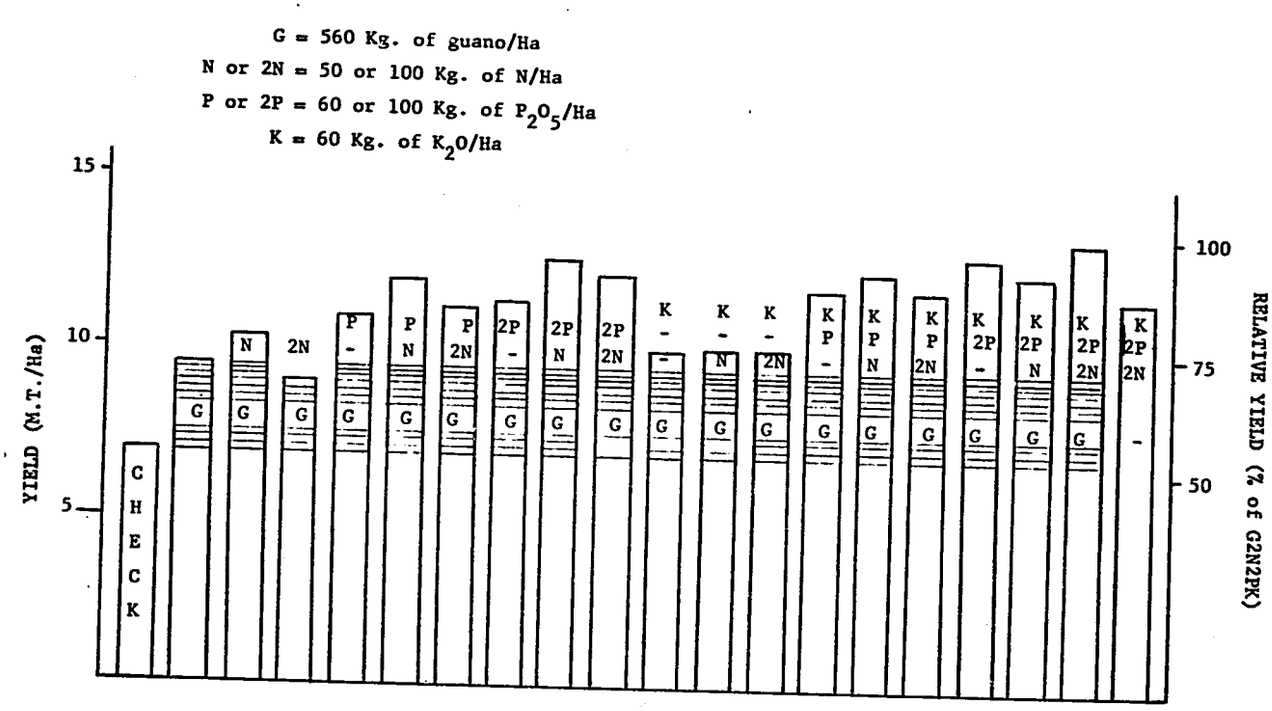

Fig. 2. Potato yields as affected by applications of N, P_2O_5, and K_2O from chemical source superimposed upon a uniform application of *guano de islas* (Average of 7 sierra locations during crop-year 1959-60). From Rodrigues, L. M. *et al.* (4).

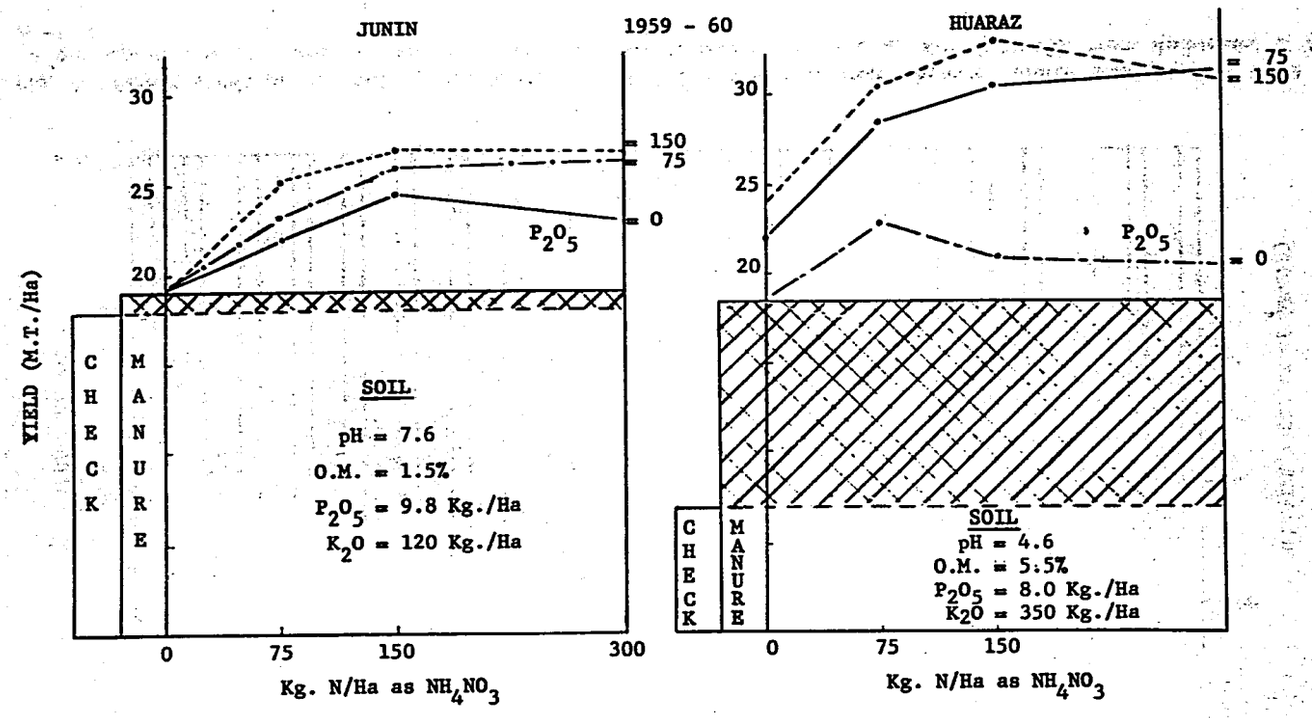

Fig. 3. Effects on potato yields of N and P_2O_5 from chemical sources factorially superimposed upon a uniform application (5,000 Kg/Ha) of barnyard manure.

two locations is especially interesting and deserves further comment. With manure alone, potato yields at the two locations were of the same order of magnitude. Yields with manure alone were not significantly different from the check treatment at Junin, however, and the highest yielding treatment combination (manure plus 150-150-75) produced about 8.5 metric tons more than manure alone. At Ancash, on the other hand, there was a 2.5-fold increase over the check for manure alone, with an additional 14-ton response to 150 Kg each of N and P_2O_5. It should be noted, however, that the yield of the check treatment in Ancash was less than half of the check yields at Junin.

Known differences in soil properties and previous management history provide some explanation of these different response patterns, but climatic factors may also be involved. Soil phosphorus levels at the two sites were roughly comparable (low), but the soil at Ancash was extremely acid (pH 4.6) and had a high content of organic matter (5.5%). In Junin, the soil reaction was above neutrality (pH 7.6) and the organic content was much lower (1.5%). In addition the soil at Junin had been under cultivation for some time and was known to have received significant quantities of fertilizer within two years prior to the initiation of the experiment. The soil at Ancash, however, had been idle for more than eight years.

Potatoes will produce acceptable yields on very acid soils if an adequate nutrient regime is maintained. In very acid soils, however, phosphorus fixation is often severe and the release of nutrients from organic residues by microbial activity is slow. Under such conditions, a high content of soil organic matter is not necessarily a valid indicator of its nutrient supplying capacity. The addition of biologically active stable manure may, however, stimulate a more rapid release of nutrients from the residual soil organic matter. These factors seem to account logically for the low productive potential of the untreated soil in Ancash and the high response to both manure and chemical fertilizers. A more favorable soil pH and the residual effects of previous fertilization at Junin also explain the higher yields of the check treatment and the lack of a measurable response to manure alone.

Nitrogen-Source Comparisons. The data in Table 1 compare potato responses to nitrogen from strictly chemical sources with responses to equal amounts of nitrogen from guano. These comparisons were made in four locations during the crop-year 1959-60.

These data indicate that the ammonium and nitrate forms of nitrogen, as applied in ammonium nitrate, are equal or superior to the nitrogen in *guano de islas* for potatoes in the sierra. In nearly every instance, the response to ammonium nitrate was greater than the response to comparable amounts of nitrogen applied as guano. Soil and climatic conditions may of course influence the relative efficiency of nitrogen fertilizers. Under severe leaching conditions, for example, soluble nitrates may be washed below the fairly shallow rooting zone of potatoes. On the other hand, much of the nitrogen in guano is in organic combination and must be mineralized by soil microorganisms before it can be absorbed by plant roots. Microbiological activity is retarded at low soil temperatures and in very acid soils. The generally cold climate throughout the sierra and the highly acid soils in many areas afford some explanation for the lower efficiency of guano where such conditions prevail.

Table 1. Effect on potato yields of nitrogen applied as *guano de islas* compared with equivalent applications of ammonium nitrate (1959-60).

Source of Nitrogen	Treatment* (Kg/Ha.)			POTATO YIELDS							
				Junin Est. Experim.		Ancash (Catac)		Cuzco (Parayoc)		Tarma (Hda. Casablanca)	
	N	P_2O_5	K_2O	Actual M.T./Ha.	Relative to Manure	Actual M.T./Ha.	Relative to Manure	Actual M.T./Ha.	Relative to Manure	Actual M.T./Ha.	Relative to Manure
Ammonium Nitrate	75	75	75	23.2	111	30.5	173	23.5	122	17.3	137
	75	150	75	27.7	132	29.5	167	26.2	136	21.1	167
	150	150	75	27.7	132	35.5	202	30.0	155	23.4	185
Guano de Islas**	75	75	75	24.3	116	26.4	150	23.1	120	14.1	112
	75	150	75	24.6	118	29.2	166	27.9	145	18.7	148
	150	150	75	25.0	120	25.8	147	30.4	157	14.0	111
Manure Alone (5,000 Kg/Ha)	60	25	45	20.9	100	17.6	100	19.3	100	12.6	100

**Except at Hacienda Casablanca, indicated treatments were superimposed upon a uniform application of manure (i.e. "Manure alone").*

***"Guano de Islas", at rates to provide the indicated nitrogen treatments, was supplemented with appropriate amounts of P_2O_5 and K_2O from chemical sources.*

Phosphorus - Source Comparisons. Table 2 shows the response to phosphorus applied as guano compared with an equivalent dose derived from superphosphate. The data show that superphosphate is equally as good as *guano de islas (Pobre)* in supplying phosphorus to potatoes in the soils used.

The Current Program in Potato Fertility

For several reasons, the number of conclusive inferences permissible from the data cited above is limited. The treatment variables, for example, were always superimposed upon a uniform application of guano or barnyard manure. Both *guano de islas* and manure are carriers of all three of the major nutrient elements. They are also high in organic residues and may contain sufficient quantities of secondary and/or trace elements to influence yields under some soil conditions. Treatment effects are therefore masked by the influence of guano (or manure), and unbiased estimates of the main effects and interactions for individual nutrients are limited to responses beyond those induced by the blanket treatment with guano or manure.

The lack of weather data and soil chemical data for each experimental site also restrict a more rigorous interpretation of these data. Microclimate is a factor of considerable importance throughout the sierra, and the wide variation in yields among locations suggests a marked climatic effect (Appendix Tables 1 and 2). Adequate soil data are available for the experiments summarized in Figure 3 only, but the difference in soil properties between these sites illustrate the wide variation among sierra soils. They also emphasize the difficulty of trying to interpret fertility data without adequate knowledge about the soils upon which the experiments were conducted.

Despite these limitations, however, the information provided by the data cited is pertinent to both the farmer and the research technician, and the following conclusions seem valid:

1. The quantities of nutrients supplied experimentally through *guano de islas* or manure were not sufficient to produce maxi-

Table 2. Average response of potatoes to phosphorus from mineral and organic sources at four locations in the Sierra (crop-year 1959-60).

Location*	YIELD (METRIC TONS/HA)		
	Source of Phosphorus		
	Super-Phosphate	Guano de Islas	No Phosphorus
Junin (Estacion Experimental)	24.5	23.6	22.4
Cuzco (Perayoc)	24.6	22.2	23.3
Huaraz (Catac)	29.8	27.9	20.7
Tarma (Hacienda Casablanca)	18.9	16.2	7.0

**The experiments at Junin, Cuzco, and Huaras, in addition to the imposed treatments, received a uniform application of manure (5,000 Kg/Ha) prior to seeding.*

mum yields of potatoes. In nearly every instance, additional nutrients from chemical sources increased yields.

2. Chemical fertilizers are equal or superior to *guano de islas* or barnyard manure as sources of nutrients for potatoes (Tables 1 and 2). The slightly superior performance of chemical sources of nitrogen and phosphorus over guano-derived nutrients is most likely related to a slow rate of mineralization of the organic nitrogen and phosphorus in guano in cold sierra soils. Available data do not provide specific evidence for this conclusion, however.
3. Nitrogen is generally the first limiting nutritional factor for potatoes in the sierra; but consistent and significant responses to phosphorus emphasize the importance of a balanced fertilization program. In this regard it should be emphasized that the phosphorus in *guano de islas*, whatever it's efficiency in comparison with mineral sources, makes it a highly desirable fertilizer material. The tendency to consider guano primarily as a nitrogen fertilizer, ignoring its phosphorus content, has perhaps led to some erroneous conclusions in previous experimental work.
4. Responses to potassium, although less frequent and smaller in magnitude than nitrogen or phosphorus responses, are sufficient to conclude that this element cannot be ignored, neither in fertility research nor in commercial practice.

The current soil fertility program in potatoes is based largely on the conclusions drawn from and the questions posed by the data cited above. Since 1960, the field research effort in fertility has been devoted almost exclusively to three types of experiments, as follows:

1. Three-factor (NPK) experiments with all nutrients applied in complete factorial combination.
2. Studies concerned with the relationships among levels of fertilization, plant population, and potato varieties (density x variety x fertilization factorials).
3. Studies on the effectiveness of different chemical and/or physical forms of nitrogen and phosphorus in supplying these nutrients to potatoes.

Because fertilizer recommendations based on field research data are of first importance economically, by far the major effort (about 80%) has been devoted to the NPK factorial experiments. The remainder of this report will, for the most part, be concerned with the summarization and analyses of these data.

Plant breeders have developed and released for commercial production a number of new or improved potato varieties. In addition, a wide selection of native, or *criolla*, varieties are produced commercially. Whatever its characteristics regarding quality, disease resistance, or other desirable properties, it is important to know how a given variety performs under varying nutritional regimes and population densities. Preliminary field observations suggested some important differences among varieties under different fertility regimes, and a program to evaluate these observations more thoroughly was initiated.

Each of the major plant nutrient elements is commercially available in several chemical forms. Fertilizer materials also differ in physical characteristics. From the viewpoint of plant nutrition, the chemical and physical properties of fertilizer materials are important primarily as

they influence nutrient availability, persistence in the soil (resistance to leaching or fixation by soil constituents), or quality of the marketable plant product. Less important physiologically but of considerable economic concern to the farmer are ease of handling and cost. Although the data to date are preliminary and in some cases inconclusive, the Soils Department of SIPA, has been studying the agronomic and economic potential of various fertilizer materials with differing chemical and/or physical properties.*

An integral part of the entire fertility program has been a concerted effort to provide soil analytical data for every experimental site. As planned, this part of the program operates in two phases. Soil samples are taken from each experimental site before the treatments are applied and sent to the laboratory at La Molina for routine analyses. The samples are then stored and held for further "characterization" analyses and for phosphorus and potassium analysis with different extractants. The purpose in using different extractants is to determine the analytical method which best correlates with yield responses in the field.

Transportation problems and personnel changes, both in the agrarian zones and at La Molina, have been made this part of the program difficult to maintain. Some samples have been lost in transit and others have not yet been analyzed. Nevertheless, considerable soil analytical data are available, and these will be used as appropriate to illustrate response patterns obviously related to soil properties.

*This portion of the program has been supported in part by the Esso Research and Engineering Company through a cooperative agreement with SIPA.

Experimental Methods

Whatever the nature or location of the experiment, field techniques have been essentially the same; and the brief description of methods presented here will apply to all.

In theory, each experiment is a joint effort by two SIPA technicians, one at La Molina and one in the agrarian zone where the work is to be done. The duties of the La Molina technician are to prepare project outlines and to provide logistical support and technical assistance as needed. On the average, he sees each experimental site about three times, once to help initiate the experiment, once during the period of vegetative growth, and finally to assist in the harvest and recording of yield data. The local, or zone, technician's duties are to oversee the routine conduct of the experiment throughout the growing season.

Accumulated data are sent to La Molina for statistical analyses and interpretation. To date, the "randomized complete blocks" experimental design has been used exclusively.

Most of the experiments have been conducted on private farms in cooperation with the land owner or administrator. Land preparation and methods of cultivation may therefore vary among sites. In general, mechanized equipment (a tractor with appropriate attachments) has been available for the initial land preparation, but mechanical power is seldom used for cultivation and harvesting even on the larger haciendas.

Once the land is prepared, rows are laid off at one-meter intervals with suitable equipment to provide a furrow (or trench) six-to-eight inches deep. Four-row plots 10 meters in length are staked off, and the appropriate fertilizer mixture is drilled uniformly in the bottom of this

furrow. All of the phosphorus and potassium with one-half of the total nitrogen is applied at seeding. The fertilizer is then covered with some two inches of soil to avoid direct contact between the fertilizer and the potato seed piece. Whole potatoes of about 50 grams each are placed directly over the fertilizer and covered with three-to-five inches of soil. When the seeding operation is completed, the field is nearly smooth, and it remains in this condition until the first cultivation.

Beginning with the first and continuing with each successive cultivation, the rows are gradually ridged up with soil from the row middles. At maturity, this ridge is some 12 to 16 inches high. The remaining half of the nitrogen is generally applied at the first cultivation *(primer aporque)*.

Except for those experiments dealing with sources of nutrients, the fertilizer materials used are ammonium nitrate (33.5% N), simple superphosphate (20% P_2O_5), and potassium chloride (60% K_2O). A routine program for the control of insects and diseases is maintained throughout the growing season by the local technician. At harvest, yield data are taken from the two center rows of each plot.

The only quality measurements made to date have been the separation of the potatoes into standard grades by size. Most of the data reported below, however, are for total yields without reference to grade.

As planned, NPK factorial experiments were to be located on representative soils in each of the agrarian zones throughout the Sierra. In practice, however, accessability and the availability of technical help, particularly at the local level, have been the principle determining factors in the coverage obtained. This has resulted in a heavy concentration of effort in the Mantaro Valley area (Junin) with some 60% of the total number of observations. Other areas where work has been done, in relative order of importance, include Cuzco, Ancash (Huaraz area), Puno, and La Libertad (Otuzco area).

NPK Factorial Experiments

Treatment of Data. Since 1961, fifty-eight experiments of this type have been completed in different zones of the sierra. The various treatment combinations employed with their appropriate mean yields (generally of four replications) are tabulated in Appendix Tables 4 through 14. The data in these tables are grouped to provide meaningful comparisons as far as possible, but the large number of locations, years, and treatment combinations included do not facilitate a convenient and easily-interpretable arrangement of the data.

Each of the individual experiments has been evaluated by appropriate statistical treatment, but no previous attempt to draw broad conclusions by a combined analysis of all of the data has been made. In studying the individual experiments, therefore, suffice it to say at this point that treatment differences should not be considered significant unless they exceed two metric tons per hectare. To summarize briefly, significant responses* to nitrogen were measured in essentially every experiment, with measureable responses to phosphorus and potassium in about 90% and 66% of them, respectively.

To reduce them to a more general and hopefully more meaningful form, the data in Appendix Tables 4-14 were treated in the following manner:

Mean yields (in metric tons/Ha) and their corresponding treatment combinations (in Kg/Ha) were punched on International Business

*At 95% level of probability.

Machine (IBM) Cards with appropriate coding for years, locations, and other pertinent information. Multiple regression equations for the composited data and for various groupings were computed on the IBM 1620 according to the polynomial

$$Y = C + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5K + b_6K^2 + b_7NP + b_8NK + b_9PK,$$

where "Y" equals estimated yields in M.T./Ha and "b" represents the coefficients for the main effects and interactions of the nutrient variables. The effects of years and locations (as agrarian zones) were also evaluated by including these data as discrete (non-continuous) variables. The application of various functional models to fertilizer response data has been reviewed by Mason (6), and the above model was selected because it seemed to comply with the general criteria discussed in this review.

The IBM computer was programmed to provide a "stepwise" regression analysis. By this procedure each variable is evaluated according to its relative contribution to the total variance, and a series of equations equal to the number of independent variables is computed. At each step (or iteration) the program selects, and includes in the resulting equation, the independent variable that will cause the greatest reduction in the unexplained variance of the dependent variable (i.e. yields).

Results

Prediction Equations. A total of 982 observations (from 58 separate experiments) were used to compute Equations I and II (Table 3). Equation I was computed without regard to the year or location in which an observation was made ("years" and "locations" pooled). It therefore does not provide any estimate of the variation in yields associated with crop-year or experimental area. Estimated yields for various treatment combinations as predicted by this equation are shown in Table 4. For comparative purposes, mean yields from a group of three-factor, three-level experiments which included the indicated treatments are shown, and specific data from two experiments are included to indicate the range in yield levels and in the magnitude of responses observed. According to Equation I, 33% of the total variation in yields was accounted for by the imposed fertilizer treatments ($R^2 = 0.33$).

Of the many other factors which may influence yield levels and response to applied nutrients, initial soil properties and climate are among the most important. Specific weather data were not available for each experimental site, but the location of an experiment and the year in which it was conducted reflect in a general way the influence of climatic conditions. In Equation II, additional factors for "locations" and "years" were included as non-continuous (shift) variables to provide some estimate of climatic effects. In this procedure, a "reference" location and year are selected, and the resulting equation evaluates the effects of other years and locations relative to this base. This results in shifting the position of the response curve up or down the "Y", or yield, axis (according to the effect of a given year or location) without altering its shape. The coefficient of a given factor (location or year) indicates the magnitude of the shift and becomes a component of the constant "C" in computing the expected yield for a given location or year. For example, the predicted yield for the Cuzco area ($L_2 = 3.88064$) in the year 1963 ($A_3 = 1.25796$) would be calculated from Equation II as follows:

Table 3. Regression equations computed from potato yield data.

Equation No.	I	II	III (Huancayo)
R^2	0.33	0.47	0.50
Constant (C)	8.02	5.25	5.85
Variable*	Coefficients (b x 10^5)		
N	6732 (3)**	7206 (8)	8380 (5)
N^2	—18 (4)	—22 (9)	—27 (6)
P	3412 (8)	2670 (15)	2571 (11)
P^2	—19 (9)	—15 (16)	—18 (10)
K	3908 (7)	4040 (12)	—74N.S. (12)
K^2	—28 (6)	—28 (11)	—2N.S. (9)
NP	17 (1)	16 (1)	14 (1)
NK	9 (2)	8 (3)	9N.S. (3)
PK	12 (5)	12 (10)	14 (8)
A_1 (1961)	—	510934 (4)	792802 (2)
A_2 (1962)	—	152451 (13)	253940 (7)
A_3 (1963)	—	125796 (14)	—129574 (4)
L_1 (Puno)	—	610684 (6)	—
L_2 (Cuzco)	—	388064 (5)	—
L_3 (Huaraz)	—	213374 (7)	—
L_4 (Otuzco)	—	1439657 (2)	—

Base year, 1964; base location, Huancayo.
***Numbers in parentheses indicate order of inclusion of variable in the stepwise computation.*

$$C'' = (5.2500 + 3.88064 + 1.25796) = 10.39$$

and

$$Y'' = 10.39 + 0.07206N + 0.02670P + 0.04040K - 0.00022N^2 - 0.00015P^2 - 0.00028K^2 + 0.00016NP + 0.00008NK + 0.00012PK$$

where N, P, and K represent kilograms of applied N, P_2O_5, and K_2O per hectare, respectively. Without applied fertilizer, the predicted yield would be 10.39 metric tons per hectare. An assumed fertilization rate of 100-100-60 would double the expected yield to 20.78 metric tons per hectare.

As Equation II shows (Table 3), the inclusion of "years" and "locations" as additional factors increased the coefficient of determination (R^2) to 47%. In the absence of specific weather data, these effects of years and locations are considered the best estimate available of the climatic influence. It should be pointed out, however, that this is a somewhat arbitrary conclusion. These factors may also reflect soil differences, but soil variability within a given region was equally as great as that among regions.

Assuming that the variation ascribed to years and/or locations does indeed reflect climatic differences, a similar calculation with data from a small area should result in an even greater reduction in the unexplained variance (higher R^2). To pursue this idea, the data cards were sorted according to location, and separate prediction equations were computed for different locations using only "years" as shift variables. Equation III (Table 3) was obtained by applying this procedure to the data from the Huancayo area.

Table 4. Potato yields as predicted by multiple regression compared with actual mean yields from representative experiments (specific data from two experiments are included to show the range of responses observed).

Treatment (Kg/Ha)			Yields (M.T. of tubers/Ha)			
N	P_2O_5	K_2O	Predicted*	Actual (Ave. of 19 Expts.)	Cuzco (Maras) 1963	Junin (San Lorenzo) 1964
0	0	0	8.0	7.6	6.6	9.4
80	0	0	12.2	11.0	11.0	8.2
160	0	0	14.2	11.8	12.1	11.4
0	80	0	9.5	8.3	6.3	9.6
80	80	0	14.8	14.4	24.1	11.8
160	80	0	17.9	16.4	32.7	11.8
0	160	0	8.6	8.8	6.6	8.5
80	160	0	15.0	15.0	27.8	14.5
160	160	0	19.1	16.3	35.4	14.1
0	0	160	7.1	7.9	6.4	8.0
80	0	160	12.4	11.7	12.2	9.4
160	0	160	14.4	13.3	13.0	8.9
0	80	160	10.1	9.8	6.1	11.8
80	80	160	15.5	15.5	22.8	15.5
160	80	160	19.6	18.7	33.0	12.5
0	160	160	10.8	10.3	8.2	9.4
80	160	160	18.3	17.6	26.9	16.6
160	160	160	22.4	21.2	38.2	16.3

**Calculated from Equation I (Table 3).*

Over half of the total observations were obtained from this relatively small zone. As the equation shows, nutritional treatments and years accounted for 50% of the variation in yields ($R^2=0.50$). Similar calculations for the "Cuzco" and "Huaraz" data resulted in an R^2 of 0.46 and 0.76, respectively.

Agronomic Interpretation. Except for soil data, Equation II included all of the factors available from the measurements made to date. In the absence of specific information on soil physical and chemical properties, Equation II is therefore considered the most appropriate predictor of responses to nitrogen, phosphorus and potassium provided by the variables included in the multiple regression.

The stepwise generation of Equation II (Table 3) revealed several points of agronomic interest. Perhaps most important is the order of inclusion of the independent variables with successive steps. For example, the N X P interaction was the first variable selected and evaluated in the stepwise program. This means that the N X P interaction caused the greatest reduction in the unexplained variation in yield ($R^2=0.22$). This variable alone accounted for nearly as much of the explained yield variation as all of the remaining factors combined. It is worth pointing out

that the N X P interaction was the most important variable for every sub-group of data evaluated (see Figure 5).

By a similar logic, Table 3 shows that the linear and quadratic effects of phosphorus were the poorest contributors to the explained variance. The stepwise computation of Equation II therefore rated the continuous (fertilizer) variables in the following order of relative importance:

$$NP > NK > N > N^2 > PK > K^2 > K > P > P^2.$$

A significant portion of the yield variance was ascribed to "year" and "location" effects, and the argument developed above suggests that these factors reflect qualitative differences in climate among experimental sites and/or crop years. Figure 4 illustrates the variation assigned to year effects for the Huancayo area. The data indicate that yields per hectare for 1961 were about seven metric tons higher than in the base year 1964. Assuming that the experiments conducted during these two years were on similar soils, the most probable reason for yield differences of this magnitude would be the influence of climate; and it is concluded that the 1960-61 crop-year was climatically more favorable for potatoes than the 1963-64 growing season. It should be emphasized that this approach does not provide any quantitative information concerning specific climatic effects. It does, however, point out the need for complementary data on weather phenomena to help explain the relatively wide variation in yields

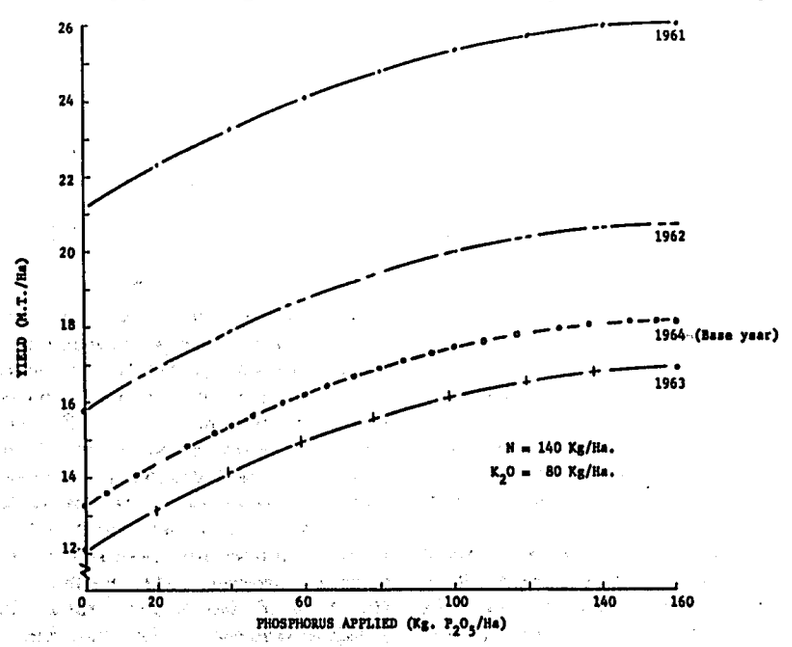

Fig. 4. Variation in potato yield levels associated with crop-year in the Huancayo area (P response curve based on prediction Equation III used as example).

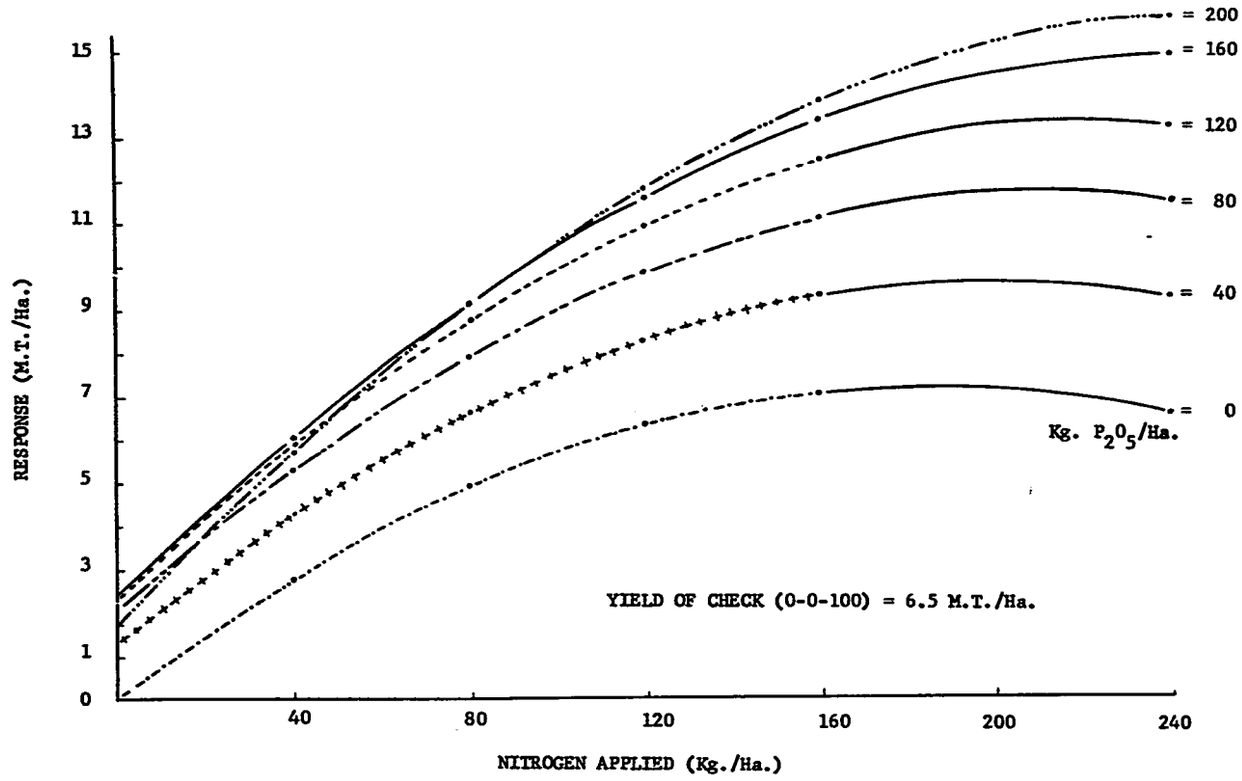

Fig. 5. Response of potatoes to varying levels of applied N and P_2O_5 as predicted by Equation II (see Table 3).

that cannot be assigned to nutritional treatments.

Nutrient responses and interactions: All of the experimental data as well as the computations made from them emphasize the importance of the combined effects of nitrogen and phosphorus (N X P interaction). It is therefore of interest to provide some estimates of the magnitude of the responses expected from varying levels and combinations of these nutrients.

Figure 5 shows the response to different rates and combinations of applied nitrogen and phosphorus as predicted by Equation II. The data in Figure 5 were calculated as increase in yield over the check (0-0-100). The 100-Kg rate of K_2O was selected somewhat arbitrarily because the experimental data suggested that the response to potassium was approaching the maximum at this level. It should also be emphasized that the rates of N, P_2O_5 and K_2O applied experimentally were always 0, 80 or 160 Kg/Ha. Segments of the response curves beyond 160 Kg are therefore extrapolations based on the prediction equation.

According to the multiple regression, the N X K interaction was the second most important nutritional factor, and Figure 6 shows the predicted response to different levels and combinations of these nutrients. Predicted responses to nitrogen, phosphorus, or potassium in the presence of fixed amounts of the other two nutrients are shown in Figures 7, 8, and 9.

Influence of soil properties: The response of plants to fertilizer-applied nutrients is inversely related to the capacity of the soils to supply them in an available form. The relationship between the measureable soil supply of plant-available nutrients and the response to nutrient applications has thus become an accepted technique for the determination of fertilizer requirements. Plant-available nutrients in the soil are generally determined by some standard laboratory technique, and responses to varying levels of applied nutrients are measured by field or greenhouse studies.

Although other chemical or physiochemical properties of soil may influence plant responses to the major nutrients, those most frequently used in interpreting fertilizer response data are soil pH, organic matter (or total nitrogen), and available phosphorus and potassium. Routine analytical procedures employed at La Molina for these properties were (1) soil pH in a 1:2.5 soil-water suspension with the glass electrode; (2) organic matter by the wet combustion method of Walkley and Black; (3) the spectrophotometric determination of phosphorus in a sodium bicarbonate extract (method of Olsen); and (4) the turbidimetric determination of potassium with sodium cobaltinitrite in a sodium acetate extract buffered at pH 4.8 (method of Morgan).

Soil chemical data were not included in the IBM procedures because many of the samples had not been analyzed when this summary was initiated. Soil data from many of the experiments have since become available, however, and these were used to relate observed nutrient responses to pertinent soil properties.

Crop responses to applied nitrogen are related to the capacity of a soil to release nitrogen in an available form from the organic residues which it contains, and the organic matter content of cultivated soils is a frequently-used index to their nitrogen supplying capacity. Table 5 shows the relative response of potatoes to the 80-160 Kg/Ha increment of nitrogen according to the organic matter content of the soil. The 80 Kg refer-

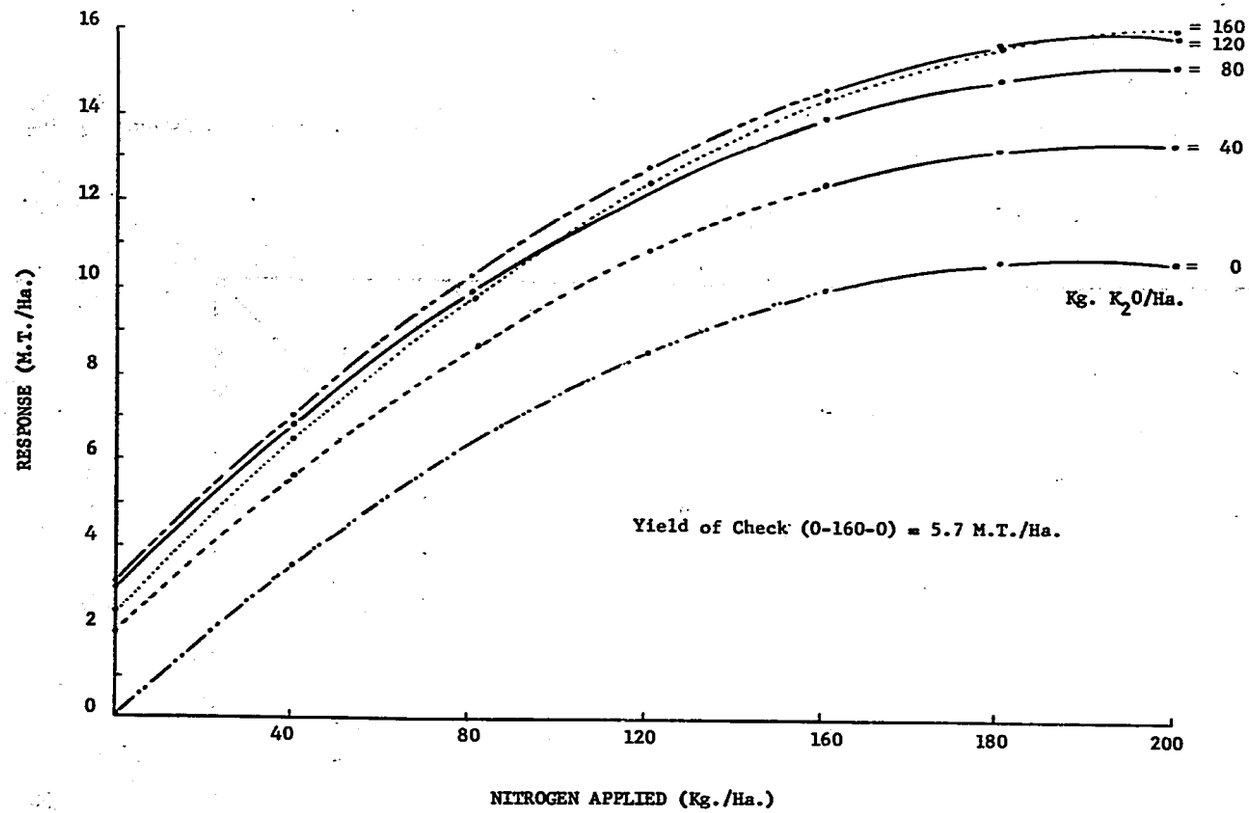

Fig. 6. Response of potatoes to varying levels of applied N and K_2O as predicted by Equation II (see Table 3).

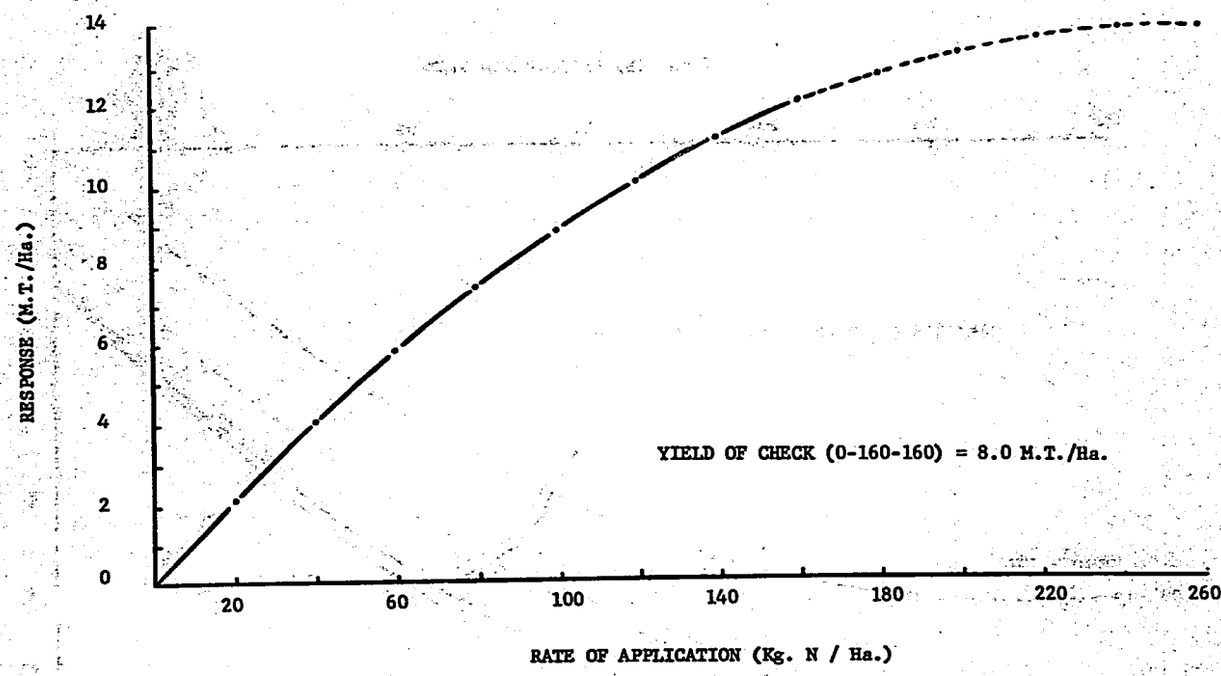

Fig. 7. Nitrogen response curve for potatoes at fixed levels of applied P_2O_5 and K_2O (based on Prediction Equation II, Table 3. Extrapolations beyond 160 Kg/Ha. are not based on experimental data).

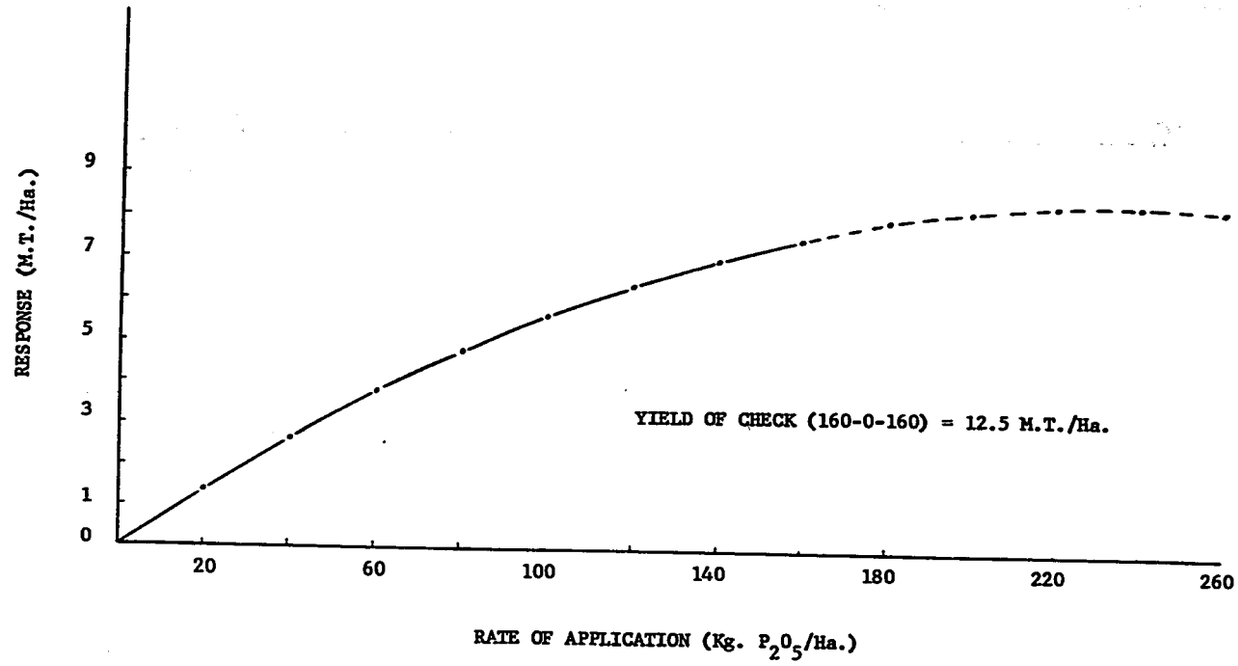

Fig. 8. Phosphorus response curve for potatoes at fixed levels of applied N and K_2O (based on Prediction Equation II, Table 3).

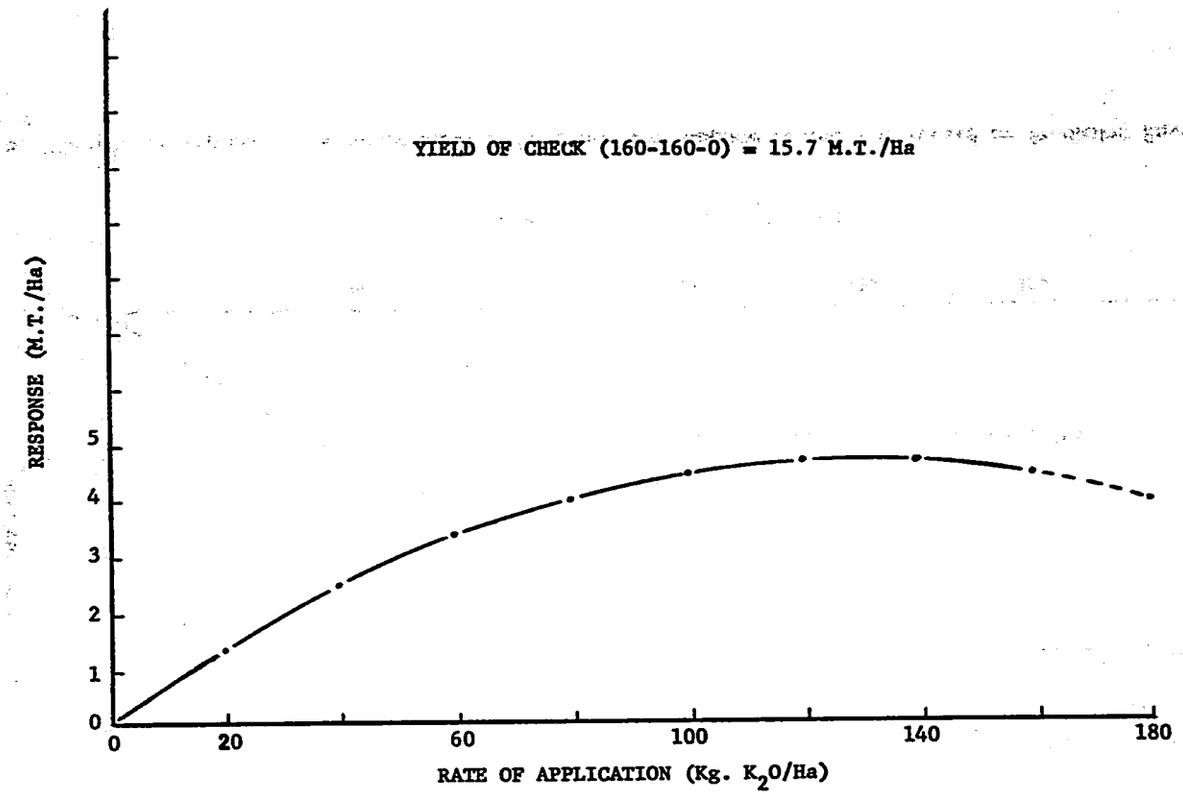

Fig. 9. Potassium response curve for potatoes at fixed levels of applied N and P_2O_5 (based on prediction Equation II, Table 3).

Table 5. Response of potatoes to the 80-160 Kg/Ha increment of applied nitrogen as related to the level of soil organic matter.

Level of Soil O.M. (%)	Number of Expts.	Response to Nitrogen (as percent of check*)	
		Average	Range
<1.0	9	134	102-169
1.0-1.9	16	121	88-152
2.0-2.9	12	111	92-156
>3.0	11	116	96-142
L. S. D. (.05)		10.8	

Check treatment (80-160-80 or 80-160-160)=100.

ence point was selected because yield response at the higher rates of nitrogen were considered a better measure of the inherent nitrogen supplying power of the soil. This conclusion is supported by the observation that the first 80 Kg of nitrogen essentially doubled the check (minus nitrogen) yields regardless of soil organic content.

There is evidence that nitrogen mineralization is retarded in the cold, and often dry, climate at altitudes above 3,000 meters in the Sierra (8). With few notable exceptions, however, the data in Table 5 indicate that the response to applied nitrogen was inversely related to the level of soil organic matter. Of special interest is the observation that the response to nitrogen on soils with more than three percent organic matter exceeded that of the next lower category (2-3 percent organic matter). The altitude at which each experiment was conducted has not been verified, but it may be that the residues in these high-organic soils were more stable because of their position. It should also be pointed out that the range in nitrogen response was rather wide at all levels of soil organic matter.

The relationship between soil phosphorus level and the response to phosphate fertilization for 45 field experiments on Sierra soils is shown in Figure 10. This procedure for determining critical soil nutrient levels has been proposed by Cate and Nelson (3). Since their technique has not been widely distributed in the literature, the following brief description of the method and the interpretation of the data seems appropriate:

A scatter diagram of percentage yield vs. soil test level is plotted on arithmetic paper. Percentage yield is defined as the yield without the nutrient in question divided by the yield with adequate nutrients times 100; and in the present example, soil test level is Olsen-extractable soil phosphorus. A pair of intersecting perpendicular lines (always with the two lines parallel to the axes of the graph) is then drawn on the scatter diagram so that the number of points falling in the two positive quadrants is at a maximum. The point where the vertical line crosses the X-axis is the "critical" soil test value for phosphorus. The

Table 6. Response of potatoes to applied phosphorus as related to Olsen-extractable soil phosphorus and soil pH.

Soil pH	P_2O_5 Applied (Kg/Ha)	Soil Phosphorus (ppm P) 0-7 (Low) Yield of Tubers (M.T./Ha)	0-7 (Low) Inc. over —P (%)	7-15 (Medium) Yield of Tubers (M.T./Ha)	7-15 (Medium) Inc. over —P (%)	>15 (High) Yield of Tubers (M.T./Ha)	>15 (High) Inc. over —P (%)
<5.5	0	9.2		12.2		22.3	
	80	22.9	149(5)*	20.1	65(4)	27.9	25(2)
5.5-6.5	0	14.7		21.1		22.7	
	80	21.5	46(4)	22.9	8(5)	23.6	4(3)
6.5-7.5	0	12.3		14.9		20.3	
	80	17.9	45(6)	17.7	19(6)	20.5	1(2)
>7.5	0	13.3		—		—	
	80	24.4	83(8)	—		—	

Note: This table includes additional data that were not available when the Spanish version of this bulletin went to press.

**Figures in parentheses refer to number of experiments in each mean.*

critical soil nutrient level (approx. 7 ppm P for the data shown) is defined as the level above which the nutrient in question is no longer a primary limiting factor. By a similar logic, the horizontal line separates those soils with a large response to applied phosphorus from those that responded moderately or not at all. Points falling in the third quadrant represent low-phosphorus soils with a high probability of a profitable response to phosphate fertilization. Conversely, those falling in the first quadrant represent high-phosphorus soils with a lower probability of a profitable response to phosphorus fertilizers.

All of the points in the second quadrant of Figure 10 (high soil P but also highly responsive to applied P) represent experiments that were conducted on red, highly acid soil (pH<5.0). Such soils frequently contain considerable quantities of exchangeable iron and aluminum which form relatively stable compounds with phosphorus. Although extractable by chemical means, these forms of phosphorus are only slowly available to plants. Growth responses to annual applications of phosphate fertilizers on acid soils, although high in soil-test phosphorus, may therefore be quite striking.

Since most of the points falling outside the two pertinent quadrants in Figure 10 appear explainable on the basis of extreme acidity, the Cate and Nelson technique seems to have considerable predictive value for potatoes on Sierra soils.

Observed responses to 80 Kg of P_2O_5/Ha as related to both soil phosphorus level and soil pH are summarized in Table 6. These data show that the average response to applied phosphorus was highest on those soils that were "low" in extractable phosphorus and also highly acid. Yield responses were lowest on soils that were slightly acid to neutral in reaction (pH 5.5-7.0). This is considered

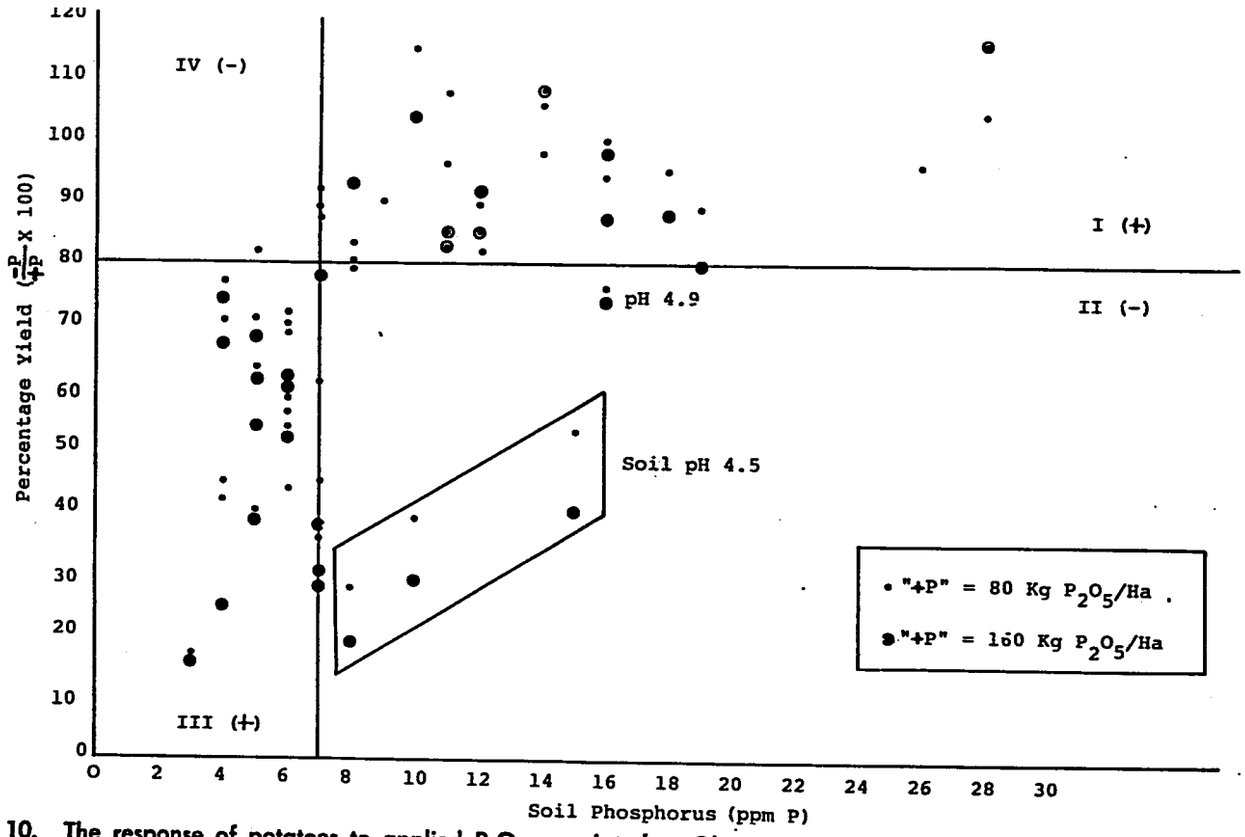

Fig. 10. The response of potatoes to applied P_2O_5 as related to Olsen-extractable soil phosphorus. (This figure, based on additional data, was revised after the Spanish version of this bulletin went to press.)

the degree of acidity for optimum phosphorus availability. The data further suggest that the relative response to applied phosphorus increased again when the soil reaction was above pH 7. All of these observations support the conclusion that both soil phosphorus level and soil reaction are pertinent considerations in phosphorus fertilization practices.

In the presence of relatively high levels of nitrogen and phosphorus, 80 Kg of K_2O/Ha increased average potato yields by about 4,000 Kg per hectare for a 24 percent increase over the check (160-160-0). The range in potassium response varied widely from 95 to 280 percent of the check treatment. On the other hand, soil potassium levels as measured by the cobaltinitrite method varied hardly at all. Routine soil potassium analyses for 34 of the experiments included in this study became available while it was in progress and all but five of the soils were classified as "low" or "very low" in potassium (less than 200 Kg of K_2O/Ha). Among those testing low, the potassium level was essentially constant at 150 Kg of K_2O/Ha. It therefore seemed evident that no meaningful relationship between soil potassium levels and the response to applied potassium could be established. It is further evident that the routine analytical procedure for soil potassium, as used in these studies, is inadequate for accurate soil test-crop response correlations.*

Economic Implications. A production function such as Equation II provides estimates of physically obtainable yields at various rates and combinations of applied nutrients. Fertilizer recommendations to producers, however, should be based on product-fertilizer price ratios as well as expected yields from a given quantity of nutrients. Equation II permits such economic analyses if prices of products and inputs are known. It is not the purpose here to develop the principles upon which it is based, but an economic analysis of the above results has been made (5) and the implications therefrom are relevant to the ultimate objectives of these studies.

One sol (Peruvian) per Kg is generally accepted as an average on-the-farm price for ungraded potatoes in the sierra. Current Lima prices for nitrogen, P_2O_5, and K_2O are approximately S/. 10.00, S/. 7.00, and S/. 5.00 per Kg, respectively.* These prices, and variations around them, were used to calculate fertilization rates for maximum expected net revenue. According to these calculations (Table 7), nitrogen, P_2O_5, and K_2O should be applied to potatoes in the ratio 1 : 1 : 0.6 and maximum net revenue would be obtained at an approximate fertilization rate of 240-240-140.

It is interesting to note that nutrient ratios derived from price relationships coincided closely with those suggested by agronomic observations. Economically optimum rates of fertilization would of course change with fluctuations in prices. Optimum nutrient ratios would also change with relative price indices. As the data in Table 7 show, however, the N : P_2O_5 : K_2O ratio remained quite stable over several assumed price situations.

For the "limited capital" situation in which most Andean farmers find themselves, it is unlikely that such high levels of investment can be made on each farm. Whatever the available capital, however, the agro-economic considerations presented here suggest

*Since the completion of this manuscript, K analysis of a $NaHCO_3$ soil extract by flame photometry has been adopted as the routine procedure at La Molina.

*At 1966 rate of exchange, one U. S. Dollar=26.8 Peruvian Soles (S/.).

Table 7. Nutrient applications for maximum expected net revenue for potatoes in the Sierra at differing price regimes.*

ON-THE-FARM						
Cost of Nutrients (S/. per Kg)			Price of Potatoes	Rate of Application		
N	P_2O_5	K_2O	(S/. per Kg)	N	P_2O_5	K_2O
8.0	5.6	4.0	1.00	257	257	150
			1.25	273	277	160
			1.50	282	289	166
10.0**	7.0**	5.0**	1.00**	243	241	144
			1.25	263	264	156
			1.50	274	279	163
12.0	8.4	6.0	1.00	242	258	142
			1.25	262	278	154
			1.50	272	289	161

**From Manning, R. C. (5).*

***Approximate prices for January, 1966.*

that, in the absence of modifying soil test information, farmers can most profitably apply N, P_2O_5 and K_2O to potatoes in the ratio of 1 : 1 : 0.6.

Since the experimental data is based on the application of N, P_2O_5, and K_2O at a maximum level of 160 Kg/Ha, the 240-240-140 application suggested for maximum net revenue represents a very substantial extrapolation. It is interesting to note, however, that the average return to potato production (total revenue as percentage of total costs) does not differ greatly for fertilization rates in the range 160-160-100 to 240-240-140 (Figure 11). Until appropriate soil analytical data becomes routinely available, it is therefore considered reasonable to recommend fertilizer applications up to the limits that can be justified experimentally (i.e. 160-160-100) and to encourage the experimental exploration of the response curves at even higher levels of fertilization.

Experiments on Sources of Nutrients

Nitrogen. Essentially all of the nitrogen extracted from the soil environment by plants is taken up as either ammonium (NH^+_4) or nitrate (NO_3^-) ions. These two nitrogen forms differ considerably in physicochemical properties and in the inorganic and biochemical reactions which they undergo in the soil. Whatever its initial form, the reaction trend of combined nitrogen in aerated soils is toward nitrate as an ultimate product. This conversion of soil nitrogen to nitrates, however, may be rapid, slow, stopped completely, or even reversed, depending upon the interacting effects of aeration, soil reaction, temperature and microbiological population. In addition, some plant species exhibit a "preference" (i.e. respond differently) for either nitrate or ammonium ions. These observations and the fact that fertilizer nitrogen is commercially obtainable

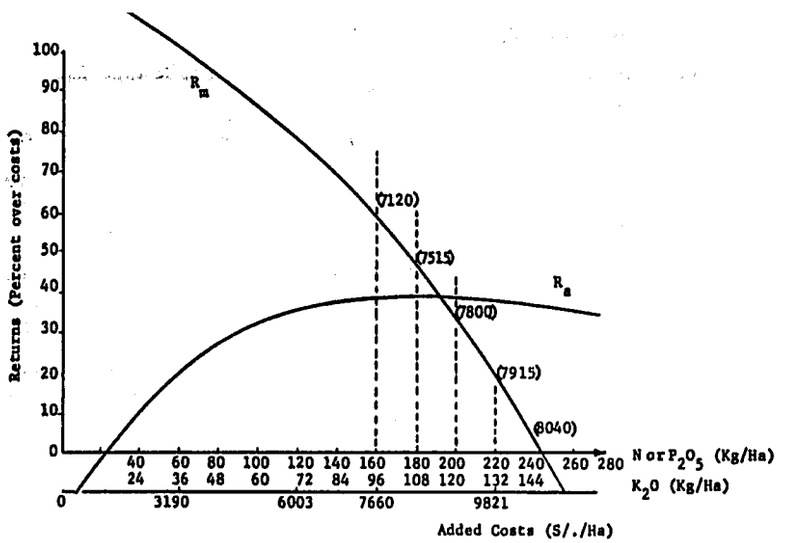

Fig. 11. Returns to potato production at varying levels of fertilization assuming prices per Kg. at S/.1.00 for potatoes and S/.10.00, S/.7.00, and S/.5.00 for N, P_2O_5, and K_2O, respectively. From Manning, R. C. (5).

Notes:

1. *Rm(Marginal return)=return to the last Sol spent for fertilizer and associated expenses. Maximum returns are obtained when Rm=O. Numbers in parentheses along curve Rm are added net returns at specified input levels.*
2. *Ra=Average return to total expenses.*
3. *"Added costs" are total additional costs, including interest on capital, associated with specified levels of fertilization.*

in a number of different chemical or physical forms impart considerable economic significance to experimentation dealing with the timing and methods of application of the various nitrogen carriers. The nitrogen-source experiments summarized below were designed to explore some of the agronomic implications connected with the use of the several synthetic nitrogen fertilizers available in Peru.

The commercially important synthetic nitrogen fertilizers sold in Peru are ammonium nitrate (NH_4NO_3), ammonium sulfate $(NH_4)_2SO_4$, and urea $CO(NH_2)_2$. Six field experiments. comparing the time and rate of application of these three materials were initiated in the Sierra during the crop-years 1962-63 and 1963-64. Three of these had to be harvested before maturity because of disease problems, and no reliable data were obtained from them. Average yields for the various treatment combinations of the three experiments which did reach

maturity are presented in Table 8.

As these data show, there were few consistent differences in yield due to nitrogen source. In two experiments, ammonium nitrate or ammonium sulfate were statistically superior to urea. In the third experiment, however, there were no significant differences for nitrogen sources, and the yield trend actually favored urea. Although these and other data favor a split application of nitrogen (i.e. one-half at seeding and one-half at the first cultivation), the absence of any "source X time-of-application" or "source X rate" interactions in the work cited here does not suggest any preferred management practices for the nitrogen carriers studied.

In summary, the results of these studies, although somewhat inconclusive, suggest that the first consideration in buying nitrogen fertilizer for potatoes is the cost of nitrogen per unit (i.e. Soles per kilogram of elemental nitrogen).

Phosphorus. Plants absorb inorganic phosphorus from natural (i.e.

Table 8. The influence of source, rate, and time of application of nitrogen on potato yields.

Source of N	Rate (Kg/Ha)	Date of Application: At Seeding %	Date of Application: At First Cultivation %	Yield (M.T./Ha): Ancash (Hda. La Florida) 1962-63	Cuzco (Quispiquilla) 1962-63	Cuzco (Maras) 1963-64	Ave.
NH_4NO_3	80	100	—	18.6	21.8	20.1	20.2
	80	50	50	25.6	25.1	15.9	22.2
	160	100	—	25.5	28.2	20.6	24.8
	160	50	50	28.6	24.1	19.3	24.0
$(NH_4)_2SO_4$	80	100	—	23.1	—	20.4	21.7
	80	50	50	25.2	—	19.6	22.4
	160	100	—	22.2	—	23.3	22.8
	160	50	50	27.8	—	23.4	25.6
Urea	80	100	—	20.9	20.5	17.5	19.6
	80	50	50	21.7	27.0	16.6	21.8
	160	100	—	20.5	29.5	19.3	23.1
	160	50	50	23.2	24.6	20.2	22.7
Calnitro (NH_4NO_3)	80	100	—	—	20.9	—	—
	80	50	50	—	23.8	—	—
	160	100	—	—	24.3	—	—
	160	50	50	—	33.3	—	—
Check (0-80-80)				17.1	16.4	9.2	14.2
G. de I. (80-80-80)				19.6	21.7	14.8	18.7

soil) or synthetic substrates primarily as orthophosphate ions ($H_2PO_4^-$, HPO_4^{-2}, or PO_4^{-3}). The relative abundance of the three valence species in the soil solution is governed by the soil pH; but in the pH-range of most soils, the monovalent ($H_2PO_4^-$) form predominates. It is also the most readily absorbed by plants. A wide range of materials carrying these and other chemicals forms of phosphorus are marketed as phosphate fertilizers. These must therefore be converted to soluble orthophosphates by soil chemical reactions before becoming available to plants, and the rate at which such conversions takes place is governed by initial solubility, the soil pH, and other interrelated factors. In addition, various soil constituents (Ca, Al, Fe, clay minerals) form relatively stable compounds with orthophosphate which makes it unavailable to plants. This so-called "P-fixation capacity" is quite high in many soils. The maintenance of a continuous and adequate supply of plant-available orthophosphate in the soil is therefore of considerable economic significance. The experiments described below were designed to evaluate the capacity of several commercial and experimental phosphorus carriers to maintain this supply as reflected in plant growth and yield.

The principal phosphate fertilizers commercially available in Peru are simple superphosphate, "escoria Thomas" (basic slag), "Hiperphosphate" (finely-ground rock phosphate), and *guano de islas*. Comparisons of superphosphate and *guano de islas* have been presented in an earlier section. The other materials were studied in field experiments during the crop-years 1962-63 and 1963-64. Experimental preparations, varying in water solubility, supplied by the Esso Research and Engineering Company were also included in four experiments. Average yields for the various treatment combinations are given in Tables 9 and 10.

The principal conclusions to be drawn from these data is that yield responses to applied phosphorus were related to the water solubility of the phosphorus in the phosphate carrier. Hiperphosphate, for example is essentially insoluble in water; and the data show that potato yields following the application of this material were only about 65 percent of those obtained from superphosphate, which is about 85% water soluble. "Escoria Thomas" is also only slightly soluble in water, and in the one experiment which included this material, the yield data indicate that its effectiveness as a phosphorus fertilizer lies somewhere between hiperphosphate and superphosphate. The experimental phosphates from Esso also support this conclusion in that low applications of the less soluble preparations were not as effective as equal rates of the highly soluble materials. These differences were largely overcome at higher rates, however, whereas increasing rates of hiperphosphate made little or no differences in yield.

The solubility of various phosphorus compounds (e.g. hiperphosphate and Escoria Thomas) is markedly influenced by soil reaction, and fairly massive doses of such materials broadcast on acid soils (pH 4.5-5.0) should provide a low but constant supply of plant-available phosphorus to the soil solution for several years. This behavior may be adequate for long-season crops (tree crops, perennial forages, etc.) but the potato data suggest that phosphorus release, even on highly acid soils, is inadequate for rapid-growing crops with a fairly short period of high-phosphorus demands. For example, the experiment at Hda. Casablanca (1963-64)

Table 9. Potato yields as related to source, rate and method of application of phosphorus (Ancash, 1962-63).*

Source of P	Rate of Application (Kg. P_2O_5/Ha)	Method Application	Yield of Potatoes (M.T./Ha)	Means for Sources
Superphosphate (20% P_2O_5)	80	Banded	29.1	
	120		25.6	
	160		28.9	
	80	Broadcast	25.1	
	120		28.9	
	160		26.7	27.4
Basic Slag (Escoria Thomas)	80	Banded	26.1	
	120		23.5	
	160		24.9	
	80	Broadcast	24.1	
	120		23.7	
	160		26.9	24.9
Hiperphosphate (rock phosphate)	80	Banded	18.5	
	120		21.1	
	160		18.4	
	80	Broadcast	22.4	
	120		19.2	
	160		18.4	19.7
Check (160-0-80)			17.2	

*Pertinent soil properties: pH 7.4; 26 Kg. of available P_2O_5 (Olsen)/Ha.

was conducted on a soil with pH 4.6, and potato yields with hiperphosphate were only about one-half of those from superphosphate.

In summary, all of the phosphorus-source data to date favor superphosphate over the other commercially important phosphate carriers that have been tested.

Density X Variety X Fertilization Experiments

The relationship between plant population and level of fertilization for several potato varieties has been studied in nine experiments since 1960. Absolute levels of the treatments imposed differed with years and with locations, but each experiment included three levels of fertilization, three plant populations, and two or three varieties in factorial combination. Fertilizer treatments were always in the ratio zero : one : two. Plant populations varied from 20,000 (low) to 50,000 (high) plants per hectare. Potato varieties included three improved strains (Renacimiento, Mantaro, and Casablanca) and three unimproved, native varieties (Ccompis, Imilla Negra and Yana Imilla). In addition to total yields, about half of the experiments included data for yield by grades. In one experiment the number of tubers per plant was also measured.

Results. Total yields for the various treatment combinations in each experiment are given in Appendix Table

Table 10. Potato yields as related to source and rate of application of phosphorus at four locations in the Sierra (1963-64).

Treatment		Potato Yields (M.T./Ha)				
Source of P	Rate of Application Kg. P_2O_5/Ha)	Otuxco (Ha. Cruz Pampa)	Jauja (Ha. Casa-blanca)	Huaraz (Conchan)	Cuzco (Quispi-quilla)	Ave.
Simple	40	19.1	25.8	—	19.9	—
Superphosphate	80	22.0	34.1	14.0	22.9	23.2
	160	24.8	29.4	15.3	21.5	22.7
	240	—	—	—	—	—
Triple	40	18.2	19.1	—	22.8	—
Superphosphate	80	19.2	30.1	13.5	21.8	22.1
(pelletted)	160	29.3	29.6	14.7	25.6	24.8
	240	—	—	17.5	—	—
Superphosphate	40	13.6	16.9	—	19.7	—
(21% soluble)	80	19.5	24.2	9.7	22.2	18.9
	160	31.2	27.9	10.9	23.0	23.2
	240	—	—	11.7	—	—
Superphosphate	40	24.9	24.0	—	21.0	—
(40% soluble)	80	26.8	24.6	12.2	25.4	22.2
	160	31.9	30.2	13.2	26.1	25.3
	240	—	—	14.5	—	—
Superphosphate	40	23.6	24.0	—	23.2	—
(87% soluble)	80	23.5	29.2	14.7	24.1	22.9
	160	25.2	32.0	15.1	27.0	24.8
	240	—	—	13.3	—	—
Hiperphosphate	40	11.7	13.0	—	22.6	—
(rock phosphate)	80	16.8	12.9	10.8	19.7	15.0
	160	13.0	19.6	8.0	19.7	15.1
	240	—	—	9.6	—	—
Check (160-0-80)	—	9.7	13.0	11.9	15.3	12.5

15. These data are further composited and presented in summary form in Table 11.

There was a highly significant response to level of fertilization in every experiment. Relative yields for the "zero", "medium", and "high" fertilization rates were roughly in the order 1 : 2 : 3, respectively, regardless of variety or population density, but the yield magnitude differed among varieties. The three improved strains consistently produced from 1.5-2.0 times more potatoes than any native variety with which they were compared.

The "main effects" for plant population and the "density X fertilization" (D X F) interaction were quite inconsistent, both within and among experiments. As the summary data show (Table 11), there was a trend toward higher yields as the population increased, but the magnitude of

Table 11. Average yields of six potato varieties as related to level of fertilization and plant population.

Relative Plant Population*	Yield of Potatoes (M.T./Ha)		
	No Fertilizer	Medium Fertilization	High Fertilization
		Renacimiento (8 expts.)	
Low	8.6	17.6	23.0
Medium	9.0	19.2	24.0
High	9.7	19.1	26.6
		Mantaro (7 expts.)	
Low	8.8	18.9	24.8
Medium	8.7	18.1	27.5
High	9.4	20.7	27.3
		Casablanca (5 expts.)	
Low	6.5	15.8	19.9
Medium	8.2	16.1	21.4
High	9.3	15.3	22.6
		Ccompis (3 expts.)	
Low	4.9	11.5	15.0
Medium	4.3	10.1	15.4
High	5.2	11.6	15.8
		Imilla Negra (1 expt.)	
Low	9.0	17.0	20.4
Medium	8.0	13.3	20.8
High	8.9	11.7	16.1
		Yana Imilla (1 expt.)	
Low	4.8	8.0	11.4
Medium	4.2	8.2	12.4
High	6.2	11.6	14.3

**See Appendix Table 15 for actual plant populations and fertilization levels employed.*

the increase was only rarely of statistical significance. In similar manner, the D X F interaction was seldom significant and, in fact, varied from positive to negative in different experiments. To illustrate the nature and magnitude of the D X F interactions encountered, data from four experiments are presented graphically in Figures 12, 13, and 14. The average yields of the three improved varieties as related to plant population and level of fertilization are plotted in Figure 15. It should be emphasized that the treatment designations in this graph are relative since treatments were not exactly the same for all experiments.

In addition to population, the number of tubers per plant and tuber size are also pertinent yield components in experiments of this type. Total yields of No. 1's and the percentage of No. 1's were used as indices of size in four experiments for which appropriate data were available. No consistent relationship between tuber size and plant population could be established, and in only two experiments was thre evidence that the percentage of No. 1 tubers was influenced by fertilization (Appendix

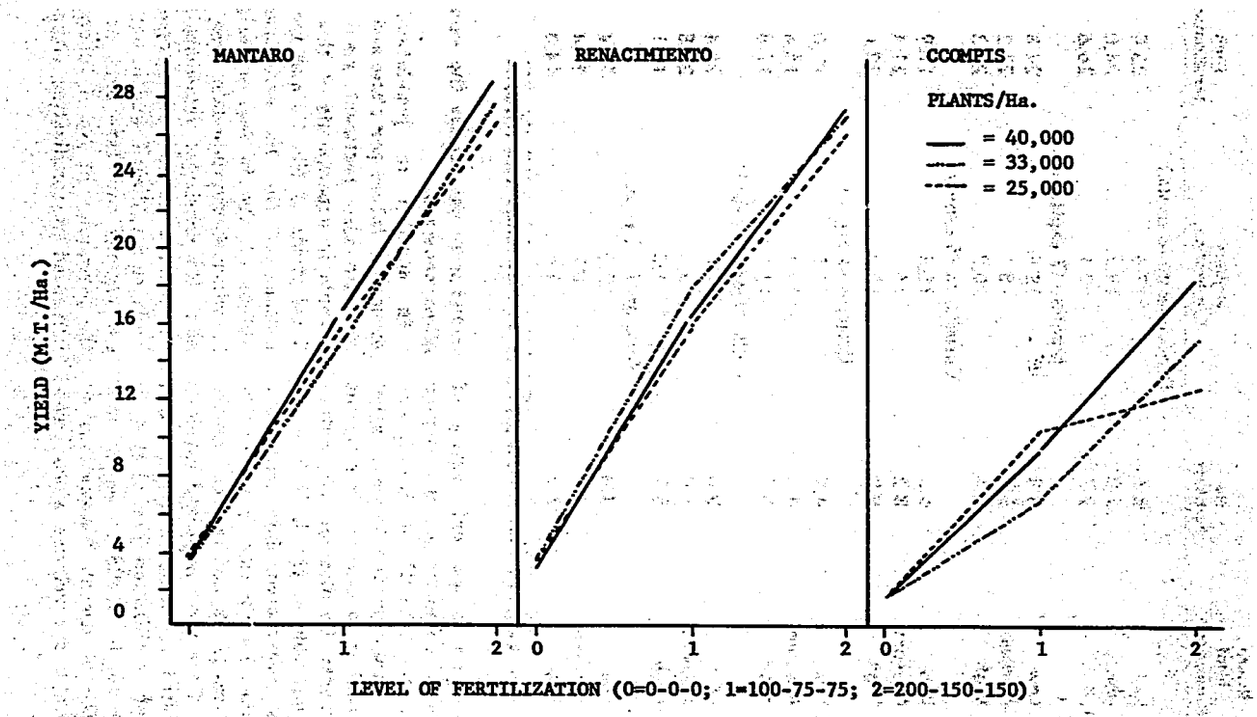

Fig. 12. Yields of three potato varieties as influenced by level of fertilization and plant population (Cuzco. 1962).

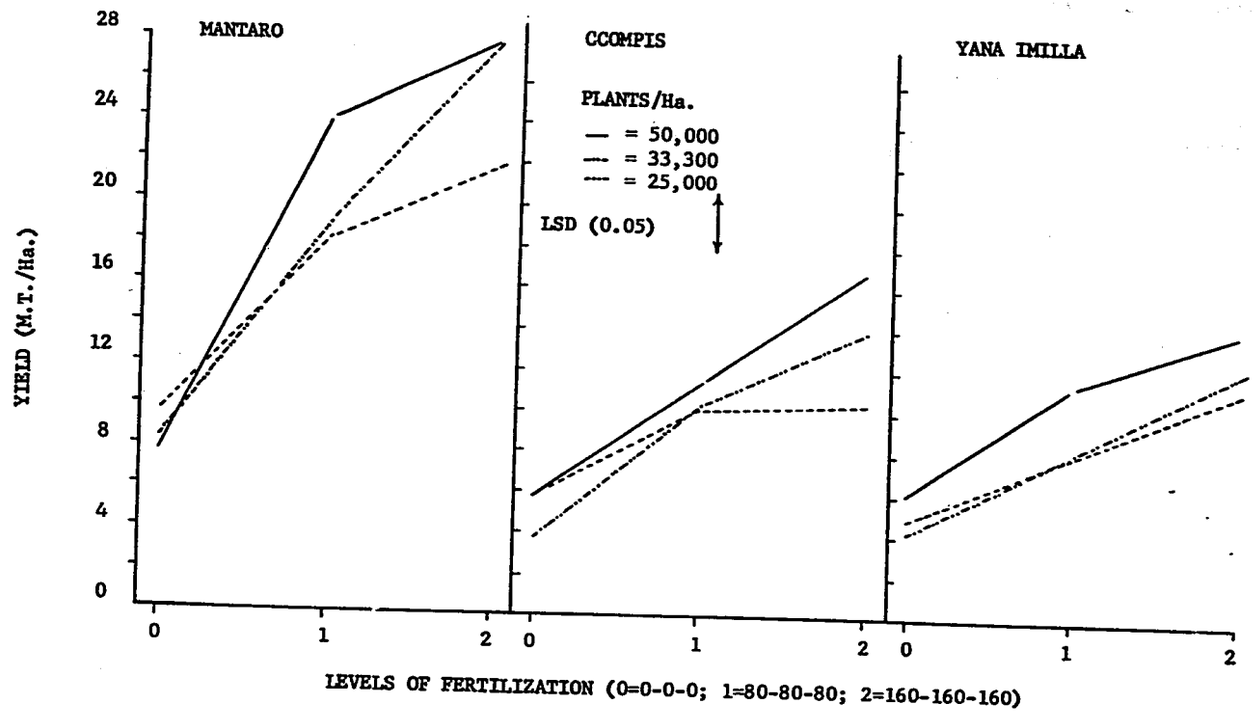

Fig. 13. Yields of three potato varieties as influenced by level of fertilization and plant population (Cuzco, 1963).

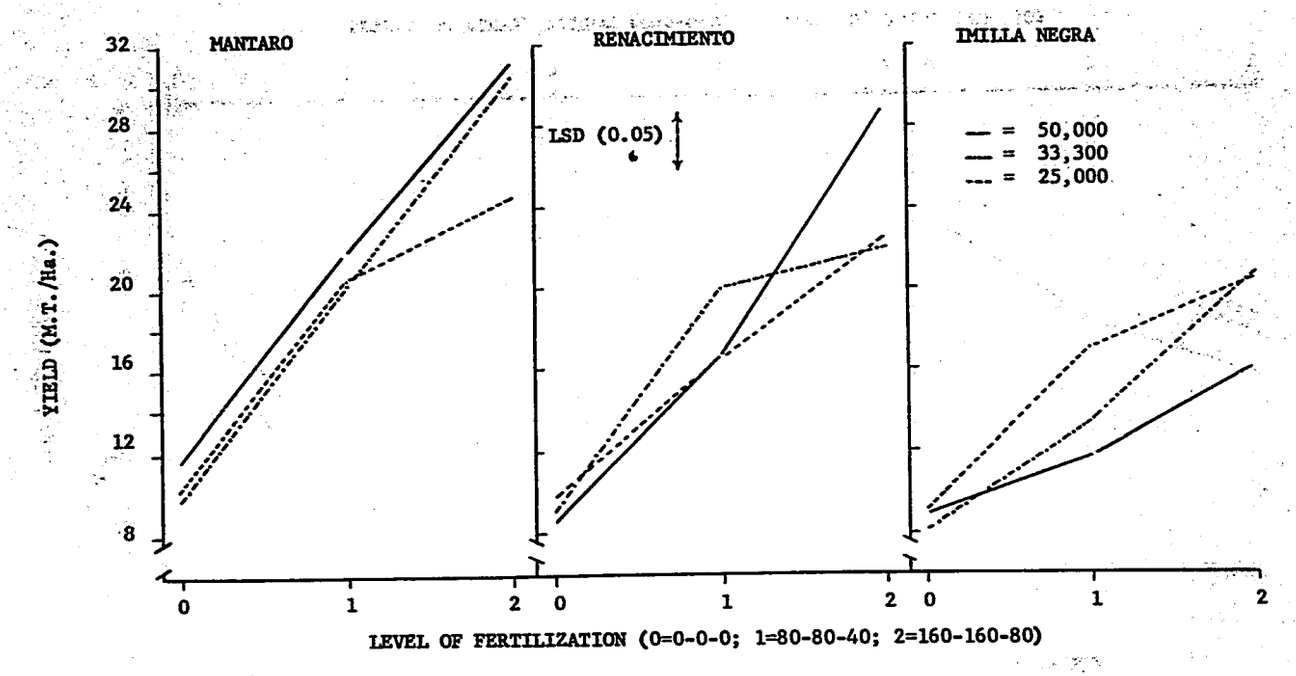

Fig. 14. Yields of three potato varieties as influenced by level of fertilization and plant population (Cuzco, 1964).

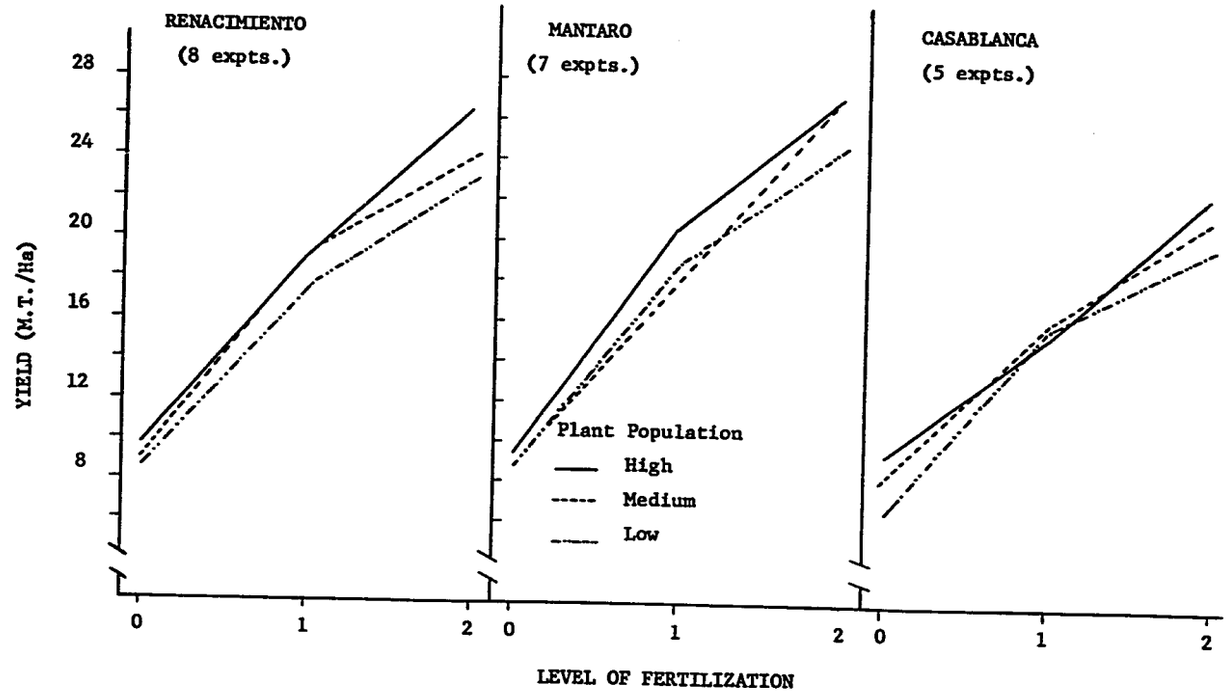

Fig. 15. Average yields of three improved potato varieties as related to level of fertilization and plant population.

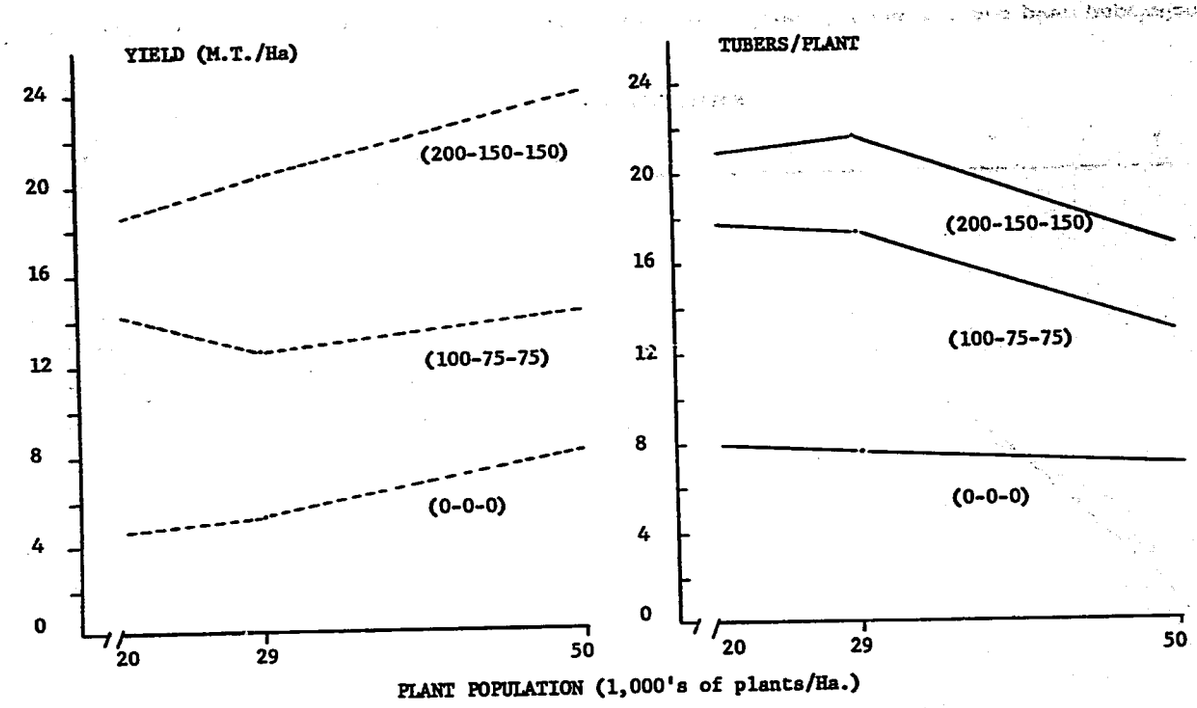

Fig. 16. Influence of level of fertilization and plant population on total yields of potatoes and on number of tubers per plant (ave. of two varieties, Renacimiento and Casablanca, in Catac, Huaraz, 1962).

Table 15). In one experiment (Cuzco, 1961-62), zero, 18, and 28 percent of the total yield were graded as No. 1's for the zero, medium, and high levels of fertilization, respectively. In another (Huancayo, 1960-61), the proportion of No. 1 tubers was significantly increased from 32% without fertilizer to 41% at the highest level of fertilization. It appears, therefore, that there is a trend toward a higher percentage of large tubers under adequate fertilization, but small differences of eight percent or less are difficult to measure because of a wide variability among replications.

In one experiment, the varieties Renacimiento and Mantaro produced a higher percentage of No. 1 tubers than the variety Casablanca, but the main varietal differences were between the improved and non-improved strains. The percentage of large tubers from the native varieties was generally lower than from the improved varieties.

Although appropriate data are available from only one experiment, the number of tubers per plant seems to be influenced by both plant population and fertilization. Ten-plant samples were taken from an experiment in Huaraz (1961-62), and the total number of tubers was counted. The resultant data (Figure 16) show that the number of tubers per plant was increased by fertilization, whereas higher populations lowered this value. The "density x fertilization" interaction term was not statistically significant, however, indicating that these two factors independently influence the initiation of tubers.

It would appear, therefore, that increased yields associated with high fertilization are influenced by the various yield components in the order: Number of tubers per plant>plant population>tuber size. Additional data are needed to make these observations more conclusive, however.

Summary and Conclusions

Soil fertility research with potatoes conducted during the decade 1950-1960 was reviewed. Results of this work provided the basis for the research program that has been in effect since 1960.

Fertilizer response data from 58 field experiments with factorially applied treatments of N, P_2O_5, and K_2O were combined, and a response function was fitted by least squares multiple regression. The combined data represented four years (1961-62-63-64) of experimentation in five regions of the Sierra (Puno, Cuzco, Huancayo, Huaraz, and Otuzco). Agronomic and economic interpretations of the experimental results based on the regression equations and on soil chemical properties were made.

These NPK experiments were complemented by field research on: (1) the relative effectiveness of different chemical or physical forms of nitrogen and phosphorus in supplying these nutrients to potatoes, and (2) the relationships among levels of fertilization, plant population, and potato varieties as reflected in yields of tubers. Although many of the data from these experiments are preliminary and inconclusive, some useful agronomic observations have been made. These data were summarized and the pertinent observations were presented.

The principle conclusions and general recommendations permitted by

the results of these studies can be summarized as follows:

1. Chemically synthesized fertilizer materials are equal or superior to natural materials such as *guano de islas* or barnyard manure in supplying the major plant nutrient elements (N, P, and K) to potatoes. When nitrogen or phosphorus applied as *guano de islas* (rico or pobre) was compared with equivalent quantities of these elements derived from chemical sources, potato yields were of the same order of magnitude. Yield differences that could be measured by statistical analyses generally favored the synthetic materials, but the nutrient content and the relatively favorable price of *guano de islas* make it a highly desirable fertilizer material. It is therefore suggested: (a) that guano or manure be used to the extent of their commercial availability, and (b) that these materials be supplemented with the more expensive chemical materials to achieve recommended rates of fertilization.
2. Positive yield responses to nitrogen and phosphorus were obtained up to the limit of the levels that were applied experimentally (160 kg/ha). Responses to potassium were less frequent and smaller in magnitude, but significant responses to the first increment of K_2O (80 Kg/Ha) were measured in about one-half of the experiments conducted.
3. An economic evaluation of the fertilizer response surface generated by multiple regression indicated that, at current potato-fertilizer price relationships, maximum net revenue for potatoes would be obtained at an approximate fertilization rate of 240-240-140. These levels of fertilization represent a substantial extrapolation from the rates that have been applied experimentally. More important, however, is the fact that the ratio $N : P_2O_5 : K_2O$ remained essentially constant at 1 : 1 : 0.6 for several assumed price regimes. This ratio is in good agreement with that suggested by agronomic observations. A general recommendation of 160-160-100 for average sierra soils can thus be supported both agronomically and economically. More specific recommendations should be based on soil properties as measured by laboratory analyses.
4. No commercially available nitrogen fertilizer material that has been studied to date was consistently superior for potatoes in sierra soils. Until these and other potentially important nitrogen materials have been studied more thoroughly, it is recommended that fertilizer nitrogen be purchased on the basis of price per unit of elemental nitrogen.
5. Of the phosphorus sources that were studied, the finely ground rock phosphate *(hiperfosfato)* was consistently inferior to other commercial or experimental materials regardless of soil acidity conditions. Potato yields with this material were less than 70% of the yields from superphosphate applied at equivalent rates. Of the three common phosphorus sources studied, the order of effectiveness as reflected by yield data were superphosphate>basic slag (escoria Thomas)>rock phosphate.
6. Evidence for an inverse relationship between the response to ap-

plied nitrogen and the nitrogen-supplying power of the soil, as measured by soil organic matter, was presented.

7. Responses to applied phosphorus were related not only to extractable soil phosphorus but also to soil pH. The largest responses to phosphorus were observed on soils that were low in extractable phosphorus and highly acid.
8. No significant relationship could be established between soil potassium levels and the response to applied potassium. The range in potassium responses was quite wide, however, and it was concluded that the routine analytical procedure used was not sufficiently precise to separate the soils according to their potassium content.
9. Both the absolute and relative response to high fertilization was greater for the improved potato varieties (Renacimento, Mantaro, and Casablanca) than for any native strain that was tested in direct comparisons (Ccompis, Yana Imilla, and Imilla Negra).
10. Although the data were inconclusive, increased yields associated with high fertilization appeared to be related to the various yield components in the order: number of tubers per plant>plant population>tuber size.

All of the attempts to relate soil nutrient levels to nutrient responses suggest that additional, more-detailed studies are needed to establish closer correlations between inherent soil nutrient levels and the response to applied fertilizers. Specific and more reliable fertilizer recommendations based upon soil analyses can then be made.

The extrapolation of the response curves beyond the levels that have been used to date seem to warrant some experimental exploration of the upper portions of the nitrogen and phosphorus curves. This conclusion is supported by the fact that higher fertilization rates can be justified economically.

Much of the variation in yield for the experiments summarized in this study could be ascribed to "year" and "location" effects. This variation was somewhat arbitrarily assumed to be the result of climatic variation among years or experimental sites. Much of it was undoubtedly due to soil differences, and the soil data are being further evaluated. Specific climatic data from the different experimental sites are not available, however, and it would be well to consider methods of accumulating climatic data in the future to facilitate a more accurate interpretation of fertilizer treatment effects.

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Appendix Table 1. Potato yields under varying fertilizer regimes at nine locations in the Sierra (crop-year 1958-59).

Treatment*	YIELDS (METRIC TONS/Ha.)								
	JUNIN Hda. Casablanca	JUNIN Hda. Casablanca	JUNIN Jauja	CUZCO Valle Cuzco	PUNO Camacani	PUNO Camacani	HUANUCO Conabamba	CAJAMARCA	ANCASH Rio Santa
Check	10.5	13.5	7.7	19.6	7.2	5.9	24.3	1.4	7.6
G	13.8	13.2	11.9	21.4	8.6	9.6	22.9	5.0	11.2
GN—	15.1	19.0	13.8	17.6	14.1	8.6	21.3	5.0	7.7
GN_2—	15.8	16.9	15.0	20.8	12.5	11.3	24.0	5.8	10.7
G— P	15.2	17.8	12.0	22.5	14.9	13.6	24.3	6.7	17.2
G N P —	14.7	18.8	15.1	17.9	12.5	11.2	24.1	5.8	21.8
G N_2 P	14.5	17.5	13.5	20.5	10.7	9.6	24.2	6.8	17.3
G— P_2	13.2	17.2	12.4	19.5	14.4	10.5	21.8	7.5	20.5
G N P_2	15.2	16.0	12.8	23.0	13.4	12.0	22.2	7.6	19.7
G N_2 P_2	15.0	17.9	12.6	21.1	15.0	12.3	24.7	6.6	21.3
G— K	19.0	19.2	15.6	20.0	14.8	12.3	23.4	6.7	13.1
G N— K	21.2	22.8	15.4	20.6	12.4	12.6	26.6	6.9	15.7
G N_2— K	20.3	22.9	15.5	19.9	13.4	13.4	22.4	5.9	10.7
G— PK	21.1	23.8	14.2	19.8	15.6	14.3	14.0	5.8	18.7
G N P K	23.0	25.7	18.6	22.4	16.4	11.6	26.1	8.1	20.3
G N_2 P K	23.6	26.9	15.4	22.2	15.2	12.8	25.8	5.5	21.1
G—P_2 K	22.2	24.0	16.9	24.9	16.1	12.5	23.1	7.6	18.2
G N P_2 K	23.1	27.8	16.6	21.9	19.6	12.6	21.9	7.4	20.8
G N P_2 K	25.2	28.2	19.0	20.9	18.4	14.3	24.9	8.6	23.8
—N_2 P_2 K	19.4	20.8	14.9	26.8	10.3	9.2	24.2	3.6	15.5
LSD (.05)	2.5	5.0	3.8	—	5.6	—	NS	2.5	3.7
CV (%)	13	18	24	—	34	—	27	—	19

*Symbols (per Ha): G=560 Kg of Guano; N and N_2=50 and 100 Kg of N; P and P_2=60 and 100 Kg of P_2O_5; K=60 Kg of K O. Data of Rodriguez, L. M. et al. (7).

Appendix Table 2. Potato yields under varying fertilizer regimes at seven locations in the Sierra (crop-year 1959-60).

	YIELDS (METRIC TONS/Ha.)						
Treatment*	JUNIN (Jauja)	PUNO (Camaceni)	HUANUCO (Viscarra)	ANCASH (R. Santa)	APURIMAC (Andahuaylas)	AYACUCHO (Huanta)	AREQUIPA (Ha. Vallecita)
Check	7.1	3.6	9.7	5.4	11.6	4.3	5.8
G	8.6	3.8	13.3	9.0	14.8	8.4	7.9
G N	8.9	3.6	15.3	9.4	17.1	8.9	8.0
G N_2	9.9	2.5	9.4	7.0	15.1	9.5	8.7
G P	9.4	4.1	12.3	17.5	15.0	9.2	8.5
G N P	10.5	3.7	13.2	19.2	14.8	14.0	8.1
G N_2 P	10.3	5.0	13.8	14.3	14.6	12.3	7.5
G P_2	9.9	3.7	13.3	17.2	15.6	11.4	7.9
G N P_2	11.3	3.6	14.8	20.2	16.2	13.4	8.5
G N_2 P_2	10.5	3.6	10.8	21.5	14.6	15.5	8.7
G— — K	10.2	5.0	10.7	10.2	16.6	7.4	9.0
G N— K	11.2	4.4	11.1	10.3	16.1	8.2	8.4
G N_2— K	13.5	2.3	12.9	8.8	16.2	9.1	7.5
G — P K	12.5	4.9	12.3	18.5	14.4	10.1	9.4
G N P K	12.1	3.3	14.5	19.0	14.7	13.8	8.2
G N_2 P K	11.8	2.5	14.3	18.1	15.0	12.0	8.1
G— P_2 K	13.2	5.8	13.7	19.9	15.7	11.3	9.5
G N P_2 K	12.6	4.1	9.9	21.1	19.3	9.1	9.6
G N_2 P_2 K	13.9	3.2	15.2	18.9	20.0	12.3	8.8
— N_2 P_2 K	12.7	4.0	13.2	15.9	15.4	10.6	8.7
LSD (.05)	2.6	2.0	NS	4.0	2.1	1.9	2.3
CV (%)	22	50	38	23	12	20	26

**See Appendix Table 1 for explanation of treatment symbols. Data of Rodriguez, L. M. et al. (7).*

Appendix Table 3. Effects of different levels of N, P_2O_5, and K_2O in factorial combination on potato yields at four locations in the Sierra (crop-year 1959-60).

Treatment: 5,000 Kg. of manure/Ha. Plus (Kg/Ha.)			YIELDS (Metric Tons/Ha.)			
N	P_2O_5	K_2O	JUNIN E.E.A.J.	CUZCO (Perayoc)	ANCASH (Hda. Catac)	TARMA* (Hda. Casablanca)
0	0	0	20.9	19.3	17.6	7.1
75	0	0	21.8	24.2	21.7	7.0
150	0	0	22.0	20.4	19.7	6.0
300	0	0	22.6	29.3	18.7	4.3
0	75	0	16.5	16.4	19.3	12.1
75	75	0	22.5	25.3	24.5	15.1
150	75	0	25.6	21.5	32.6	16.6
300	75	0	23.4	26.8	31.4	19.9
0	150	0	19.3	21.0	23.2	16.0
75	150	0	23.4	26.2	28.6	19.1
150	150	0	26.4	31.8	33.2	19.4
300	150	0	16.5	25.5	31.8	18.5
0	0	75	16.6	20.8	19.3	7.4
75	0	75	24.3	22.2	23.8	8.5
150	0	75	26.1	23.4	23.1	5.3
300	0	75	22.2	22.5	19.8	5.1
0	75	75	18.4	19.3	22.5	14.0
75	75	75	23.2	23.5	30.5	17.3
150	75	75	24.5	25.7	30.9	19.7
300	75	75	26.3	25.3	30.0	18.0
0	150	75	18.0	17.8	24.5	18.1
75	150	75	27.7	23.3	29.5	21.1
150	150	75	27.7	30.0	35.5	23.4
300	150	75	28.6	21.1	29.9	21.3
0	0	150	19.2	21.2	18.3	9.0
75	0	150	20.2	23.6	22.9	6.4
150	0	150	25.3	29.1	20.0	5.4
300	0	150	24.3	25.4	23.2	6.7
0	75	150	20.4	19.7	24.1	17.3
75	75	150	23.9	21.4	31.0	21.0
150	75	150	28.1	28.8	28.3	18.5
300	75	150	29.5	23.5	32.8	20.1
0	150	150	19.5	17.1	24.2	18.8
75	150	150	24.7	20.3	33.6	24.3
150	150	150	27.0	25.6	30.2	21.0
300	150	150	25.5	28.0	30.6	22.4
No Treatment			18.0	17.8	6.9	—
Soil Properties:						
pH		7.6	7.6	4.6	4.3	
O.M. (%)		1.5	2.8	5.5	3.7	
Kg. P_2O_5/Ha		10	15	8	18	
Kg. K_2O/Ha		120	150	350	100	

**The experiment at Hda. Casablanca (Tarma) did not include a broadcast application of manure as indicated under "treatment."*

Appendix Table 4. Potato yields in a 4N x 3P x 3K factorial experiment at four locations (crop-years 1960-61 and 1961-62).

Treatment (Kg./Ha.) N	P_2O_5	K_2O	YIELDS (Metric Tons/Ha.) 1960-61 JUNIN (Conception)	CUZCO (Anta)	1961-62 TARMA (Hda. Casab)	CUZCO (Maras)	Mean
0	0	0	7.8	7.4	6.4	8.2	7.4
0	0	75	5.6	7.3	6.9	8.4	7.0
0	0	150	8.9	9.9	7.8	8.3	8.7
0	75	0	5.7	6.5	6.4	9.0	6.9
0	75	75	6.9	7.8	9.6	8.2	8.1
0	75	150	10.9	8.1	9.9	8.6	9.4
0	150	0	3.9	9.0	8.6	8.2	7.4
0	150	75	7.7	12.1	10.4	8.4	9.6
0	150	150	10.8	12.1	12.6	8.6	11.0
75	0	0	14.1	16.7	6.2	11.2	12.0
75	0	75	11.4	11.8	8.7	10.8	10.7
75	0	150	16.6	16.0	10.4	11.8	13.7
75	75	0	16.4	13.3	10.2	19.6	14.9
75	75	75	17.1	19.3	13.8	20.4	17.6
75	75	150	16.1	12.8	14.4	18.2	15.4
75	150	0	12.0	14.4	10.3	19.1	1[illegible].9
75	150	75	15.9	11.8	14.4	21.4	15.9
75	150	150	17.8	14.6	16.8	22.6	17.9
150	0	0	10.1	16.7	6.6	13.1	11.6
150	0	75	15.6	15.8	9.0	14.4	13.7
150	0	150	22.8	22.6	10.9	11.6	17.0
150	75	0	15.8	17.6	10.2	27.3	17.7
150	75	75	20.3	17.7	13.9	21.8	18.4
150	75	150	16.9	19.7	17.6	27.5	20.4
150	150	0	9.4	14.5	11.4	21.3	14.1
150	150	75	16.4	16.9	16.1	27.9	19.3
150	150	150	20.5	20.8	19.4	31.8	23.1
300	0	0	13.8	24.5	6.9	11.1	14.1
300	0	75	21.1	26.2	8.5	14.3	17.5
300	0	150	19.4	25.8	9.9	10.6	16.4
300	75	0	18.9	19.9	10.1	34.4	20.8
300	75	75	18.5	21.7	16.1	35.0	22.8
300	75	150	21.6	20.0	17.6	40.0	24.8
300	150	0	16.6	20.4	12.8	31.9	20.4
300	150	75	22.2	26.7	17.6	35.7	25.5
300	150	150	21.2	27.1	18.9	42.3	27.4
C.V. %			21	26	20	17	
Soils Properties							
pH			6.6	6.0	4.6	7.0	
O.M. (%)			2.3	3.5	3.2	1.3	
Kg. P_2O_5/Ha.			24	9.2	19	5	
Kg. K_2O/Ha.			120	120	150	165	

Appendix Table 5. Potato yields in a 3N x 3P x 3K factorial experiment at three locations in the Mantaro Valley (Junin) during the crop-year 1961-62.

Treatment (Kg/Ha)			YIELD (Metric tons/Ha)			
N	P_2O_5	K_2O	PALIAN	ORCOTUNA	LA MEJORADA	MEAN
0	0	0	3.8	7.8	6.0	5.9
0	0	75	3.8	6.5	6.0	5.4
0	0	150	4.4	7.6	6.1	6.0
0	75	0	4.4	7.2	7.0	6.2
0	75	75	4.4	7.1	6.5	6.0
0	75	150	4.4	7.9	6.5	6.3
0	150	0	4.7	8.2	6.1	6.3
0	150	75	5.2	7.2	6.5	6.3
0	150	150	4.9	7.3	6.7	6.3
75	0	0	8.4	14.6	13.2	12.1
75	0	75	9.8	16.1	14.5	13.5
75	0	150	9.6	14.8	15.3	13.2
75	75	0	9.4	15.6	11.9	12.3
75	75	75	10.4	15.8	15.4	13.9
75	75	150	9.9	16.4	15.9	14.1
75	150	0	9.9	16.0	11.0	12.3
75	150	75	11.1	18.7	15.5	15.1
75	150	150	12.3	17.7	17.4	15.8
150	0	0	10.2	18.2	14.3	14.2
150	0	75	12.4	20.6	16.5	16.5
150	0	150	13.4	18.3	18.0	16.6
150	75	0	11.2	19.8	14.4	15.1
150	75	75	15.1	22.5	18.8	18.8
150	75	150	16.3	23.8	19.9	20.0
150	150	0	9.7	22.2	12.5	14.8
150	150	75	16.9	24.5	18.1	19.8
150	150	150	15.6	24.6	20.4	20.2
C. V. (%)			27	13	14	
Soil Properties:						
pH			6.0	6.0	5.7	
% O.M.			1.9	0.6	1.4	
Kg. Avail. P_2O_5/Ha.			90	18	119	
Kg. Avail. K_2O/Ha.			120	120	120	

Appendix Table 6. Effect of varying levels of N, P_2O_5, and K_2O in factorial combination on potato yields at different locations in the Department of Junin during the crop-year 1962-63 and 1963-64.

Treatment (Kg/Ha)			YIELDS (Metric tons/Ha)						
			1962-63		1963-64				
N	P_2O_5	K_2O	Hda. Casab.	Mantari Farm	San Lorenzo	Tambo	Hda. Casab.	Huancas	Mean
0	0	0	3.2	3.9	9.4	4.0	12.9	7.9	6.9
0	0	80	4.4	4.3	8.3	5.2	10.6	6.0	6.5
0	0	160	4.0	4.0	8.0	6.7	8.8	3.9	5.9
0	80	0	3.7	7.3	9.6	5.9	13.8	6.5	7.8
0	80	80	8.3	9.0	13.4	7.1	16.4	6.4	10.1
0	80	160	11.9	8.8	11.8	5.8	13.5	4.0	9.3
0	160	0	4.0	7.6	8.5	4.0	14.9	7.2	7.7
0	160	80	12.2	9.9	11.5	5.7	16.4	6.9	10.4
0	160	160	13.1	10.4	9.4	6.9	17.7	3.6	10.2
80	0	0	4.3	2.6	8.2	7.9	12.9	14.6	8.4
80	0	80	5.8	2.7	11.1	11.1	11.4	13.6	9.3
80	0	160	4.4	2.1	9.4	9.6	9.2	13.8	8.1
80	80	0	5.2	10.4	11.8	7.8	18.2	16.5	11.6
80	80	80	12.6	14.0	12.3	9.8	17.5	16.1	13.7
80	80	160	13.4	12.6	15.5	11.5	17.1	12.7	13.8
80	160	0	8.4	12.4	14.5	8.4	20.1	15.4	13.2
80	160	80	15.6	18.3	13.5	10.9	24.2	16.8	16.5
80	160	160	18.4	16.9	16.6	9.9	25.5	14.9	17.0
160	0	0	3.8	2.9	11.4	9.3	9.1	18.1	9.1
160	0	80	4.9	2.8	11.8	10.9	8.4	20.6	9.9
160	0	160	4.2	2.8	8.9	12.8	7.0	17.8	8.9
160	80	0	6.8	12.9	11.8	9.2	17.2	18.9	12.8
160	80	80	12.1	18.6	12.9	11.2	21.9	19.4	16.0
160	80	160	15.1	16.8	12.5	11.8	17.9	20.1	15.7
160	160	0	8.6	15.3	14.1	6.9	20.2	18.7	14.0
160	160	80	14.9	19.4	18.1	11.8	22.9	22.0	18.2
160	160	160	22.2	19.8	16.3	15.4	23.5	22.6	20.0
C.V. (%)			19	20					
Soil Properties:									
pH			4.4	4.4	7.1	6.4	4.0	4.5	
% O.M.			3.8	9.0	2.3	2.5	2.9	1.7	
Kg. P_2O_5/Ha.			14	19	46	74	118	133	
Kg. K_2O/Ha.			150	340	150	150	187	262	

Appendix Table 7. Effect of varying levels of N, P_2O_5, and K_2O in factorial combination on potato yields in different areas during the crop-years 1962-63 and 1963-64.

Treatment Kg./Ha.			YIELDS (Metric Tons/Ha)					
			1962-63		1963-64			
N	P_2O_5	K_2O	PUNO (Camacani)	CUZCO (Maras)	CUZCO (Quispiqu.)	CUZCO	HUARAZ (Anta)	MEAN
0	0	0	13.7	6.6	13.8	9.6	7.1	10.2
0	0	80	15.1	7.1	14.6	11.4	8.6	11.4
0	0	160	13.0	6.4	15.0	11.1	10.0	11.3
0	80	0	18.4	6.3	16.1	10.8	9.5	12.2
0	80	80	18.0	6.8	13.7	12.8	10.4	12.3
0	80	160	21.9	6.1	17.6	12.0	10.2	13.6
0	160	0	17.6	6.6	19.5	12.6	10.5	13.4
0	160	80	16.4	8.3	19.6	12.6	9.6	13.3
0	160	160	16.4	8.2	21.3	10.0	8.8	12.9
80	0	0	13.4	11.0	20.4	12.8	12.4	14.0
80	0	80	15.4	12.4	19.8	15.4	15.5	15.7
80	0	160	18.0	12.2	20.6	13.6	9.9	14.9
80	80	0	21.3	24.1	20.4	21.3	12.7	20.0
80	80	80	20.4	17.2	20.5	23.0	14.1	21.0
80	80	160	17.9	22.8	21.4	23.1	11.4	19.3
80	160	0	19.5	27.8	18.4	22.4	14.0	20.4
80	160	80	19.8	27.0	22.9	21.9	11.5	20.6
80	160	160	17.8	26.9	21.8	22.6	13.6	20.5
160	0	0	14.3	12.1	20.3	13.9	13.0	14.7
160	0	80	14.6	14.8	19.1	14.7	12.9	15.2
160	0	160	20.8	13.0	18.4	14.4	10.5	15.4
160	80	0	18.0	32.7	24.4	24.2	11.2	22.1
160	80	80	19.8	37.3	21.5	23.9	12.5	23.0
160	80	160	19.8	33.0	19.7	23.3	14.9	22.1
160	160	0	20.7	35.4	17.3	25.6	16.1	23.0
160	160	80	21.5	37.4	24.7	28.0	10.4	24.4
160	160	160	17.2	38.2	20.3	26.8	12.5	23.0

Appendix Table 8. Effects of varying levels of N, P_2O_5, and K_2O in factorial combination on potato yields during three crop-years.

Treatment (Kg/Ha)			YIELDS (Metric tons/Ha)			
			1960-1961		1961-1962	1962-1963
N	P_2O_5	K_2O	JUNIN E.E.A.J.	HUARAZ (Catac)	HUARAZ (Catac)	HUARAZ Hda. La Florida
80	50	0	27.4	15.4	7.8	24.4
80	50	75	34.2	18.1	8.9	24.6
80	50	150	30.5	20.1	12.2	27.7
80	100	0	30.9	15.8	9.4	24.2
80	100	75	27.5	20.6	14.5	24.3
80	100	150	30.3	21.6	11.4	25.7
80	150	0	30.4	16.7	11.9	25.9
80	150	75	20.0	21.8	16.4	25.7
80	150	150	29.7	19.9	15.0	24.7
160	50	0	33.7	21.2	9.3	26.3
160	50	75	34.1	24.6	10.4	24.2
160	50	150	29.2	25.1	10.1	25.1
160	100	0	29.2	19.6	11.4	27.2
160	100	75	32.9	24.6	11.8	26.6
160	100	150	30.2	25.4	15.7	24.8
160	150	0	29.4	24.8	12.7	29.2
160	150	75	31.5	29.7	18.4	27.8
160	150	150	28.9	29.5	18.1	25.3
240	50	0	27.3	22.8	8.1	24.2
240	50	75	25.8	25.9	10.3	24.2
240	50	150	35.9	30.8	9.1	23.5
240	100	0	32.7	22.2	9.0	27.1
240	100	75	35.1	30.5	11.2	23.4
240	100	150	27.1	31.4	11.9	25.6
240	150	0	26.2	26.1	11.9	29.1
240	150	75	37.1	31.4	15.3	28.8
240	150	150	30.8	33.7	15.6	25.2
0	0	0	12.4	7.4	9.0	21.7
C.V. (%)			20	12	30	9
Soil Properties:						
pH			7.0	4.8		7.6
% O.M.			2.5	4.5		3.3
Kg. Avail. P_2O_5/Ha.			20	6		16
Kg. Avail. K_2O/Ha.			240	120		225

Appendix Table 9. Potato yields in a 2N x 3P factorial experiment at 8 different locations in the Department of Junin during the crop-year 1961-62.

Treatment* (Kg/Ha)		YIELDS (Metric tons/Ha)								
N	P_2O_5	Hda. Huachac	Sicaya	Huayao Observ.	Huayao Pamparca	Huancas	Sanos Chico	Jauja	Mata-Huasi	Mean
75	0	23.8	21.0	20.3	11.8	23.1	9.2	23.8	13.8	18.3
75	75	23.9	20.5	19.4	12.2	27.8	12.1	26.9	13.7	19.6
75	150	24.1	20.9	18.4	12.2	29.4	10.5	27.1	16.1	19.8
150	0	30.1	27.1	24.9	16.6	29.2	11.3	26.1	14.0	22.4
150	75	31.1	26.8	26.2	17.2	31.0	14.0	26.7	15.8	23.6
150	150	28.1	27.4	26.4	19.4	33.6	12.2	32.0	17.8	24.6
0	0	11.6	10.9	11.6	3.1	14.0	4.5	22.8	6.6	10.6
C. V. %		11	11	9	9	38	15	14		
Soil Properties:										
pH		6.3	6.1	5.5	5.5	5.2	6.2	8.2	7.5	
% O.M.		1.5	1.[illegible]	0.7	0.8	2.1	1.4	1.5	1.8	
Kg. Avail. P_2O_5/Ha.		89	92	27	81	114	32	25	53	
Kg. Avail. K_2O/Ha.		120	120	120	120	150	120	625	150	

Except for check plot, indicated treatments received 75 kg. of K_2O/Ha.

Appendix Table 10. Potato yields in a 2N x 2P x 2K factorial experiment at 10 locations in the Department of Junin during the crop-year 1962-63.

Treatment (Kg/Ha)			YIELDS (Metric tons/Ha)										
N	P_2O_5	K_2O	Pelian	Sanos Chico	Huayao (Comm)	Huayao (Cerron)	Huachac	Sicaya	Huanchar	E.E.A.J.	Huancas	San Juan	Mean
80	0	0	17.9	5.6	11.1	13.9	5.9	11.8	12.5	7.6	5.9	6.1	9.8
80	0	80	22.3	8.8	12.5	18.9	8.5	10.8	12.2	9.9	7.3	7.1	11.8
80	80	0	16.3	6.1	11.3	14.3	5.0	11.4	12.1	7.9	6.5	8.4	9.9
80	80	80	18.5	10.1	15.5	22.6	10.0	14.7	11.9	12.0	11.1	12.7	13.9
160	0	0	18.1	6.4	12.0	15.7	5.8	11.8	13.0	9.5	9.8	9.2	11.1
160	0	80	21.4	8.4	11.1	18.9	12.1	11.5	13.9	13.6	12.8	6.9	13.1
160	80	0	18.1	7.2	13.4	16.9	6.0	16.1	14.4	8.5	13.2	10.9	12.5
160	80	80	25.7	8.9	19.8	26.8	16.8	19.0	15.2	14.2	15.7	13.0	17.5
0	0	0	10.9	3.7	4.0	8.7	2.6	6.7	8.5	4.5	1.7	3.5	5.5
10 tons manure			16.7	5.6	5.0	14.3	5.0	7.8	7.3	5.0	4.2		
C. V. %			15	40	17	16	22	23	24	21	24	24	
Soil Properties:													
pH			5.7	6.5	7.5	6.0	6.3	7.4	6.9	7.6	5.0	8.2	
% O.M.			1.62	1.54	0.82	0.54	0.66	1.01	1.5	0.9	1.16	0.90	
Kg. Avail. P_2O_5/Ha.			27	16	45	51	37	41	69	121	84	39	
Kg. Avail. K_2O/Ha.			150	150	150	150	150	150	150	150	150	150	

Appendix Table 11. Potato yields in a 2N x 2P x 2K factorial experiment at 5 locations in the Department of [illegible]in during the crop-year 1963-64.

Treatment (Kg/Ha)			YIELDS (Metric tons/Ha)					
N	P_2O_5	K_2O	PALIAN	SAN LORENZO	ORCOTUNA	HUAYAO	MATA-HUASI	MEAN
80	0	0	17.0	9.8	10.6	9.4	16.0	12.6
80	0	80	18.8	11.9	11.9	14.4	20.5	15.5
80	80	0	16.9	12.9	10.6	9.1	16.3	13.2
80	80	80	22.1	12.7	12.9	17.2	17.4	16.5
160	0	0	19.6	10.3	9.1	9.4	14.1	12.5
160	0	80	24.6	6.8	12.0	11.4	19.0	14.8
160	80	0	16.2	12.1	11.0	8.1	16.2	12.7
160	80	80	22.9	14.1	13.1	16.0	16.7	16.6
0	0	0	10.9	9.4	6.6	5.4	13.4	9.1
75 (615 Kg. G. de I.)	60	10	17.6	12.0	10.1	9.1	17.4	13.2
Soil Properties:								
pH			5.7	7.4	5.7	7.2	6.5	
% O.M.			2.7	2.4	1.3	1.6	3.2	
Kg. Avail. P_2O_5/Ha.			44	7	48	6	5	
Kg. Avail. K_2O/Ha.			150	150	187	150	150	

Appendix Table 12. Potato yields in the Department of Cuzco as influenced varying levels of N, P_2O_5, and K_2O during the crop-years 1961-62 and 1963-64.

Treatment (Kg/Ha)			Yields (M.T./Ha) 1961-1962	
N	P_2O_5	K_2O	Judas Grande	Ha. Pancar-huaylla.
75	0	75	29.3	11.3
75	75	75	27.6	33.2
75	150	75	27.8	32.0
150	0	75	31.6	15.7
150	75	75	29.9	29.4
150	150	75	29.8	38.6
0	0	0	22.5	7.5
20 tons manure			27.7	25.0
C.V. (%)			13	28
Soil Properties:				
pH			—	—
% O.M.			4.2	3.2
Kg. Avail. P_2O_5/Ha.			63	19
Kg. Avail. K_2O/Ha.			300	150

Treatment (Kg/Ha)			Yields (M.T./Ha) 1963-1964		
N	P_2O_5	K_2O		Hda. Pancar-huaylla.	Anta
80	0	0	19.4		
80	80	0	18.6	4.9	5.5
80	160	0		14.2	12.2
160	0	0	18.7		
160	80	0	18.6	5.5	3.5
160	160	0		15.6	11.3
80	0	80	20.0		
80	80	80	22.9	5.8	4.0
80	160	80		12.5	10.9
160	0	80	24.2		
160	80	80	21.9	5.4	3.1
160	160	80		17.2	13.2
0	0	0	11.6	3.9	3.1
75	60	10	17.7	8.2	8.9
(615 Kg guano)					

Appendix Table 13. Potato yields in the Department of Ancash (Huaraz) as influenced by varying levels of N, P_2O_5, and K_2O during the crop-years 1962-63 and 1963-64.

Treatment (Kg/Ha)			YIELDS (Metric tons/Ha)				
			1962-1963				1963-1964
N	P_2O_5	K_2O	La Florida	Tica-pampa	Sr. Olleros	Anta	La Florida
80	80	80	25.0	19.7	27.0	14.3	16.2
80	80	160	24.5	21.0	29.1	13.8	12.6
80	160	80	24.0	23.4	31.4	17.1	17.6
80	160	160	25.5	21.5	31.8	16.4	12.8
160	80	80	25.4	21.8	32.0	17.0	17.2
160	80	160	25.0	23.3	32.4	15.0	11.8
160	160	80	27.0	28.4	31.7	16.0	17.7
160	160	160	26.9	24.3	33.7	17.4	15.6
0	0	0	17.5		18.5	10.9	11.4
C. V. (%)			6	21	6	21	
Soil Properties:							
pH			7.2	4.6	6.1	7.9	
% O.M.			3.4	1.4	2.3	2.2	
Kg. Ovail. P_2O_5/Ha.			42	60	16	7	
Kg. Avail. K_2O/Ha.			300	225	150	225	

Appendix Table 14. Potato yields in the Departments of La Libertad (Otuzco) and Puno as influenced by varying levels of N, P_2O_5, and K_2O during the crop-years 1962-63 and 1963-64.

Treatment (Kg./Ha.)			OTUZCO		PUNO
			1962-63	1963-64	1962-63
N	P_2O_5	K_2O			
80	0	0	16.9	16.4	—
80	80	0	28.1	29.2	26.7
80	160	0	—	—	24.2
160	0	0	15.3	30.1	—
160	80	0	30.4	41.2	29.1
160	160	0	—	—	30.7
80	0	80	18.1	26.0	—
80	80	80	31.0	31.7	22.5
80	160	80	—	—	23.7
160	0	80	16.7	32.2	—
160	80	80	36.9	40.3	28.3
160	160	80	—	—	29.5
0	0	0	15.2	14.9	11.7
C.V. (%)			10	10	—
Soil Properties					
pH			5.2		5.9
O.M. (%)			3.5		2.1
Kg. Avail. P_2O_5/Ha.			36		130
Kg. Avail. K_2O/Ha.			187		300

Appendix Table 15. Yields of different varieties of potatoes as influenced by plant population and level of fertilization (Metric tons/Ha.).

Kg. of N-P_2O_5—K_2O per Ha.	0 — 0 — 0	100 — 75 — 75	200 — 150 — 150
No. Plants/Ha.	**25000 33300 50000**	**25000 33300 50000**	**25000 33300 50000**
		JUNIN (SAN LORENZO) 1963	
Renacimiento	3.9 4.8 4.4	11.1 14.1 15.8	17.9 17.4 23.4
Casablanca	2.7 3.5 4.3	11.7 13.4 11.3	17.9 19.1 19.1
Mantaro	3.7 4.8 4.4	13.7 14.9 13.1	14.5 18.1 22.1
		JUNIN (CONCEPCION) 1961	
	25000 33300 40000	**25000 33300 40000**	**25000 33300 40000**
Renacimiento	10.3 11.5 13.0	16.1 18.7 20.0	18.4 20.2 22.0
Casablanca	9.1 12.5 14.0	15.0 15.6 17.6	21.4 21.8 18.9
Mantaro	16.3 14.9 18.7	20.8 22.1 22.5	26.5 27.8 24.9
		HUARAZ (CATAC) 1961	
Renacimiento	5.0 4.8 5.9	22.2 18.0 21.1	28.8 27.5 27.8
Casablanca	5.3 7.4 6.1	17.7 19.8 17.1	25.1 27.0 30.0
Mantaro	5.1 5.0 5.4	20.2 31.7 21.2	31.4 31.7 33.0
		CUZCO (ANTA) 1961	
Renacimiento	13.6 14.3 14.4	21.3 24.9 23.1	23.0 26.0 27.3
Mantaro	13.7 14.9 14.7	22.3 16.4 26.8	16.0 29.3 25.7
Ccompis	7.4 7.5 8.2	15.0 13.3 13.0	16.3 16.8 17.8

Appendix Table 15. (Continued).

Kg. of N-P_2O_5—K_2O per Ha.	0 — 0 — 0			80 — 80 — 80			160 — 160 — 160		
	25000	33300	50000	25000	33300	50000	25000	33300	50000
					CUZCO (MARAS)			1963	
Mantaro	9.6	8.2	7.6	18.2	19.0	24.0	21.8	27.8	27.9
Yanaimilla	4.8	4.2	6.2	8.0	8.2	11.6	11.4	12.4	14.3
Ccompis	5.8	3.7	5.8	10.0	10.3	11.5	10.4	14.0	17.0
					CUZCO			1964	
	0 — 0 — 0			80 — 80 — 40			160 — 160 — 80		
	25000	33300	50000	25000	33300	50000	25000	33300	50000
Renacimiento	9.8	9.0	8.5	16.5	20.0	16.6	22.5	22.0	29.5
Mantaro	10.2	9.7	11.6	20.4	20.2	21.8	24.5	30.4	31.2
Imilla Negro	9.0	8.0	8.9	17.0	13.3	11.7	20.4	20.8	16.1
					HUARAZ (CATAC)			1962	
	0 — 0 — 0			100 — 75 — 75			200 — 150 — 150		
	20000	28500	50000	20000	28500	50000	20000	28500	50000
Renacimiento	5.8	6.8	9.6	12.9	11.9	17.3	18.3	20.7	23.1
Casablanca	3.4	3.7	6.4	15.6	13.0	11.2	18.8	19.9	24.5
					HUARAZ (HA. LA FLORIDA)			1963	
	0 — 0 — 0			100 — 80 — 80			200 — 160 — 160		
	20000	28500	50000	20000	28500	50000	20000	28500	50000
Renacimiento	17.2	17.5	18.4	24.0	28.1	23.0	27.5	32.1	34.1
Casablanca	11.8	13.9	15.8	19.2	18.5	19.5	16.4	19.1	20.7

Appendix Table 16. The influence of population density, level of fertilization, and potato variety on tuber size in four experiments.

Relative Plant Population*	Variety	Level of Fertilization*	No. 1 Tubers (As percent of total)			
			CUZCO 1960-61	CUZCO 1960-61	CONCEP. 1960-61	HUARAZ. 1961-62
LOW	Mantaro	Low	28	0	52	—
		Medium	26	29	39	—
		High	35	37	46	—
	Renacimiento	Low	33	0	33	32
		Medium	37	26	46	27
		High	27	35	42	39
	Casablanca	Low	—	—	16	31
		Medium	—	—	32	38
		High	—	—	37	36
	Ccompis	Low	13	0	—	—
		Medium	26	4	—	—
		High	36	18	—	—
MEDIUM	Mantaro	Low	23	0	39	—
		Medium	29	28	51	—
		High	36	36	42	—
	Renacimiento	Low	45	0	30	32
		Medium	41	30	33	22
		High	37	34	41	34
	Casablanca	Low	—	—	16	35
		Medium	—	—	43	33
		High	—	—	35	36
	Ccompis	Low	21	0	—	—
		Medium	25	6	—	—
		High	34	11	—	—

Appendix Table 16. (Continued).

Relative Plant Population*	Variety	Level of Fertilization*	No. 1 Tubers (As percent of total) CUZCO 1961-62	CUZCO 1961-62	CONCEP. 1960-61	HUARAZ. 1961-62
HIGH	Mantaro	Low	23	0	36	—
		Medium	36	26	38	—
		High	37	34	43	—
	Renacimiento	Low	30	0	29	28
		Medium	37	20	41	29
		High	30	32	47	33
	Casablanca	Low	—	—	34	38
		Medium	—	—	33	37
		High	—	—	37	33
	Ccompis	Low	4	0	—	—
		Medium	11	4	—	—
		High	10	16	—	—

**See Appendix Table 15 for actual plant populations and fertilization levels.*