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Increase and Development of Wheat Production

TECHNICAL
REPORT

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Chapter 1. INTRODUCTION

1.1 The Assignment

The writer was appointed to the post of FAO Agronomist (Field Trials), at the EMBRAPA's National Wheat Research Centre (Centro Nacional de Pesquisa de Trigo - Empresa Brasileira de Pesquisa Agropecuária) of Passo Fundo, Rio Grande do Sul State, as a member of the international staff assigned to the Project titled UNDP SF 381 - FAO/BRA/69/535 "Increase and Development of Wheat Production in Brazil".

The expert arrived in Brazil on October 15th, 1974.

1.2 Terms of Reference

Following terms of reference were given to the expert.

Under the direct supervision of the Project Manager, the expert will:

i) work and assist as a member of a multidisciplined international and Brazilian research team in the identification and solution of problems related to wheat production and alternative crops (mainly soybean, sorghum, barley and others) which need further experimental work, as well as pasture crops, and in developing production systems to increase income and better yield stabilization;

ii) assist the multidisciplined research team and organize agronomic trials crop rotations and fertilizer use in the project area; develop production systems and assist in the design and arrangement of large scale demonstrations of agricultural practices;

iii) identify the needs of additional manpower for effective operation of the project and arrange medium and high level training centres, seminars, workshops and symposia.

Upon request of the Project Manager, dated 18/12/1975, these terms of reference were extended as follows:

iv) develop rational soil management systems through adotpion of agricultural practices and machinery use hindering or reducing soil erosion risks, and identify the needs of agricultural implements adapted to the best production systems;

v) assist in the identification and solution of problems occurring in the new potentially wheat-growing areas;

vi) assist in the design of experiments on pasture management, in close collaboration with agroeconomists, in order to improve integrated production systems especially composite ones combining cash-crops and livestock.

Additionally, the expert was designated as Acting Project Manager from February 2nd, 1979, after retirement of the past Project Manager Dr. W.F. Kugler in December 1978.

1.3 Technical Background and Work Plan

1.3.1) General background

The very broad terms of reference given to the expert allowed him a relative liberty for determining a sound programme of work. From the beginning of the Project, almost nothing had been done in the field of general agronomy of wheat production. During the period 1970-74, the wheat research was carried out into an analytical view of identification of the problems hindering stable and high wheat yields. Although this analytical approach was successful and clear appraisement of the problems was gained, the wheat research was performed within the limited and narrow scope of a double-cropping "wheat-soybean" system prevailing on this time.

This restricted approach was discerned and acknowledged as soon as January 1974 by the Project Manager, who stated in his final report: "It is inconceivable that only soybeans will continue to be used as an alternate crop.", and "it has been shown that it is physically impossible to obtain optimum yields of either soybean or wheat under the present regime." (13)

1.3.2) Previous studies and investigations (period 1970-1974)

The above-expressed conclusions clearly derived from the experimental work performed by the Brazilian scientists with the assistance of the Project's staff over the years 1970-1974. Outstanding findings held the attention of the expert:

An experiment realized in 1972 (10) stated that Brazilian wheat cultivar Lagoa Vermelha was genetically suited for high yields, reaching 9.6 t/ha (1971) and 5.4 t/ha (1972) when grown under controlled conditions: soil sterilization, fungicide treatments applied weekly, under insect-proof cages. In relation to the check (full plant protection), foliar diseases were found to reduce the yield by 69%, soil borne factors by 50% and aphids by 49% (each factor being considered isolately). It was therefore proven that soil borne problems had a very significant part in the wheat yield reduction. This finding was considered by the expert of fundamental importance for outlining his programme of work.

Reviewing the performances of newly released varieties under field conditions, no apparent breakthrough in wheat yields occurred in spite of a broad and permanent work in plant breeding over the years.

Innumerous field trials carried out on nitrogen, more especially those of FAO Expert C-L. PAN (15) showed abnormal response curves of wheat yields to nitrogen and, moreover, a very low effectiveness of nitrogen applied. In 1973, C-L. PAN stated that most of the response curves were 3rd-degree shaped, and that the average productivity of N was only 3.71 kg of grain per kg of nitrogen applied. Obviously, the wheat plant did not work normally.

In all wheat fields observed, the wheat root system appeared weak, stunty and somewhat cankered especially at latest stages of growth, but not at early stages. Apparently, barley, oats and rye did not show these symptoms.

The total national wheat production derived from a "wheat-soybean" double-cropping system, almost solely used all over the wheat-growing areas. This meant, in agronomical terms, a "double monocultivation". This somewhat simplistic cropping system developed in Brazil during some 15 years, under the economical stress induced by the fantastic and successful expansion of soybeans which turned rapidly the dominant and "untouchable" crop in Brazil, because of its economical and strategical importance: soybeans exportations, in 1977, balanced oil importations of the country.

All these statements and observations focused towards a common question: <u>is the widespread "wheat-soybean" double cropping system suited for obtaining high and stable wheat yields? ... and, if not, why?</u>

1.3.3) <u>Outlining a Programme of Work</u>

The expert's Programme of Work logically derived from the above question. It was therefore essential to get a clear appraisal of the reasons for which unstable and low wheat yields are observed within a "wheat-soybeans" production system. These reasons can be shared out in two main problems:

A. Assuming that the wheat-soybean system might be suited for good wheat yields, what is the influence of the production factors (soil preparation, fertilization, crop residues, liming, etc...) on the wheat yields?

B. Assuming that the wheat soybean system is <u>not</u> suited for stable wheat production, why? and by what production system could it be replaced?

The work plan was therefore build up as follows:

<u>questions (= experiments)</u>	<u>Trial number</u>
A. <u>Production factors, within the wheat-soybean production system</u>	
1) <u>Fertilizers</u> (especially N)	
. Effectiveness of different nitrogen sources	I

. Effectiveness of foliar fertilization II

. Effectiveness of phosphorus sources III

. Differential response of wheat cultivars to N IV

2) Cultural practices

. Five factors (liming, soil preparation, crop residues, seedrates, nitrogen levels), direct effects and interactions V

. Interaction "Soil preparation x Fertilizers" VI

. Different methods in soil preparation VII

. Seedrates and row spacing XV

B. Influence of the production system itself

. Crop rotation A (winter fallow, one year) VIII

. Crop rotation B (double-cropping, 2-year rotation) IX

. Influence of soil cropping history on the wheat root system XVI

(Some of these trials are visible on Photograph 1)

Additionally, the expert assisted in the experimental design of an experiment on soil erosion (determination of the coefficients of the Universal Equation on soil erosion losses, experiment X). The expert was also asked to help in the identification and solution of specific problems in wheat production in Mato Grosso State, where wheat cropping was rapidly expanding (trials No. XI, XII, XIII and XIV).

It has to be noted that the initial work plan proposed and discussed with the Brazilian counterpart was broader as above-described, especially on crop rotations and demonstrative network. For different reasons, discussed further on (see Part 1.), the work plan was somewhat restricted.

1.3.4) Particular Framework and Counterpart Training

Most of the experimental work was realized in the experiment fields of the CNPT in Passo Fundo, with the exception of the experiments carried out in Dourados (Mato Grosso) in collaboration with the UEPAE (Experiment Station of EMBRAPA). As early as the beginning of his activities, the expert directly assisted two

1. General view of CNPT's Experiment Field No. 1, winter 1975.

Brazilian counterparts working in the specific research area. Full assistance was received from CNPT's Management through farm machinery, field workers, experiment fields and laboratory facilities.

The expert's work plan was approved on March 1975 by the Director and Co-Director of the Project. Annually, the results obtained were jointly examined and the work plan revised accordingly. Eighteen quarterly Progress Reports were written, forming the bulk of the experimental work realized, in which all detailed information may be found if necessary. Additionally, most of the experimental results have been presented in the successive "RACPET" "Reunião Anual Conjunta de Pesquisa de Trigo" (Annual Joint Wheat Research Meetings), and published through corresponding Proceedings. All details on the experiments can be found in these Proceedings, at the CNPT's Library.

After retirement of the Project Manager (December 1978) and his designation as Acting Project Manager (February 2nd, 1979), a significant part of the expert's field activities was taken over by the Brazilian counterpart.

Last, but not least, this report must be considered as a common work of a Team, so complete and permanent was the cooperation between the expert and his Brazilian colleagues. The reader is kindly invited to keep this permanent cooperation in mind: the expert's activity in counterpart training, over the days and the years, was his permanent care and certainly the most enjoying part of his mission. This is why the special chapter "Counterpart Training" is voluntarily left out.

The two above-mentioned Brazilian counterparts are actually attending post-graduation courses for Ph.D. degree, one at the University of Wisconsin (USA), the other at the Federal University of Viçosa (Brazil). It is therefore a great satisfaction for the writer to have somewhat contributed to their training, and to be sure that the work he initiated at CNPT will be continued in the best conditions.

Chapter 2. STUDIES ON WHEAT PRODUCTION FACTORS WITHIN THE "WHEAT-SOYBEAN" PRODUCTION SYSTEM

2.1 Organization and Implementation of Field Trials

Attempt has been made with a view of obtaining better connexion and relation between different field trials. Since the CNPT's No. 1 experiment field had a good homogeneity (soil characteristics, precedent crops), in spite of being contour cultivated, the flat area of the hill's top was reserved for the big trial V (254 plots) and the two crop rotation trials (72 and 144 plots), surrounding terraces being reserved for related trials. Trial V was considered, more or less, as a "Central Trial" to which all other experiments were related by at least one treatment in common. It is evident that one single statistical analysis for this "experiment complex" is not possible, for the simple reason of site effect. However, such an arrangement made easier and more reliable the comparisons between different trials, with a certain degree of confidence. Similar arrangement, with "central" and "satellite" trials are already in use at CIAT's Experiment Station of Turrialba (Costa-Rica).

An averaged example of soil characteristics is given in Annex Whenever possible, all cultural practices have been executed with common farm machinery.

The set of photographs presented in Annex gives a clear picture of the experimental complex.

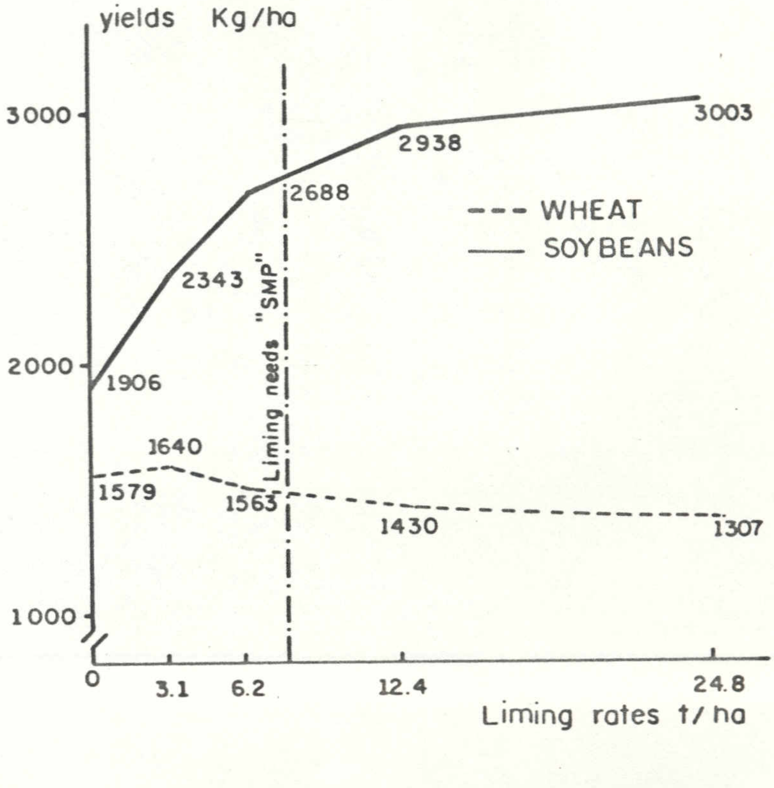
2.2 Studies on Fertilizers

According to the Revised Plan of Operations (October 1974), the problems of soil fertility were taken over by the counterpart team working on Soil Science. Therefore, the expert only advised and assisted in this activity. Many trials were carried out on liming and fertilizers, as early as the beginning of the Project, and summarized conclusions are presented below.

2.2.1) <u>Problems related to liming, soil acidity and Al^{+++} toxicity</u>

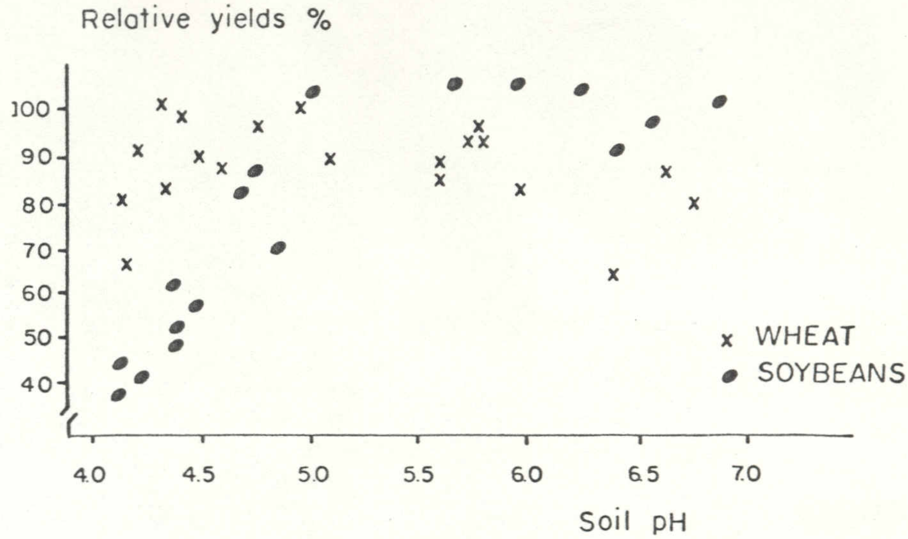
Within the double-cropping system "wheat-soybeans", liming has been proved very efficient for soybeans, but rather dangerous for wheat, especially when mismanaged. The "SMP Method" determining the lime requirements (developed by SHOEMAKER, MCLEAN and PRATT in Southern Brazil) (28) arrives to figures much higher than the reality, because extracting not only exchangeable Al^{+++} and H^+, but also the non exchangeable H^+ from organic matter. Lime requirements being first overestimated, the situation is worsened by irregular distribution of limestone in the field (overlapping) and poor incorporation (shallow discing, sometimes "duck-foot" only).

The following Graph 1 summarizes the effect of liming rates on the yields of soybeans and wheat, in average of 8 experiments carried out over 5 years (33). A clear depressive effect of increasing liming rates on wheat yields is shown.



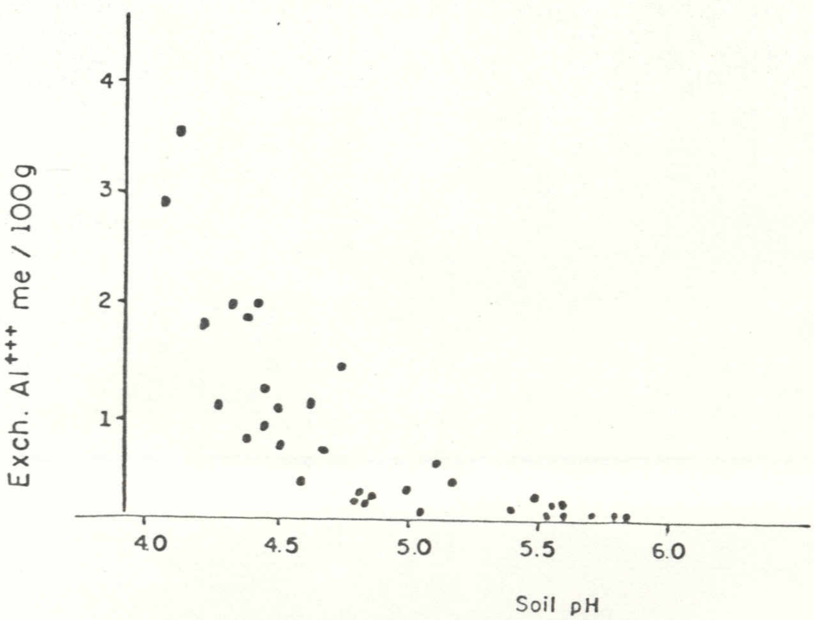
Graph 1. Response of wheat and soybeans to liming.

Under the local conditions, the best wheat yields were observed within the range of pH = 4.7 - 5.5, whilst the optimum range for soybeans was pH = 5.5 - 6.0 (Graph 2) (33). Significant reduction in soybeans yields was observed where pH is lower than 5.2



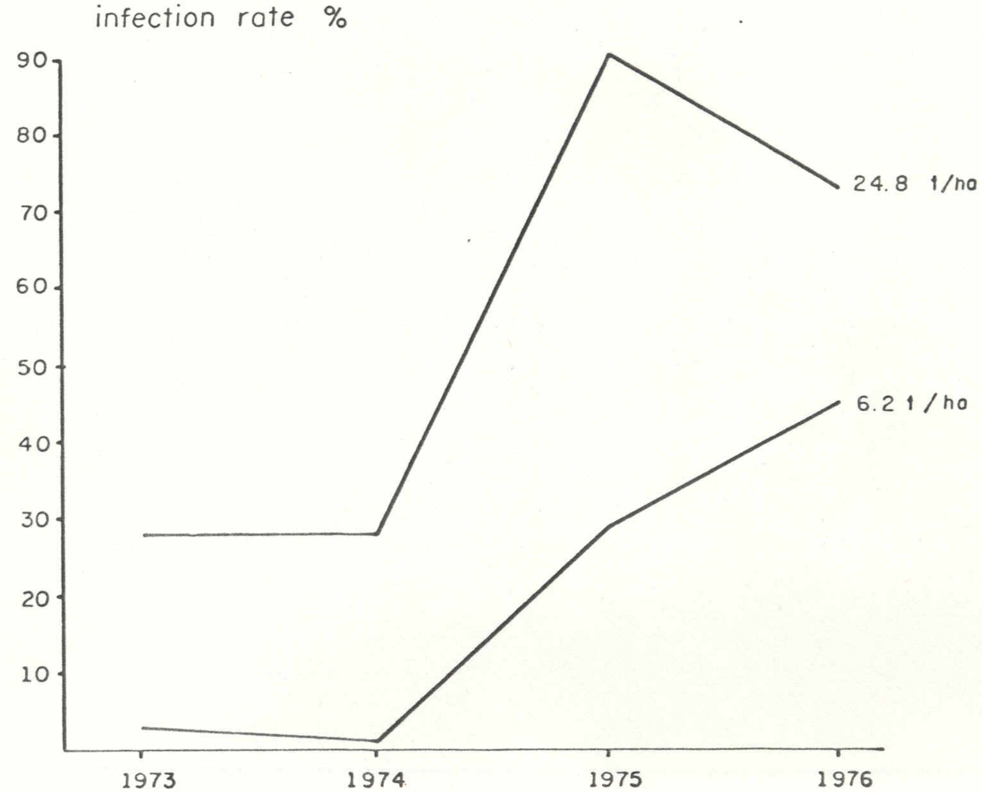
Graph 2. Wheat and Soybeans yields as related to soil pH.

Graph 3 shows that Al^{+++} toxicity is eliminated, in general, by applying only one half of the SMP recommendations, i.e. <u>3-4 t/ha</u> for 3 or 4 years. This amount is enough for rising soil pH up to 5.5.



Graph 3. Relation between soil pH and Aluminium.

However, the problem of liming (as far as the "wheat-soybeans" system is concerned) is rather complicated, because maximum efficiency of limestone for soybeans is well beyond the recommended rate 3-4 t/ha, whereas maximum wheat production is obtained below this rate, due to the fact that liming exacerbates the wheat "take-all" disease (Gaeumannomyces graminis) in severity and intensity. Graph 4 shows the effect of two liming rates (6.2 and 24.8 t/ha of ground limestone) applied two years before wheat cultivation, on the occurrence of "take-all" over the following years (32). Of very relative importance are the liming rates when considering that disease intensity increased over the years, due to repeated wheat cropping every year. Therefore, it is not possible to assume that limestone alone has a detrimental effect on wheat production, but rather the continuous wheat cropping.



Graph 4. Intensity of wheat "take-all" disease as related to liming (t/ha limistone applied in 1972) and years of wheat cropping. Average of 3 experiments (Passo Fundo, Vacaria, Lagoa Vermelha).

This assumption is consistent with the evidence that many countries having calcareous soils with pH as high as 7.8 or 8.0 are yielding 5 or 6 t/ha of wheat provided that a rational crop rotation is respected (ex.: Champagne soils, in France).

Other aspects of liming, related to cultural practices, are examined further on. (see: 2.3)

2.2.2) Phosphate fertilizers

. Wheat response to phosphorus

Many experiments on the wheat response to P-fertilizers were carried out in several locations in Rio Grande do Sul, as early as 1971, and were continued till 1976. In his final report, C-L. PAN (15) stated that the average productivity of phosphorus was about 1.8 kg of wheat grain per kg of P_2O_5 applied, within the experimental range 0-300 kg P_2O_5. Two experiments carried out in 1976 in Passo Fundo and Erexim (20) showed that phosphorus productivity was substantially better within the range 0-90 kg P_2O_5 : respectively 3.09 and 4.89 kg of grain per kg P_2O_5. It has to be pointed out that the trials 1976 were conducted under plant protection treatments (fungicide and insecticide), whereas no protection was applied in 1971. Beyond the year-effect on the wheat yields, it may be assumed that a good plant protection strengthens the effect of P-fertilizers and increases their economical effectiveness.

. Compared effectiveness of P-fertilizers (Trial III)

Several experiments were realized with a view of screening the effectiveness of different phosphates, among them Brazilian ones. This research has a great economical importance when considering the high cost of the phosphates, either imported or industrially solubilized (superphosphates). Brazilian phosphates-measures are mostly constituted of apatitic rock-phosphates with very low solubility. However, it is important to know about the possibility of agricultural use. Pot experiments realized in 1975 and 1976 (29 , 30) compared the agronomic effectiveness of several rock-phosphates in relation to superphosphates:

Table 1. Relative effectiveness of different P-sources, as compared to triple superphosphate, tested in corrected soil (pH = 5.7 - 5.8) through wheat dry matter production.

P sources (ppm P_2O_5 applied)		Relative effectiveness to triple superphosphate (TSP) (in ppm P_2O_5)	(in % TSP)
240 ppm as simple superphosphate	:	280 ppm as TSP	120%
430 ppm as Basic Slags	:	280 ppm as TSP	65%
480 ppm as Gafsa phosphate	:	260 ppm as TSP	55%
640 ppm as thermophosphate	:	260 ppm as TSP	41%
640 ppm as Rhenania phosphate	:	200 ppm as TSP	31%
1000 ppm as natural Florida phosphate	:	200 ppm as TSP	20%
1000 ppm as Patos de Minas phosphate	:	140 ppm as TSP	14%
1000 ppm as Alvorada phosphate	:	60 ppm as TSP	6%
1000 ppm as Araxá phosphate	:	20 ppm as TSP	2%
1000 ppm as Jacapiranga phosphate	:	0 ppm as TSP	0

Though the wheat plant is known to be a weak feeder of phosphorus (SCHLEHUBER & TUCKER, 1967) (23), there is no doubt that immediately available phosphorus is essential to growth and production. In this experiment, wheat being used as a test plant, there was a separation between phosphate fertilizers, especially in function of their original characteristics: natural rock-phosphates having crystalline grating (apatites) expressed the lowest immediate availability.

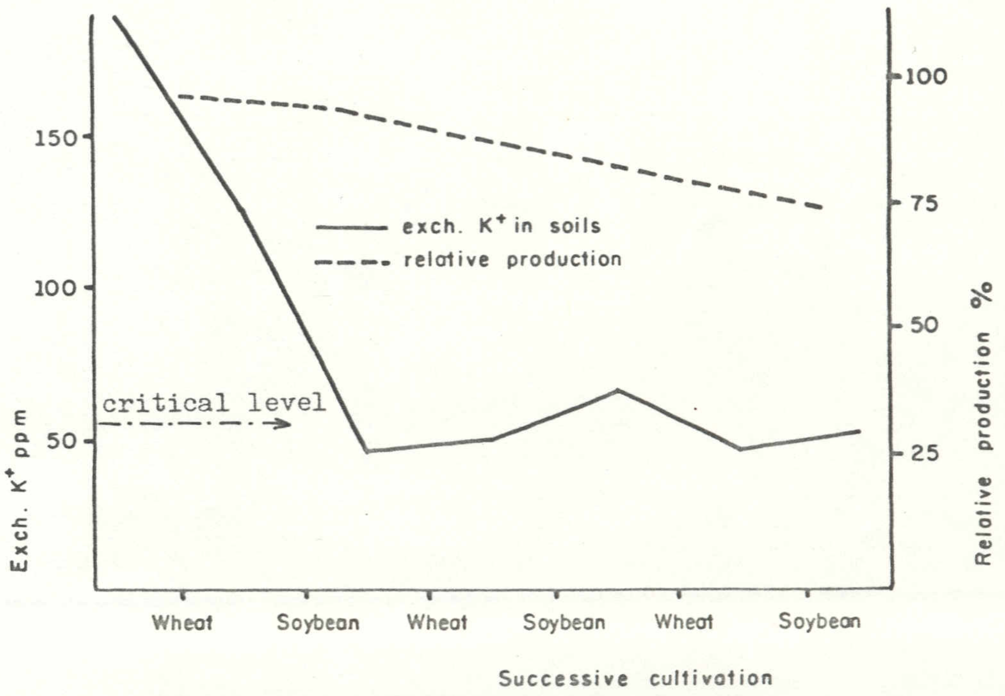
It is interesting to note that soil analysis made at the end of the experiment showed better phosphorus "recovery" for natural rock-phosphates, in inverse relation to the agronomic effectiveness. This is characteristic of the analytical method used (method "North Carolina", extractant: H_2SO_4 0.025 N + HCl 0.05 N).

However, this kind of experiment only gives an approximation of the immediate effectiveness of phosphates used. Long-term field experiments (5-6 years) would give a more realistic view on the problem of national rock-phosphates. Special attention should also be paid to mycorhizes, which play an essential part in phosphorus extraction and solubilization from crystalline rock-phosphates.

2.2.3) Potash and K-fertilizers

During the period 1971-1975, an experimental network of 10 field trials was carried out in Rio Grande do Sul State, aimed at to characterize the response curves of wheat and soybean to N, P, K-fertilizers (5). Though the results are somewhat fluctuating and inconsistent, special attention deserves to be paid to potassium evolution within the "wheat-soybeans" intensive system.

On and after the second year of wheat-soybean cultivation, significant decrease in "exchangeable" K of the soil occurred, as shown by the Graph 5 below.



Graph 5. Effect of successive wheat - soybean cultivation on potash content of the soils of Rio Grande do Sul.

The "critical level" was determined to be 50-60 ppm exchangeable K in the soils of the Planalto Médio (wheat growing area in Rio Grande do Sul State). The experiment also demonstrated that annual application of 100 kg K_2O/ha is needed, at least, for keeping the soil content in potash above the critical level. The official recommendations have been modified accordingly.

2.2.4) Foliar fertilizers (Trial II)

Due to the commercial aggressivity of several business firms producing and selling foliar fertilizers, special experiments were realized in order to verify the technical and economical efficiency of foliar fertilization. Field experiments carried out in 1975 and 1976 (25) demonstrated that foliar fertilization (with N, P, K or micronutrients) was useless and unefficient.

Table 2. Profitability of foliar fertilization on wheat, as an average of 4 field experiments in two years (1975-1976) realized at the CNPT of Passo Fundo. (34)

Treatments	Average wheat yield (1975/76, kg/ha)	Differential income (Cr$/ha)	Differ.cost (Cr$/ha)	Net profit (Cr$/ha)
Check (water)	1604	-	-	-
Foliar fertilization	1603	-1.90	223.60	-225.50

From the moment that recommended rates of common fertilizers are applied by the farmer, further foliar fertilization on the wheat plant was proved to be a waste of time and money. Even when wheat N P K fertilization is known to be insufficient or inadequate, foliar fertilization is not able to compensate the yield loss.

2.2.5) Studies on nitrogen (Trials I, IV)

Numerous experiments on the effect of nitrogen on wheat production were realized in Brazil, as soon as N-fertilizers were available on the market. Unfortunately, no clear results were obtained for the simple reasons that:

- no systematical approach was observed. Innumerable experiments were realized according to innumerable designs without any continuity in the time. It is a common temptation to put all together into a single experiment many agronomic questions dealing with nitrogen: rates, sources, time of application, etc... Usually, no clear response arises from a too much complicated design.
- under the local conditions, the wheat plant does not respond normally to nitrogen applications.

In his technical report, FAO expert C-L. PAN (15), in 1973, stated an average productivity of nitrogen as being 3.71 kg of wheat grain per kg N added (average of a 3-year experiment), as well as a differential response to N among wheat cultivars.

From his own experience of about 14 years on the matter, the writer was impressed by this low productivity, which is normally within the range of 14-22 kg of grain per kg N. Should nitrogen efficiency be modified or depressed by some common cultural practice, thorough study on N was introduced into the "Central Trial" V (as described in paragraph 2.3) in order to observe wheat response to nitrogen according to liming, soil preparation, crop residues and seedrates. Detailed methodology is described under paragraph 2.3.

This trial V, initiated in 1975 at the CNPT of Passo Fundo, was carried out during 5 years with a continuous wheat-soybeans double-cropping system, the residual effect on nitrogen applied only to wheat being tested on the following soybeans crop. Following fertilization was uniformly applied, every year, at sowing time (averaged on 5 years):

	$kg\ N.ha^{-1}$	$kg\ P.ha^{-1}$	$kg\ K.ha^{-1}$
For wheat :	15	40	43
For soybeans :	15	41	41
Total per year :	30	81	84

Only wheat received split applications of nitrogen, as follows:

	Sowing time (with P and K)	Tillering stage	Feekes' stage 6	Total N received:
N_0	15 kg $N.ha^{-1}$	0 kg $N.ha^{-1}$	0 kg $N.ha^{-1}$	15 kg $N.ha^{-1}$
N_1	15 kg $N.ha^{-1}$	30 kg $N.ha^{-1}$	10 kg $N.ha^{-1}$	55
N_2	15 kg $N.ha^{-1}$	60 kg $N.ha^{-1}$	20 kg $N.ha^{-1}$	95
N_3	15 kg $N.ha^{-1}$	90 kg $N.ha^{-1}$	30 kg $N.ha^{-1}$	135

It has to be noted that the method of application of N, based on the physiological needs of the wheat plant (1), is different of the official recommendations still in use in Brazil, which are based on the organic matter content of the soil:

Soil O.M. content %:	Recommended rates of N*
0 - 2.5	40 kg $N.ha^{-1}$
2.6 - 5.0	20 kg $N.ha^{-1}$
> 5	0 kg $N.ha^{-1}$

(*: to be applied at tillering stage, ± 40 days after sowing)

2.2.5.1) Trial V - Nitrogen efficiency

Optimum rates for nitrogen have been calculated on a constant basis (i.e. V/C ratio = 1, one kilogram of nitrogen from Urea 46% being paid by 2.43 kg of wheat grain, broadcasting cost included). Table 3 gives the average nitrogen productivity, calculated between 15 N and N optimum:

Table 3. Average Nitrogen efficiency in wheat production (Trial V, 1975-79)

	Cultivars	"Optimum" N level (kg $N.ha^{-1}$)	Wheat yields at N opt. ($kg.ha^{-1}$)	Average productivity from 15 N to N opt. (kg grain per kg N)
1975	IAS.59	62	1,340	3.17
1976	IAS.59	92	2,640	10.53
1977	CNT.10	70	1,049	4.49
1978	CNT.10	77	2,285	4.73
1979	CNT.10	0*	822*	0*

(* generalized lodging and glume blotch due to excessive rainfalls in October 1979)

The best productivity of nitrogen was observed in 1976, where ammonium nitrate 27.5% N was used instead of urea for the second top-dressing (before boot-stage). Since 1979 was an exceptional bad year with miserable wheat yields, the above results have been averaged on four years 1975-1978, each year being considered as a replication. Statistical analysis is summarized below:

	F test (calculated)	P=	0.05	0.01	0.001
			F (Tables)		
"Year" effect	121.25 ***		3.86	6.99	13.90
N (linear)	21.90 **		3.36	5.12	22.86
N (quadratic)	6.65 *		3.36	5.12	22.86
N (cubic)	0.04 n.s.		3.36	5.12	22.86

Coefficient of variation = 7.05%

The average regression equation of the wheat yields $\hat{y}$ (kg.ha^{-1}) against nitrogen rates x (kg N.ha^{-1}) is:

$$\hat{y} = 1305.3 + 10.495\ x - 0.04883\ x^2$$

This equation shows a maximum for $x = 107$ kg N, but the optimum value for N is given by deriving the equation up to the "limit productivity" 2.43 kg of grain per kg N:

$$10.495 - 0.09766\ x = 2.43$$

$$\text{i.e.} \quad x = \text{N opt.} = \underline{83 \text{ kg N.ha}^{-1}}$$

According to this figure, the average productivity of nitrogen applied was, for the period 1975-1978, of <u>5.7 kg of wheat grain per kg of added nitrogen</u>, within the experimental range 15-83 N.

Due to the variation of prices of both urea and wheat, the limit productivity in 1979 was 3.7 kg of grain for 1 kg N. In these conditions, the average optimum becomes 70 kg N.ha^{-1}, with an average N-productivity of 6.3 kg of grain per kg N added.

Compared with the previous data obtained by C-L. PAN (i.e. 3.71 kg grain/kg N), there is a substantial increase in N productivity. However, this improvement cannot be attributed only to the split-application method used, but rather to the plant protection treatments (fungicide + insecticide) which have been systematically applied during the 5-year experiment.

2.2.5.2) Trial V - Interactions with nitrogen

Wheat response to nitrogen was modified mainly by liming and soil preparation. Limestone was applied in 1975, at the beginning of the experiment, on the basis of 1/2 SMP (i.e. 3.75 t/ha of limestone), on one half of the field. Before liming, pH was 5.10 and Al^{+++} content 1.40 meq/100 g of soil. In 1976 occurred a significant "liming x nitrogen" interaction, calculated as:

$$\hat{y}_i \text{ (kg grain)} = 200.6 - 4.961\ x + 0.09441\ x^2 \qquad (x = \text{kg N})$$

This means a positive synergical effect between lime and N for low rates of nitrogen, becoming antagonistic for higher levels over 50 kg N/ha. Accordingly, the average nitrogen productivity was reduced by 18% by liming : from 11.5 kg grain/kg N without lime to 9.4 kg grain/kg N with lime. (17)

There was also a significant interaction between nitrogen and soil preparation methods, calculated as being:

$$\hat{y}_i \text{ (kg grain)} = 121.6 + 5.065\ x - 0.02428\ x^2 \qquad (x = \text{kg N})$$

Optimum N levels were similar for either conventional soil preparation (ploughing + discing) or direct-drilling, i.e. 90 and 93 kg N/ha, respectively. Direct-drilling improved nitrogen efficiency by 23%, within the limits of productivity (15-92 N), i.e. 11.6 kg grain/kg N for direct-drilling against 9.4 kg grain/kg N for conventional soil preparation. (17)

These interactions only were observed in second year of experiment (1976).

It is worth to be pointed out that, in 5 year of observations, never crop residues (burned or incorporated) nor seedrates interacted on wheat response to nitrogen.

2.2.5.3) Other experiments related to nitrogen

. In 1975, 238 wheat cultivars were tested under two nitrogen levels, 30 and 120 kg $N.ha^{-1}$ (4). Among them, 73 cultivars yielded at least 2000 kg/ha. However, 37 cultivars reached this level with only 30 kg N whereas 36 cultivars (mostly from Mexican origin needed 120 kg N for reaching 2000 kg/ha. In 1976 (24), 19 wheat cultivars and one triticale were selected from 1975' results and tested under four Nitrogen levels (0, 30, 60 and 120 kg N/ha). There was no significant difference between cultivars in regard to their response to nitrogen, and no interaction N x cultivars. This is rather surprising in this kind of experiment, because each wheat cultivar is normally supposed to have a specific comportment in regard to nitrogen.

. Different nitrogen sources (urea, ammonium sulphate) and two slow-release N-fertilizers (sulphur-coated urea SCU, unknown compound "ICI" 36% N) were tested in 1975 (2), with 5 nitrogen rates (0 - 30 - 60 - 90 - 120 kg $N.ha^{-1}$) applied either in full at sowing time or splitted 1/3 at sowing time + + 2/3 at tillering stage. There was no significant difference in wheat yields between nitrogen sources, rates or methods of application, in spite of a visible effect of N on the wheat growth.

It has to be pointed out that these experiments were carried out under protection of phytosanitary sprayings (fungicide + insecticide) maintaining them practically free of foliar diseases and aphids.

2.3 Studies on Wheat Cultural Practices in the "Wheat-Soybean" System

Several cultural practices in wheat production were systematically studied through an experimental network realized at CNPT's Experiment Field No. 1. Two trials (VI and VII) were related to the trial V (called "central trial") for more detailed studies on soil preparation, as well as other trials on fertilization already above-described:

Trial V ("Central Trial")	"Satellite Trials"
- Liming	Counterpart trials (32) (33)
- Soil preparation	Trials VI, VII
- Crop residues	Crop rotation trials VIII, IX
- Seedrates	Trial XV
- Nitrogen levels	Trials I, IV (see 2.2.5) Counterpart trials (4) (24) (2)

2.3.1) Trial V. "Central Trial" (see Photograph No. 2)

This experiment started in 1975, and is still underway. Five factors were studied through a randomized split-plot design with four replications:

. Main plots: Liming

- No lime
- With lime: a) "conventional" plots: 3.75 t/ha (1975) + + 3.10 t/ha (1978)
  b) "direct-drilled" plots: 1.05 t/ha (1978, top-dressed)

. Sub-plots: Soil preparation

- "Conventional": ploughing and discing
- Direct-drilling: using a direct-driller "HOWARD-Rotocaster" (after weed-control by paraquat-diquat: REGLONE 0.5 l/ha + GRAMOXONE 0.5 l/ha, 2-3 weeks before sowing)

. Sub-sub-plots: Crop residues (wheat and soybeans straw)

- Burned
- Incorporated (conventional) or remaining on the soil top-layer (direct-drilling)

. Sub-sub-sub-plots: Seedrates

- Standard seedrate S_1: 300 germinating seeds per square meter ($\pm$ 110 $kg.ha^{-1}$) for wheat, 40 germinating seeds per square meter for soybeans
- Increased seedrate S_2 (by 40%): 420 germinating seeds/m^2 ($\pm$ 154 $kg.ha^{-1}$) for wheat, 56 germinating seeds per square meter for soybeans

Row spacing was 17 cm for wheat and 51 cm for soybeans. Wheat cultivar was IAS.59 in 1975 and 1976, CNT.10 on and after 1977.

Soybean cultivar was HARDEE in 1975 and 1976, IAS.4 on and after 1977

- Sub-sub-sub-sub-plots: Nitrogen levels (as described under 2.2.5). Nitrogen was applied only to wheat, its residual effect being tested through the following soybeans crop.

Every year, the wheat crop was protected against foliar diseases and aphids by phytosanitary treatments (fungicide + insecticide), according to the official CNPT's recommendations.

The experiment was carried out on a typical "Humic Ferralsol" (Fh), representative of most of the wheat-growing area in Rio Grande do Sul.

Each unit plot was 3 m width and 6 m length (18 m^2). All works (but nitrogen hand-broadcasting) were executed with common farm-machinery. Including borders and tracks for machinery traffic, this trial occupied 1.5 ha. All results were statistically analysed, according to classical analysis for split-plot design, by the expert himself or sometimes with the help of EMBRAPA's computer in Brasília. Soil analysis, realized in 1975, is given below:

Clay: 61% of mineral fraction	pH (H_2O, 1:1)	: 5.10
Silt: 16% of mineral fraction	Exchangeable Al:	1.40 meq/100 g.soil
Fine sand: 12% of mineral fraction	Exch. Ca + Mg	: 3.90 meq/100 g.soil
Coarse sand: 11% of mineral fraction	*Available P	: 15.5 ppm
Organic Matter: 5 g./100 g. soil	Exchangeable K	98 ppm

(*): "North Carolina" method (see 2.2.2)

2.3.1.1) Effects on the wheat yields

2.3.1.1.1. Direct effects:

Table 4. Wheat yield as influenced by five production factors (Trial V), from 1975 to 1979, in $kg.ha^{-1}$ and index (‰ of year average yield).

	1975		1976		1977		1978		1979		Weighted Average indexes	
	$kg.ha^{-1}$	index	$kg.ha^{-1}$	index	$kg.ha^{-1}$	index	$kg.ha^{-1}$	index	$kg.ha^{-1}$	index	(a)	(b)
No lime	1377	1035	2370	1004	971	985	2207	1001	952	1158	1020	1023
Lime	1285	965	2350	996	1000	1015	2203	999	692	842	980	977
Conventional	-	-	2202	933	865	878	2234	1013	908	1105	974	-
Direct-drilling	-	-	2518**	1067	1106*	1122	2176	987	737	897	1026	-
No residues	-	-	2304	976	981	996	2226	1010	912	1109	1008	-
Residues	-	-	2416	1024	989	1004	2184	990	733*	891	992	-
Seedrate 1	1289	968	2325	985	989	1004	2199	997	800	973	991	987
Seedrate 2	1372	1031	2395	1015	982	996	2212	1003	844	1027	1009	1013
N_0	1180	887	1824	773	802	814	1990	902	815	991	852	858
N_1	1313**	986	2437**	1033	1004**	1019	2218**	1006	789	960	1012	1007
N_2	1399**	1051	2617**	1109	1086**	1103	2312**	1049	840	1022	1076	1072
N_3	1431**	1075	2561**	1085	1048**	1064	2300**	1043	844	1027	1060	1063
$\bar{m}$	1331	1000	2360	1000	986	1000	2205	1000	822	1000	(a) 1593 $kg.ha^{-1}$	(b) 1541 $kg.ha^{-1}$

(a): 4-year average

(b): 5-year average

*: significant difference at P = 0.05

**: significant difference at P = 0.01

- Liming: The first liming was applied in 1975, at the beginning of the experiment, and carefully mixed with the soil by ploughing and discing. The amount of limestone applied corresponded to 1/2 SMP (see 2.2.1) given by soil analysis 1975, i.e. 3.75 t/ha of dolomitic limestone. After soil analysis made in 1978, a new application was made before the wheat crop 1978: 3.10 t/ha of limestone in "conventional" sub-plots (i.e. 1/2 SMP, incorporated by ploughing), and 1.05 t/ha on the "direct-drilled" sub-plots (i.e. 1/6 SMP, broadcasted on the surface, repeated again before wheat 1979).

  No significant difference in wheat yields was ever observed between limed or unlimed plots, with the unique exception of the 1979 wheat season during which a strong attack of Wheat Mosaic Virus (WMV) accurred in the direct-drilled plots where reduced amount of limestone was surface-broadcasted ("confounded" effect direct-drilling/ superficial liming).

  Significant yield decrease resulted (-19%), consistent with previous observations made by C-L. PAN (15) and J.C. SANTIAGO (22), who reported that the soil borne fungus *Polymyxa graminis* (vector of WMV) is favoured by liming. It is therefore proved that superficial liming in direct-drilling is not advisable in wheat production. Once more, it can be stated that liming by *itself* has no detrimental *direct* effect on the wheat yields, *unless pathological factors interfere*. X

- Soil preparation: by comparison with "conventional" soil preparation, *direct-drilling gave significant increases* in wheat yields (+14% in 1976, +28% in 1977). Other favourable features of direct-drilling are reported further on (effects on soil characteristics, 2.3.3), as well as interactions (see 2.3.1.2).

. Crop residues: Either burned or not, crop residues did not induce significant yield difference, except in 1979. That year was characterized by torrential rainfalls early October: generalized lodging occurred, and a strong attack of glume blotch (Septoria nodorum) developed later on, significantly stronger in the direct-drilled plots where crop residues were left on the top layer. This is consistent with a lower number of spikes per plant observed in such plots where crop residues are kept (see 2.3.2). It is therefore assumed that crop residues maintained on the top layer, in case of direct-drilling, could play a negative part in preserving and harbouring pathogenic inoculum of aerial (Septoria sp.) or soil borne wheat diseases ("take-all", Helminthosporium sp.).

. Seedrates: increasing the wheat seedrate by 40% never led to any significant difference in yield. Another experiment related to seedrates and row spacing (Trial XV) put additional light on this problem.

. Nitrogen: (direct effects are described under paragraph 2.2.5.1).

2.3.1.1.2. Interactions

Noteworthy interactions involving nitrogen (N x liming, N x soil preparation) have been described under 2.2.5.2.

In 1978 and 1979, there were significant interactions between soil preparation and seedrates, showing opposite effects on the wheat yields when seedrate is increasing:

Table 5. Interaction "seedrates x soil preparation" on the wheat yields ($kg.ha^{-1}$), averaged on two years 1978 and 1979

	Conventional	Direct-drilling	$\bar{m}$
Seedrate 1	1496 (100)	1504 (100)	1500 [100]
* Seedrate 2	1647 (110)	1410 (94)	1529 [102]
$\bar{m}$	1572 [100]	1457 [93]	

(*) Seedrate 2 = Seedrate 1 x 1.4.

Increasing the seedrate led to increased yields when the soil is conventionally prepared (probably through improved stand), whereas the yield is decreased in case of direct-drilling. Since better stand (or plant population) is commonly observed with direct-drilling, an increased seedrate possibly leads to an excessive plant population.

In 1978 was also observed an interaction between soil preparation and crop residues, with a negative effect of the crop residues in direct-drilling. This is consistent with the observations made on the direct effect of crop residues (2.3.1.1) on wheat yields.

2.3.1.2) Effects on the wheat yield components

Systematical observations were realized in 1977 on the effect of the 5 factors on the wheat yield components, with appropriate statistical analysis

The following table summarizes the observed trends:

Table 6. Average effects, observed in 1977, on the wheat grain yields and yield components, of 5 factors of production in a continuous "wheat-soybeans" sequence.

Treatments	Grain Yield	Specific weight	100g.weight	Stand	Spikes/m^2	Spikes/plant
L vs. L_o	=	-3%**	=	=	-12%*	-12%*
DD vs. CONV	+28%**	=	=	=	=	=
RR vs. BR	=	CONV: = DD :-7%**	=	- 6%*	-15%**	CONV: = DD :-20%**
S_2 vs. S_1	=	=	=	+20%**	CONV: = DD:-18%**	CONV: = DD :-18%**
N-levels	+31%**	-5%**	decr. trend	=	+ 7%*	+ 6%*

L : liming; L_o: no lime — *: significant at $P \leq 0.15$

DD: direct-drilling; CONV: conventional — **: significant at $P \leq 0.05$

RR: remaining crop residues; BR: burned crop residues

S_2: high seedrate; S_1: standard seedrate

- Liming decreased the specific weight, the number of spikes per m^2 and the number of spikes per plant.
- The presence of crop residues decreased stand and spikes population, but also specific weight and spikes/plant when direct-drilling is used.
- The highest seedrate obviously increased the plant population, but decreased by 18% spikes population and spikes/plant in case of direct-drilling.
- The highest N-rates decreased the specific weight, as usually observed, and increased both spikes population and spikes/plant.

Although direct-drilling gave noteworthy increases in yield, as an average in five years, this favourable trend seems to be offset by opposite effects linked with the presence of crop residues on the soil surface, and increased seedrates.

The very important component "number of spikes per plant", obtained by dividing the number of spikes per m^2 by the number of plants in the same area (as determined by counting at the same place at tillering stage), was in average 0.85 spikes per plant, i.e. less than one. It means, as an evidence, that a minimum of 15% of wheat plants died between tillering stage and harvesting time, because a living plant always produces at least one spike. Once again, crop residues and seedrates are involved in this problem:

- the highest number of spikes per plant, 1.03, was observed by combining direct-drilling with burned crop residues and lowest seedrate
- the lowest number, 0.68, by combination of direct-drilling, presence of crop residues on the soil surface and the highest seedrate.

2.3.1.3) Effects on soil characteristics

Systematical soil sampling from 0 to 20 cm depth in each plot was realized soonafter wheat harvest 1977. Annex A.1 gives detailed results of chemical analysis. By comparison with the initial analysis made in 1975 when the experiment V started, and after three successive wheat crops alternated with two soybeans crops, following trends are stated:

. Soil acidity (pH) rose by 8% and Al^{+++} content by 32% without lime. The residual effect of liming applied in 1975 was just enough to hold Al^{+++} content at approximately the initial level (1.40 meq/100 g.), but did not hinder pH decrease from 5.10 to 4.85. High levels of nitrogen increased both acidity and Al^{+++} content, as commonly observed. There was an interesting effect of synergy between liming and direct-drilling : no-tillage extends the effect of liming in reducing $Al^{+++}$by 14% in relation to initial content. Another synergy was pointed out between the highest seedrate S_2, liming and direct-drilling (triple interaction), reducing Al^{+++} by 18% possibly because of more crop residues. This explanation is supported by another interaction ("liming x crop residues x seedrates") which displays the same effect of S_2 only in presence of crop residues.

. "Ca + Mg" content displays trends exactly opposite to those observed for Al^{+++}, with the same synergies already noted between liming, direct-drilling and high seedrate.

. Owing to the P-K fertilizers used, the average P content reached 19.4 ppm, i.e. 25% more than the initial content. Liming had no effect on it, but direct-drilling increased the available P content three times more than conventional tillage (+39% and +12%, respectively). This positive action of no-tillage on P content is consistent with world references (14) (26).

. The average K content of the soil increased by 7%, but this is obviously a consequence of no-tillage : +14% in direct-drilled plots, against 0% in conventional tillage.

. There was no significant evolution in the organic matter content of the soil.

2.3.2) Trials IV and VII - Tillage methods and fertilization methods in the "wheat-soybeans" system

Two field trials started in 1975, in the same Experiment Field No. 1 where the "Central Trial V" was installed, aimed at to test different tillage methods and different methods of application of fertilizers.

. Trial IV: Six tillage sequences were applied to successive wheat and soybeans crops, with four replications. The average yields from 1976 to 1978 (i.e. three years wheat/soybeans) are presented below:

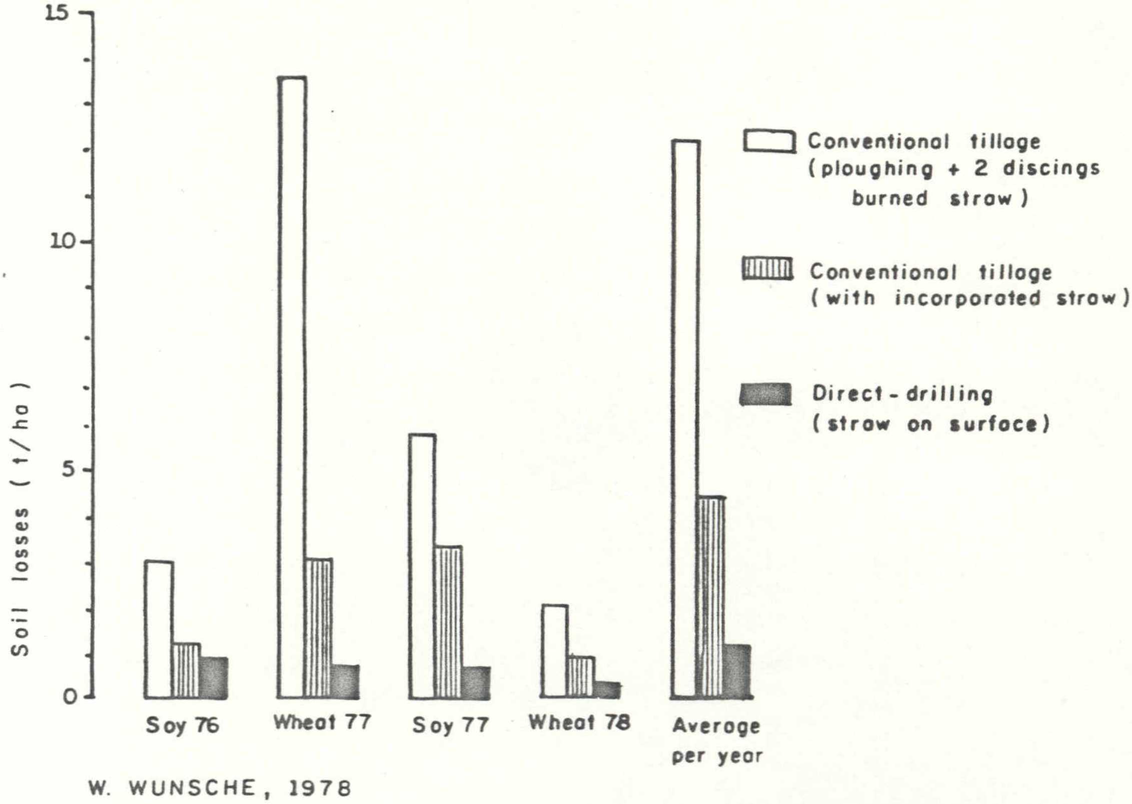
Table 7. Effect of six tillage sequences on the wheat and soybeans yields, averaged on 3 years (1976-1978).

Tillage sequences		Average Yields ($kg.ha^{-1}$)	
for Soybeans	for Wheat	Soybeans	Wheat
Conventional*	Conventional	2900	1335
Direct-drilling	Conventional	3225	1319
Minimum tillage **	Conventional	3068	1298
Duck-foot + Discing	Conventional	3139	1343
Direct-drilling	Direct-drilling	3036	1381
Direct-drilling	DD + CONV, every 3 years	3110	1350

*: Conventional = ploughing + 2 discings

**: Min. tillage = heavy discing + light discing

No significant difference in average yields occurred, according to the different tillage sequences. However, other studies (36) put into evidence dramatic differences in terms of soil erosion regarding soil preparation methods, as shown by Graph 6. Incorporatin crop residues (instead of burning it, as usually done), or direct-drilling with crop residues on the top layer, are the best means for reducing soil erosion. (see also paragraph 4.2).



Graph. 6. Soil losses, under natural rainfall conditions, influenced by different tillage methods.

. Trial VII: Three different tillage systems arranged with three methods of application of fertilizers, in five treatments with four replications. 3-year averaged yields are presented below:

Table 8. Effect of tillage systems and fertilizer placement on the wheat and soybeans yields, averaged on 3 years (1976-1978).

Tillage systems	Fertilizers	Average yields ($kg.ha^{-1}$) Soybeans	Wheat
Direct-drilling	on-the-line	2597	1761
Direct-drilling	broadcasted in surface	2973	1735
Conventional	on-the-line	2627	1653
Conventional	incorporated (0-15 cm)	2666	1684
Direct-drilling, and duck-foot + discs every 3 years	on-the-line	2563	1774

There is a slight trend for better wheat yields in direct-drilling, whatever is fertilizers placement. These results confirm those obtained in the Trial V ("Central Trial").

2.3.3) Trial XV - Seedrates and row spacing

During three years (1977-1979), two wheat cultivars (CNT.10, IAS.54) were planted in a factorial design 2 x 4 x 3 where three seedrates ($D_1 = 300$; $D_2 = 400$; $D_3 = 500$ germinating seeds per square meter) and four row spacings ($E_1 = 10$; $E_2 = 20$; $E_3 = 30$ cm) were used with four replications. An additional treatment E_4 = broadcasted seed, was added in 1978. Both trials received plant protection treatments (fungicide + insecticide).

- No significant difference was observed in the wheat yields when the seedrates increase, should the wheat be sown in lines or broadcasted;

- There was a significant trend for reduced yields whenever row spacing increases (linear regression). x ¿und

Table 9. Effect of row spacing and seedrate on the wheat yields, spikes population and number of spikes per plant.

		Wheat yields* (kg.ha^{-1})	Spikes population** (Nb. spikes/m^2)	Nb. of spikes** per plant
	D_1 :	1985 (100)	316 (100) b	1.06 (100) a
Seedrates: (in lines)	D_2 :	2061 (104)	367 (116) a	.96 (91) a
	D_3 :	2060 (104)	363 (115) a	.78 (74) b
	E_1 :	2226 a (100)	370 (100) a	.99 (100)
Row spacing:	E_2 :	2062 b (93)	335 (91) b	.89 (90)
	E_3 :	1817 c (82)	341 (92) b	.92 (93)
	D_1 :	4113 (100)	467 (100)	1.00 (100)
Broadcasted**	D_2 :	4132 (100)	455 (98)	1.00 (100)
	D_3 :	4143 (101)	457 (98)	1.00 (100)
Average "broadcasted" 1978:		4130 (100)	460 (100)	1.00 (100)
Average "in lines" 1978 :		3934 (95)	349 (76)	.93 (93)

* average 3-year results (1977-1979)

** results 1978

In summary, the experimental results lead to the conclusion that any increase of on-the-line wheat population, either by increasing seedrate or row spacing, has a detrimental effect on the yield components and, finally, on the final results. (19)

2.4 Conclusions

Examining findings and results obtained through experiments on liming, fertilization and cultural practices applied to the wheat crop in the double-cropping system "wheat-soybeans", through which is produced almost 90% of the Brazilian wheat, following conclusions may be stated:

. The problem of liming, when considered only in terms of soil correction (pH, Al toxicity), looks like an unsolvable compromise because liming was proven very favourable for soybeans, but rather useless for wheat from the moment that Aluminium toxicity has been reduced by reasonable amounts of limestone (one half of the recommended rates through "SMP method", applied for 3 or 4 years). This problem cannot be solved as long as wheat is grown in a continuous wheat-soybeans system because of pathological factors (namely, "take-all" disease and root-rots). When wheat crop is repeated every year in the same soil, there is a fast build-up of soil borne inoculum, the infectivity of which is favoured and exacerbated by liming. Therefore, it is the wheat production system itself which is concerned. The eradication of take-all and root-rot diseases being subject to "break" crops still to be introduced into a more diversified and more rational crop rotation, the problem of liming will really set in totally different terms when eliminated these pathological factors.

. Most of the experiment on fertilizers, especially on nitrogen, have been carried out within the wheat-soybeans production system. It is therefore not surprising that inconsistent results were obtained, for the same reason of pathological factors. Two FAO Consultants (21) (27) brought in 1979 an essential contribution to the Project in identifying Gaeumannomyces graminis and Helminthosporium sativum as being the main fungi attacking the wheat root system and greatly damaging it. They also found these pathogens to be widespread over almost all wheat-growing areas in Brazil (see also 3.4.3). Since the response of wheat to any fertilizer is measured through grain yield variations as resulting of plant uptake, all experimental results turn questionable when it is proven that the root system does not work normally. The very low productivity on nitrogen, as stated by numerous experiments, is a clear confirmation of this assumption. The same also applies for phosphorus and potash, up to a certain extent. Consequently, all experimental results obtained on fertilizer use during the previous years are restricted to wheat production through a wheat-soybeans system. They are therefore of little value for the future, when more rational crop rotations will take place instead of the rather simplistic wheat-soybeans system.

. In spite of the narrow scope into which the researches on fertilizers were realized in the CNPT, some outstanding conclusions remain valid:

- Split applications of nitrogenous fertilizers at tillering stage and Feekes stage 6 (beginning of stem elongation) gave better results than the actual recommendation 1/3 at sowing time + 2/3 at tillering stage. A nitrogen top-dressing just before boot-stage seems to be essential, because any top-dressing at tillering stage (favouring good tillering) in reality creates future needs for nitrogen on time of spike differenciation.
- N-fertilization on wheat is a question of plant physiology. The plant needs must be satisfied whatsoever is the ability of the soil for supplying nitrates. This ability is function of microbial mineralization of organic matter and leaching, which are unpredictable. It is therefore somewhat non-sensical to recommend, as still in use now, nitrogen rates calculated in inverse function of the organic content of the soil. This is all the more non-sensical as very few (if any) is known about organic matter mineralization, potential supply of nitrogen and leaching in Brazilian soils.
- National rock-phosphates, due to their mineral structure, have a low solubility and therefore a low immediate effectiveness. However, 1-year of 2-year experiments are not suited for this kind of assessment, which obviously needs a long run (5 or 10 years) to give consistent and unquestionable results.
- Significant decrease of soil potash content over the years has been put into evidence in the wheat-soybeans cropping system. Special attention must be paid to this problem and annual application of 100 kg $K_2O.ha^{-1}$ seems a minimum for maintaining K level above the critical one (60 ppm exchangeable K).
- Foliar fertilization has been proved unefficient and economically useless.

. The experiments on cultural practices put into evidence the advantages of direct-drilling in wheat production. No-tillage was found to save 71% of fuel, which is considerable in terms of energy savings, and to considerably reduce soil erosion. This is especially important in wheat and soybeans cropping, because these crops keep the soil unprotected during the first stage of their growth, what stage corresponds with a relative high frequency of rainfalls. However, pathological problems linked to the presence of crop residues (especially wheat straw) on the soil surface may hinder this practice to develop satisfactorily for wheat production, in so far as the wheat-soybeans system is concerned. Limestone must be ploughed down and carefully incorporated in the soil before starting a 3 or 4-year direct-drilling cycle, furtherly broken by one conventional tillage aimed at incorporating a new application of limestone. An alternative solution (to be experimented) might be superficial broadcasting of reduced amounts of limestone before the soybeans crop, because this has been proven disastrous when made before the wheat crop.

. The most important conclusion, after reviewing all the experiments included in this chapter 2, is that all production factors studied herein have a very limited influence on more stable and higher wheat yields. No definite breakthrough in wheat yields was ever observed in five years, should it be from fertilizers, liming, soil preparation, crop residues management, seedrates, row spacing, etc... and, over all, from the use of new improved wheat cultivars cropped under costly phytosanitary treatments. Plant protection through chemical sprays was proven to increase the wheat yields by about 30%, but it represents only an increase of about 300 kg of wheat grain per hectare, just enough (sometimes not enough) to pay the cost of the treatments.

In the writer's opinion, the simplistic wheat-soybeans system, in which wheat is grown every year, must be hold responsible for such a situation. From the very beginning of the history of agriculture, wheat monocultivation has been recognized as leading to a failure, because of increasing damages of pests and diseases. Such a disaster was already reported in Brazil by Dr. Antonio José Gonçalves Chaves in 1822 in relation to rust epidemics in Rio Grande do Sul, where wheat completely disappeared from that date. Therefore, it was fully justified to suspect the wheat-soybeans system (which is in reality a double monocultivation) to hinder any progress in wheat production. The following Chapter 3 gives a clear evidence of this assumption.

Chapter 3. STUDIES ON CROP ROTATIONS

3.1 Experimental Designs on Crop Rotation Trials

Immediatist preoccupations and certain administrative constraints prevailed at the CNPT, in December 1974, when the expert presented his programme on crop rotations. This is why, unfortunately, all proposed crop rotations including pastures, forages and green manuring have been discarded. Therefore, the work presented below was restricted only to study:

- barley or fallow, as alternative to wheat in winter;
- corn or sorghum, as alternative to soybeans in summer.

A simple demonstration trial however was realized in 1976, with three forage legumes, in collaboration with Engº Agrº J. GRAZZIOTIN in his own farm.

Two crop rotation experiments (Trials VIII and IX) were installed in the CNPT's Experiment Field No. 1, in a typical red lathosoil (see soil analysis 1975, 2.3) representative of the wheat-growing area of Planalto Médio. A two-year cycle of rotation was chosen, in function of the above-cited impediments. For this reason and practical problems of plot size and trafficability for field machinery, crossed-square schemes were designed for both trials. Basically, the design was a split-plot in which the main-plots were wheat and barley (or winter fallow); sub-plots were soybeans, corn or sorghum. The following year, the same design was applied at 90^{o} in relation to previous design. This system allowed to obtain all 36 possible combinations, in two years, of two winter crops with three summer crops.

Individual plot size was standardized as 6 x 6 m in both trials, with 2 m-wide tracks between plots. Four replications were disposed in a full square pattern (105 x 105 m) with two median broad ways (8 m-wide) for machinery traffic. All cultivation operations (tillage, sprayings, etc...) have been executed with the common farm machinery available at the CNPT.

. Crop Rotation "A" was designed in such a way that three crops are obtained in two years, using alternatively wheat and fallow as winter crops combined with the three summer crops. Winter fallow allowed earlier planting of the summer crops (1st planting date, around 15 October). The second planting date of the summer crops was immediately after wheat harvest (i.e. between 1st and 15 December). For each summer crop, three cultivars (early, medium, late) were planted on each sowing date, in order to determine the best adapted to crop rotation B and to evaluate the effect of late planting against early planting. Graph 7 below gives the 18 combinations possible, and Photograph No. 3 shows the crops during summer 1975-76. Photograph No. 1 also shows the trial during winter 1975.

1st YEAR:	FALLOW S_1	FALLOW C_1	FALLOW So_1	WHEAT C_2	WHEAT So_2	WHEAT S_2	
2nd YEAR: WHEAT So_2	F+S /W+So	F+C /W+So	F+So /W+So	W+C /F+C	W+So /F+C	W+S /F+C	FALLOW C_1
WHEAT S_2	F+S /W+S	F+C /W+S	F+So /W+S	W+C /F+So	W+So /F+So	W+S /F+So	FALLOW So_1
WHEAT C_2	F+S /W+C	F+C /W+C	F+So /W+C	W+C /F+S	W+So /F+S	W+S /F+S	FALLOW S_1

F = Winter fallow
W = Wheat
S_1 = Soybeans
C_1 = Corn
So_1 = Sorghum
1st planti time

S_2 = Soybeans
C_2 = Corn
So_2 = Sorghum
2nd planti time

Three crops in 2 years

Graph 7. Crop rotation "A". Design for one block.

. Crop rotation "B" was designed for determining the effect of the preceding crops on the yield of each crop involved in the rotation (photograph No. 4). In this report, the results concerning wheat and barley only will be taken into consideration. However, useful observations were also gained for corn, soybeans and sorghum. Detailed information on summer crops are described in the expert's quarterly reports. Graph 8 below gives 36 combinations of wheat or barley as winter crops with soybeans, corn or sorghum as summer crops.

WHEAT			BARLEY				
Soy	Corn	Sor	Corn	Sor	Soy		
W+S /W+S	W+C /W+S	W+So /W+S	B+C /W+S	B+So /W+S	B+S /W+S	Soy	WHEAT
W+S /W+So	W+C /W+So	W+So /W+So	B+C /W+So	B+So /W+So	B+S /W+So	Sor	WHEAT
W+S /W+C	W+C /W+C	W+So /W+C	B+C /W+C	B+So /W+C	B+S /W+C	Corn	WHEAT
W+S /B+C	W+C /B+C	W+So /B+C	B+C /B+C	B+So /B+C	B+S /B+C	Corn	BARLEY
W+S /B+S	W+C /B+S	W+So /B+S	B+C /B+S	B+So /B+S	B+S /B+S	Soy	BARLEY
W+S /B+So	W+C /B+So	W+So /B+So	B+C /B+So	B+So /B+So	B+S /B+So	Sor	BARLEY

Way of cultivation 1st year

Way of cultivation 2nd year

W = Wheat
B = Barley
S = Soybeans
C = Corn
So = Sorghum

Four crops in 2 years

Graph 8. Crop rotation "B". Design for one block

In both rotations A and B, the place of each "treatment" (i.e. each crop) was determined at random in each block. Therefore, the statistical analysis of the results was separately done for each crop, on a classical split-plot basis.

All cultural practices, fertilization and phytosanitary sprayings were identical in both trials A and B. Crop residues were systematically ploughed down. On a 5-year average, the fertilization was:

	kg $N.ha^{-1}$	kg $P.ha^{-1}$	kg $K.ha^{-1}$
Wheat	70	40	50
Barley	80	40	50
Soybeans	12	40	50
Corn	95	40	50
Sorghum	95	40	50

This means an average of P = 80 $kg.ha^{-1}$ and K = 100 $kg.ha^{-1}$ per year, according to the official recommendations.

Nitrogen was applied, for wheat and barley, on a basis of 15 kg $N.ha^{-1}$ at sowing time (present in the compound fertilizer applied), 30 kg $N.ha^{-1}$ at tillering stage and 20-30 kg $N.ha^{-1}$ at Feekes' stage 6 (beginning of stem elongation). Barley always received 10 kg N more than wheat, at elongation stage.

Phytosanitary treatments (fungicide + insecticide) were also applied to wheat and barley, according to the recommendations of the CNPT's Plant Pathology team.

It is important to recall that all physical data recorded from rotations A and B are essential for the work developed by the FAO Agroeconomist on the economics of production systems. These data, transformed in economical terms, will be utilized for linear programming and simulation through computerized processing. (Photograph No. 5 refers).

3.2 Crop Rotation "A" (trial VIII): Three Crops in Two Years

Wheat cultivars used were IAS.54 (in 1975 and 1976), and CNT.10 (from 1977 to 1979), at sowing rate of 110 $kg.ha^{-1}$, sown around 15 June every year. There were two sowing time for summer crops: around 15 October (after winter fallow), and between 1st and 15 December (after wheat harvest).

This trial was essentially aimed at to give answer to the following questions:

1) Has 1-year fallow any effect on the wheat yields?
2) What is the difference in yields of the three summer crops when planted early (after winter fallow) or late (after wheat harvest)?
3) What is the effect of each summer crop on the wheat yields?

In this experiment, wheat is always cropped after a summer crop sown early (after winter fallow), which follows itself a summer crop sown late (after wheat), according to the scheme:

"2-yr. cycle"	1st year :	wheat, and summer crop (late)
	2nd year :	fallow, and summer crop (early)
	3rd year :	wheat, and summer crop (late
	etc...	

The successive wheat seasons have been very different, with broad differences between average yields obtained in rotation A:

1975: "medium" year, 1874 $kg.ha^{-1}$

1976: good year , 2526 $kg.ha^{-1}$

1977: bad year (many diseases), 990 $kg.ha^{-1}$

1978: very good year, 3135 $kg.ha^{-1}$

In order to minimize the year-effect, all wheat yields have been expressed in per thousand of the yield obtained with the "check" rotation 'wheat + soybeans / fallow + soybeans'. The distribution remains unchanged, as verified by GEAVY's test. A simplified statistical analysis was made, in which 'years' are considered as "blocks". Therefore, the F test is made against a 'residual error' which is, in reality, the interaction "years x treatments". Following results were obtained:

Table 10. Four-year averaged wheat yields (expressed in per thousand of the check rotation "wheat + soybeans / soybeans"), as influenced by nine types of "three crops in two years" rotations. Crop Rotation "A" (1975-1978).

	Preceding crops (year y-2) *	Preceding crops (year y-1)**	Wheat yields (index) (year y)	
Direct effect	Soybeans	-	988	
	Corn	-	1014	(not significant)
	Sorghum	-	1010	C.V. = 3.91%
Direct effect	-	Soybeans	1021	(significant at
	-	Corn	999	P = 0.0952)
	-	Sorghum	992	C.V. = 3.17%
Interaction	Corn	Soybeans	1038	
	Sorghum	Soybeans	1026	
	Sorghum	Corn	1009	
	Corn	Sorghum	1006	(significant at
	Soybeans	Soybeans (check)	1000	P = 0.0609)
	Corn	Corn	999	C.V. = 3.17%
	Sorghum	Sorghum	996	
	Soybeans	Corn	990	
	Soybeans	Sorghum	974	

* = sown after wheat (late)

** = sown after winter fallow (early)

There was no difference between summer crops, whatever is the combination, on the following wheat yields; only a slight trend developed (P = 0.06) in favour of soybeans as precedent crop with soybeans or sorghum as ante-precedent crop.

Summer crops yields showed better stability over the years, and no transformation of data was necessary. Three years of experiment are summarized below:

Table 11. Three-year averaged yields (in $kg.ha^{-1}$) of 3 summer crops, as influenced by sowing time and cultivars. Crop Rotation A (1976-1978).

	Cultivars	When sown after winter fallow (early)		When sown after wheat (late)		Difference (late/early %)
SOYBEANS	Early	2689*	(100)	2259	(100)	-16%
	Medium	2791	(104)	2442	(108)	-13%
	Late	2902	(108)	2461	(109)	-15%
	Average	2794	[100]	2387	[85]	-15%
CORN	Early	3616	(100)	2348	(100)	-35%
	Medium	5038	(139)	2922	(124)	-42%
	Late	5317	(147)	3525	(150)	-34%
	Average	4657	[100]	2932	[63]	-37%
SORGHUM	Early	4141	(100)	3759	(100)	- 9%
	Medium	4576	(111)	3430	(91)	-25%
	Late	5451	(132)	3622	(96)	-34%
	Average	4723	[100]	3604	[76]	-24%

(*): two year average only

There is a marked trend for reduced yields in each summer crop when sown later: -15% for soybeans, -37% for corn and -24% for sorghum. However, these averaged data are masking broader variations, the amplitude of which being highly variable depending on the year. By example, heavy rainfalls occurring soonafter the early planting in 1975 led to a very poor stand in soybeans, and those planted later gave a 17% better yield.

Late cultivars, especially when sown early, gave the best yields. Nevertheless, their harvest is also late, and often reduced the time available in soil preparation for wheat sowing.

Since soybeans are the cash-crop giving the highest profit to the farmers, a decreasing effect of about 15% less in the yields when soybeans are planted late (after wheat) is one reason more for the farmer not being enthusiastic for wheat cropping.

The influence of winter fallow on wheat production will be examined by comparison with crop rotation B.

This crop rotation A was cancelled in 1978, after wheat harvest, for allowing installation of new diversified rotations.

3.3 Crop Rotation "B" (trial IX): Four Crops in Two Years

As for rotation A, wheat cultivars used were IAS.54 (in 1975 and 1976) and CNT.10 (from 1977 to 1979). Barley cultivar used was Bzenn's "Volla" (malting barley). There were only one sowing date for winter crops (around 15 June) and one for summer crops (all planted after cereal harvest, between 1 and 15 December).

This trial was essentially aimed at to test the direct and back-effects of 18 different crop rotations in a 2-year cycle.

As already noted above, the successive wheat seasons were very different, with broad differences between average wheat and barley yields:

		Wheat	Barley
1975 :	starting year, "medium",	1736 $kg.ha^{-1}$	3260 $kg.ha^{-1}$
1976 :	good year,	2731 $kg.ha^{-1}$	3545 $kg.ha^{-1}$
1977 :	bad year (diseases),	948 $kg.ha^{-1}$	717 $kg.ha^{-1}$
1978 :	very good year,	2668 $kg.ha^{-1}$	1998 $kg.ha^{-1}$
1979 :	extremely bad year (diseases, lodging)	529 $kg.ha^{-1}$	656 $kg.ha^{-1}$

The starting year 1975 is not included in the average results.

As for Crop Rotation A, wheat and barley results were expressed in per thousand of the wheat or barley yields obtained with the "check" rotations wheat-soybeans or barley-soybeans, in order to minimize the year-effect. A simplified analysis was made on 4-year results, in the same manner as for crop rotation A. Basically, statistical analysis was these of a split-plot design.

Summarized results for wheat and barley are presented below:

3.3.1) Wheat Results

Table 12. Crop Rotation "B". Effect of summer and winter crops on the wheat yields, in average of 4 years (yields expressed in per thousand of the check rotation Wheat-Soybeans)

Crop Rotation Schemes	Wheat yields (index ‰)		
A) Continuous vs. Alternate Winter Crops:			
Wheat only (every winter)	1010		(100)
Wheat-Barley (alternating)	1156		(114)
B) Continuous double-cropping ("monocultivation"):			
Wheat-Soybeans	1000	(check)	(100)
Wheat-Corn	1166		(117)
Wheat-Sorghum	910		(91)
	$\overline{m}$ = 1025	[100]	
C) Continuous winter wheat, alternating summer crops:			
Wheat-Soybeans / Wheat-Corn	1029		(100)
Wheat-Soybeans / Wheat-Sorghum	979		(95)
Wheat-Corn / Wheat-Sorghum	1002		(97)
	$\overline{m}$ = 1003	[98]	
D) Alternating winter crops, continuous summer crops:			
Wheat-Soybeans / Barley-Soybeans	1101		(100)
Wheat-Corn / Barley-Corn	1211		(110)
Wheat-Sorghum / Barley-Sorghum	1136		(103)
	$\overline{m}$ = 1149	[112]	
E) Alternating winter and summer crops ("diversified"):			
Wheat or Barley - Soybeans or Corn	1167		(100)
Wheat or Barley - Soybeans or Sorghum	1134		(97)
Wheat or Barley - Corn or Sorghum	1176		(101)
	$\overline{m}$ = 1159	[113]	

a). When wheat alternates with barley, whatever is the summer crop, the average yield is 14% better when compared with continuous wheat cropping. This trend has a probability of P = 0.11 in the 4-year average, but was highly significant (P 0.01) in 1979 where the difference reached 55%. In 1978, although very good wheat season, this difference was already +6% in favour of alternating wheat/barley, whereas no difference was observed in 1976 and 1977. Therefore, it seems that this trend is cumulative, increasing over the years.

b). When wheat is cropped every year, corn is the best summer crop to be associated with it, giving 17% better wheat yield than soybeans. This trend is the consequence of direct- and back-effects of corn on wheat yields:

		Wheat yields (index ‰)	
Direct-effect (preceding crops) :			
	Soybeans :	1061 b (100)	Tukey 5% = 41
	Corn :	1109 a (105)	($P \leq 0.05$)
	Sorghum :	1079 ab (102)	
Back-effect (ante-preceding crops):			
	Soybeans :	1075 (100)	
	Corn :	1141 (106)	(P = 0.19)
	Sorghum :	1033 (96)	

This favourable effect of corn is closely related to pathological factors (see 3.5 Conclusions).

c). There is no effect on the wheat yields when summer crops alternate, whenever wheat is cropped every winter.

d). The favourable effects of corn and barley are confirmed when looking the rotations in which barley alternates with wheat, with corn as continuous summer crop: 10% better wheat yields, in average. Winter "diversification" leads to 12% better wheat yields.

e). Full "diversification" of the cropping system gives a 13% increase in wheat yields, in average.

No significant interaction occurred. Finally, only four crop rotation schemes are significantly better than "wheat-soybeans" double-cropping:

	4-yr average wheat yields (index ‰)	
Wheat + Corn/ Barley + Sorghum	1222 a	
Wheat + Corn/ Barley + Corn	1211 a	Tukey 5% = 153
Wheat + Corn/ Barley + Soybeans	1184 a	
Wheat + Corn/ Wheat + Corn	1166 a	
Wheat + Soybeans/ Wheat + Soybeans	1000 b	

3.3.2) Barley Results

Table 13. Crop Rotation "B". Effect of summer and winter crops on the barley yields, in average of 4 years (yields expressed in per thousand of the check rotation Barley-Soybeans)

Crop Rotation Schemes	Barley yields (index ‰)		
A) Continuous vs. Alternate Winter Crops:			
Barley only (every winter)	1110		(100)
Wheat-Barley (alternating)	1009**	($P \leq 0.01$)	(110)
B) Continuous double-cropping ("monocultivation"):			
Barley-Soybeans	1000	(check)	(100)
Barley-Corn	1049		(105)
Barley-Sorghum	908		(91)
	$\bar{m}$ = 986	[100]	
C) Continuous winter barley, alternating summer crops:			
Barley-Soybeans / Barley-Corn	1005		(100)
Barley-Soybeans / Barley-Sorghum	1028		(102)
Barley-Corn / Barley-Sorghum	1030		(102)
	$\bar{m}$ = 1021	[104]	
D) Alternating winter crops, continuous summer crops:			
Wheat-Soybeans / Barley-Soybeans	1140		(100)
Wheat-Corn / Barley-Corn	1124		(99)
Wheat-Sorghum / Barley-Sorghum	1096		(96)
	$\bar{m}$ = 1120	[114]	
E) Alternating winter and summer crops ("diversified"):			
Wheat or Barley - Soybeans or Corn	1111		(100)
Wheat or Barley - Soybeans or Sorghum	1122		(101)
Wheat or Barley - Corn or Sorghum	1084		(98)
	$\bar{m}$ = 1106	[112]	

a). As for wheat yields (see 3.3.1 a).), barley yields are significantly better when wheat and barley alternate.

b). There is no significant effect of the different summer crops on barley yields. However, there is a significant interaction between summer and winter crops:

Preceding crops	Following Barley yields (index ‰)		
Wheat and Soybeans	1168	a	
Wheat and Sorghum	1117	ab	
Wheat and Corn	1045	bc	(Tukey 5% = 84)
Barley and Corn	1034	bc	
Barley and Sorghum	996	c	
Barley and Soybeans	996	c	

3.3.3) Comparison between Crop Rotations "A" and "B"

Although crop rotations A and B are different trials and therefore not statistically analysable together, an interesting comparison is made in relation to the effect of one-year fallow on the wheat yields, more especially as wheat cultivars used and fertilization are identical.

Table 14. Evolution of the wheat yields (in $kg.ha^{-1}$) in three years in crop rotations A and B

Crop rotation schemes	Wheat yields ($kg.ha^{-1}$) 1976	1977	1978	3-year average
One-year winter fallow ("A")				
Wheat-Soybeans/Fallow-Soybeans	2698 (100)	1009 (100)	2997 (100)	2235 (100)
Wheat-Corn/Fallow-Corn	2490 (92)	972 (96)	3213 (107)	2225 (100)
Wheat-Sorghum/Fallow-Sorghum	2390 (89)	937 (93)	3151 (105)	2159 (97)
Averages	2526 [92]	973 [101]	3120 [121]	2206 [106]
Continuous wheat ("B")				
Wheat-Soybeans/Wheat-Soybeans	2896 (100)	878 (100)	2630 (100)	2135 (100)
Wheat-Corn/Wheat-Corn	2813 (97)	1047 (119)	2780 (106)	2171 (102)
Wheat-Sorghum/Wheat-Sorghum	2566 (89)	978 (111)	2310 (88)	1953 (91)
Averages	2758 [100]	968 [100]	2573 [100]	2086 [100]

The year 1978 was the first wheat crop showing an appreciable difference of +21% in favour of one-year fallow. Other observations (see 3.4) led to recommend to grow wheat every two or three years only, based on the presence of soil borne pathological factors.

3.3.4) Evolution of Soil Fertility in Rotation B

Systematical soil sampling was made in each plot, soonafter the first two-year rotation cycle (May 1977, after summer crops). Analytical results have been statistically tested.

After two years, the average Al^{+++} content of the soil rose up to 1.90 meq/100 g., i.e. increased by 36% in relation to initial content 1.40 meq/100 g. However, Al^{+++} content was significantly higher after wheat than after barley (1.98 and 1.82, respectively, i.e. a difference of 8%). Summer crops also interacted with winter crops:

	Soybeans	Corn	Sorghum	
Wheat	1.96 ab	2.10 a	1.87 ab	(Tukey 5% = 0.31)
Barley	1.90 ab	1.71 b	1.85 ab	

The average content in P decreased by 13% (15.2 ppm P in 1977, against 17.4 ppm P in 1975), though the average P-fertilization was 80 kg P per year. Corn is playing the most important part in the variation of P content of the soil: this content is always higher whenever corn is involved into the rotation.

The same trend occurred for K content, as far as corn is concerned. Corn always gave the highest level in available K after two years of rotation. Soybeans, at the contrary, show an opposite trend, and are confirmed to be high-consumers in potash. In average, available K content decreased by 10% in relation to the initial content (81.9 ppm K, and 91.5 ppm K, respectively.

More detailed data on soil analysis are given in Annex A.2.

3.4 The Wheat Root System as Influenced by the Soil Cropping History

Many reasons led the expert to suspect a "wheat root problem", as soon he became acquainted with wheat cropping in Brazil.

- The low productivity of nitrogen meant an abnormal plant uptake (see 2.4 Conclusions).
- Barley and wheat being cropped side by side in the crop rotation A, in the same conditions, it was easy to see the poor root development of the wheat plant, in comparison to this of barley.
- In 1975 was made the first observation (in crop rotation B) stating the low wheat plant fertility, expressed in number of spikes per plant. This observation was confirmed over the years:

	Number of spikes per plant*	
	Wheat	Barley
1975	0.77	2.63
1976	0.74	1.87
1977	0.65	1.12
1978	1.05	1.81

(*: number of heads at harvesting time divided by the number of wheat plants at the end of tillering stage, on the same 2 m-long double line).

- Factorial experiments (see 2.3.3) led to the conclusion that any increase of on-the-line plant population has a detrimental effect on yield components and, finally, on wheat yields. This perhaps meant an effect of increasing inoculum rate in case of this inoculum carried by the seed.

These observations strongly supported a "pathological" assumption of the existence of some pathogenic factor, soil borne or carried by the seed (or both), progressively attacking the root system and leading to reduced head population per unit area.

3.4.1) Observations in Crop Rotation B

During the 1978 wheat season, systematical sampling of whole plants including roots was realized (11), aiming at to quantify the severity of root/crown injury, and to identify the responsible pathogen, following six different crop rotations in trial IX (crop rotation B).

Table 15. Wheat roots infection rates, as influenced by different crop rotation schemes (J.A. DIEHL, 1978)

Rotation Schemes	Infection index*
Continuous wheat-soybeans	over 50%
Continuous wheat-corn	25-50%
Continuous wheat-sorghum	over 50%
Wheat-Soybeans/Barley-Soybeans	over 50%
Wheat-Corn/Barley-Corn	25-50%
Wheat-Sorghum/Barley-Sorghum	over 50%

(*: 0 = without lesion; 1-25% = slight; 25-50% = moderate; over 50% = severe infection)

Helminthosporium sativum was the organism the most frequently encountered, in association with root rot and/or crown necrosis. At a lower rate, Fusarium roseum 'graminearum' and 'avenaceum' were also found. Whenever corn is associated with wheat into a double-cropping sequence, the severity of the infection is significantly lower. This observation is consistent with the trends reported on the wheat yields (Table 12. 3.3.1)

3.4.2) Pot Experiment on Soil Sterilization (Trial XVI)

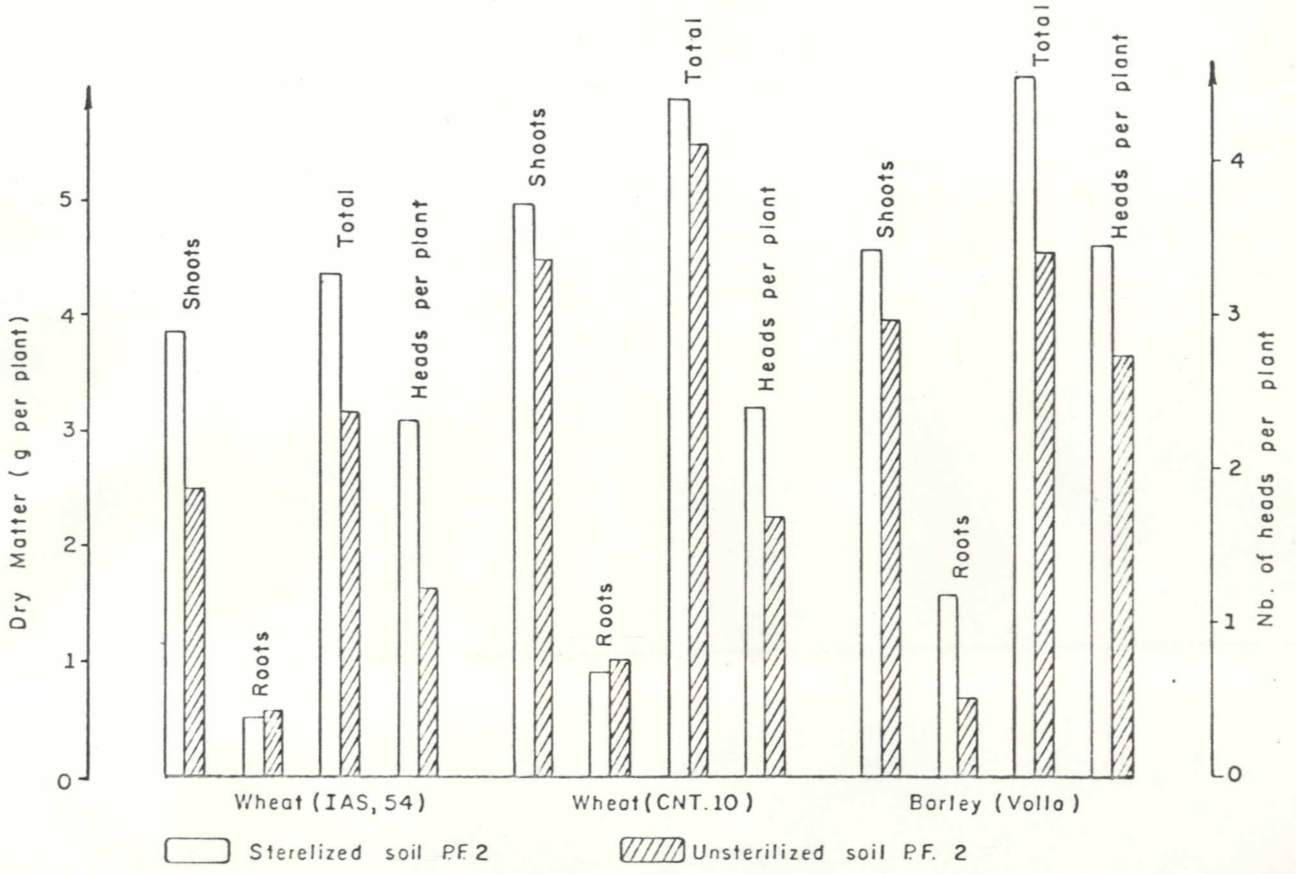
In 1978, a pot experiment was realized, with the objective of drawing schematic curves for the growth of both aerial part and root system of wheat and barley in soils having different cropping histories. This was a factorial experiment 3 x 2 x 3 with 20 replications. One half of three soils has been sterilized by "BASAMID" (20 g/m^2, thoroughly mixed in 20 cm depth):

- Soil JUA: yellow-greyish vertisol from Juazeiro (Bahia State) where the first wheat crop was ever made in 1977, under irrigation.

- Soil PF.1: typical Passo Fundo dark-red lathosoil, from crop rotation B, having a continuous wheat-soybeans sequence.
- Soil PF.2: typical Passo Fundo dark-red lathosoil, from a farm near CNPT, in which 2-year winter fallow was observed (2 years without wheat nor barley).

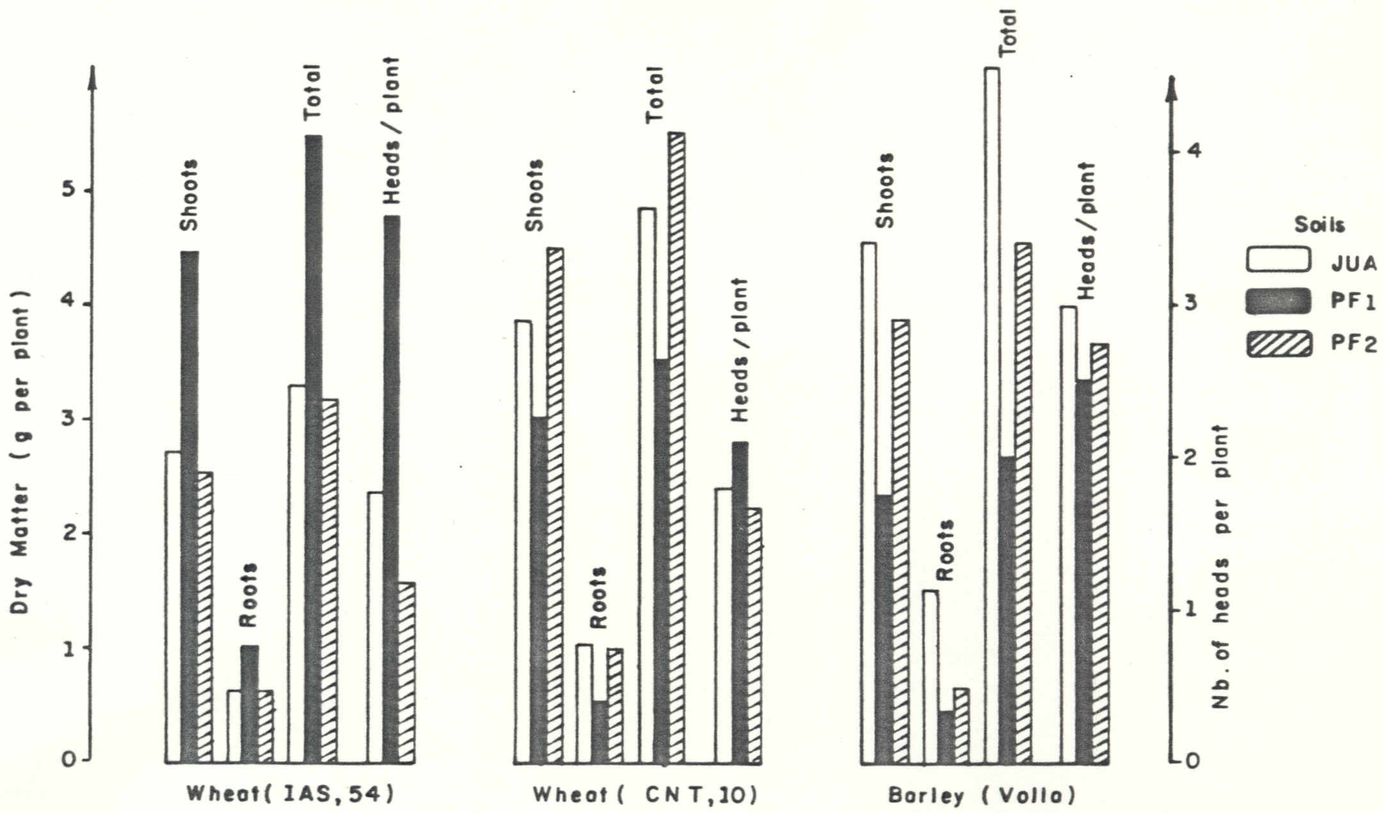
Soils	pH (H_2O, 1:1)	exch.Al^{+++} (meq/100g)	exch.Ca+Mg (meq/100g)	avail.P (ppm)	avail.K (ppm)	O.M. %
JUA	7.0	0	22.15	12.5	153	0.4
PF.1	5.3	0.65	3.65	20.5	155	2.6
PF.2	5.0	1.40	2.90	13.0	110	3.1

Unfortunately, Basamid treatment showed a strong residual phytotoxic effect on the series JUA and PF.1. Therefore, comparisons were available only between sterilized and unsterilized PF.2 soils (Graph 9) as well as between unsterilized series (Graph 10).



Graph 9. Effect of soil sterilization on shoot / root growth and number of heads per plant of wheat and barley (P.F. 2 soil).

Graph 9 shows a positive effect of soil sterilization on the growth of aerial part of wheat and barley, but a negative effect on root growth of wheat, whereas positive for barley roots. This may be related to lower susceptibility of barley to a slight residual phytotoxicity of Basamid. However, the number of heads per plant was significantly improved, in all cases, by soil sterilization.



Graph 10. Effect of different soils on shoot/root growth and number of heads per plant of wheat and barley.

In relation to soil types, there were marked differences between wheat cultivars and barley. IAS.54 grew the best in PF.1 soil, CNT.10 in PF.2 soil and barley in JUA soil, and the number of spikes per plant was correlated with dry matter production. (Graph 10).

Numerous black-tipped or necrotic-shaped tip roots were observed on the wheat plants growing in the unsterilized PF.1 soil, and the same occurred on barley, though at much lower extent. Helminthosporium sativum was found the most frequent organism encountered in association to necrotic or brownish spots on the roots or root crowns. However, the fungus was also found on the roots of barley growing in sterilized PF.2 soil. Doubtless there is a problem of seed contamination.

3.4.3) Consultancies on the "Wheat Root Problem"

A first FAO Consultant (12), in 1977, stated that wheat roots growth was conditioned by soil borne factors, as early as germination stage, still unexplained. Later on, two decisive FAO consultancies (21) (27), in 1979, clearly identified two fungi (Gaeumannomyces graminis var. tritici, "take-all" disease; and Helminthosporium sativum) as being the major root diseases on wheat in Rio Grande do Sul. There was no evidence of nematode damage to roots in any sample observed. The widespreadness and the economical importance of these soil borne diseases was also stated. A field survey, undertaken to assess root diseases in 31 fields chosen at random on a 1,200 km route in western and northern Rio Grande do Sul, showed that all fields (100%) were infected with Helminthosporium and about one third (32.2%) with "take-all". The value of overall yield losses to Rio Grande do Sul State has been estimated to excess US$ 76 million for 1979. The frequency and the intensity of these diseases was closely correlated with repeated wheat cropping, the strongest damages being observed where wheat is cropped every year.

3.5 Conclusions

Though very short in duration, crop rotation trials A and B have been essential in giving to the Brazilian counterpart scientists full consciousness of the dangers of wheat monocultivation, as well as in giving the first experimental data supporting a drastic change in wheat production approach. These trials, as well as FAO consultancies on wheat root-rot, put into clear evidence the progressive accumulation and build-up of soil borne pathogenic inoculum attacking the wheat root system. Therefore, the continuous wheat-soybeans double-cropping system must be considered as directly responsible of the situation, more especially as soybeans are suspected to harbour wheat "take-all" disease (27) : in a wheat-soybeans system, no decline of the disease is observed after 3 or 4 years, as usually observed elsewhere. The same may be true for Helminthosporium. Some 15 years of wheat-soybeans double-cropping, without any seed treatment (because toxicity of mercurial chemicals), led to the present situation of soils being 100% infected by Helminthosporium and 33% by "take-all" disease. (21)

This fully explains the poor results obtained in fertilization experiments: all experiments have been distorted by the complex syndrome called "wheat root problem" hampering normal plant uptake. In the same way, the best breeding programme carried out during a lot of years with the best germplasm available and the highest care, is useless if the newly improved cultivars are grown in such conditions that the expression of accrued yield potential or disease resistance is hindered by abnormal root development.

Therefore, more diversified crop rotation schemes are essential for obtaining more stable and higher wheat yields, by "cleaning up" the soil from soil borne inoculum and strengthening the protecting effects of phytosanitary treatments. As a prove, just let us have a look on the following data collected in 1979 from the experiments underway at CNPT and from a farm survey (38 farms) realized by CNPT the same year:

Table 16. Overall effects of crop rotation and phytosanitary sprayings on the wheat yields 1979 in Rio Grande do Sul State

	Average wheat yields ($kg.ha^{-1}$)	
a) General average of Rio Grande do Sul		less than 500
b) No rotation, no treatments	450	(CNPT trials)
c) No rotation, with two treatments	529	(CNPT trials)
d) With rotation*, no treatments	800	(CNPT trials)
e) With rotation, with two treatments	1221	(survey, 13 farms)
f) With rotation, with three treatments	1454	(survey, 19 farms)

(*: i.e. no wheat nor barley during 2 years)

(**: fungicide + insecticide sprayings)

There is an evident synergical interaction between rotation and treatments:

	No rotation	With rotation	$\overline{m}$
No treatments :	450	800	625 (100)
With 2 treatments:	529	1221	875 (140)
$\overline{m}$	490 (100)	1011 (206)	

Two phytosanitary treatments increased the yield by 40% in average, whereas the average effect of rotation is +106%, more than double. The synergical interaction represents, alone, 171 $kg.ha^{-1}$ of wheat grain, i.e. 38% of the check yield 450 $kg.ha^{-1}$.

It means that crop rotation is the dominant factor for obtaining good and stable wheat yields : once the wheat secured with good conditions of growth in a "clean" soil, the efficiency of crop protecting treatments is significantly increased.

Crop diversification is now officially recognized by Brazilian authorities as the stumbling-block of any profitable agriculture, in the long run, especially for improving the wheat production. This is why a new set of "diversified crop rotations" experiments has been established in 1980 at the CNPT, where rapeseed, lineseed, oats, lupines and winter cover-crops (green manuring) have been introduced in three-year or six-year crop rotations, as alternative winter crops.

Chapter 4. SPECIFIC STUDIES

4.1 Overcoming Drought Conditions for Wheat Sowing in Southern Mato Grosso

The southern part of Mato Grosso State, considered as potentially favourable for wheat production, represents about 6 million hectares. The most favourable zone is located between parallels 20° and 24° S, especially around the cities of Dourados and Maracajú. The soils are typical dark-red lathosoils (Humic or Rhodic Ferralsols, Fh, Fr), with a good structure and variable fertility according to their origin:

Table 17. Chemical analysis of two characteristic soils of southern Mato Grosso

	pH (H_2O) (1:1)	exch. Al (meq/100g)	exch. Ca + Mg (meq/100g)	avail.P* (ppm)	avail.K (ppm)	O.M. (%)
Forest soil	6.3	0.05	15.40	7.5	150	6.2
Savanna soil	4.6	1.40	3.00	2 to 5	80	5.2

(*: "North Carolina" method, extractant: H_2SO_4 0.025N + HCl 0.05N)

These soils have an excellent natural draining, but a low field water capacity. Moreover, there is a steep decrease in rainfall height and frequency from March to May. These negative factors, to which normally dry winter must be added, make risky any wheat sowing early April as usually made immediately after soybeans harvest. Additionally, soil preparation (ploughing and discing) leads to fast evaporation of the residual soil moisture. The best sowing time for wheat should be the beginning of March, increasing the probability of rainfalls and decreasing this of late frosts. However, soybeans are normally harvested on the first days of May. That is why the technique of wheat overseeding was experimented.

Overseeding wheat by plane into standing soybeans, about 40 days before soybeans harvest, was experimented during three years in the region of Dourados (1975-1978), at real scale, and gave yields at least equivalent, or even better, to those obtained through conventional soil preparation and sowing after soybean harvest. (7, 35, 36)

Seedrate in overseeding must be at least 130 $kg.ha^{-1}$ of seeds having a high germinating rate. Overseeding by plane equipped with a "duck-foot" spreading system must be made when the first leaves at the top of the soybean plants begin to turn yellow, into a soybean crop having strong vegetative development and fully closed canopy (row spacing less than 0.80 m). Overseeding time being about 40 days earlier than conventional sowing, with no soil disturbance, this avoids any residual soil moisture losses occurring during conventional soil preparation and allows to take advantage of more frequent rainfalls at the end of March or early April.

Airplane overseeding allows sowing of 35 to 45 hectares per hour (8), with considerable fuel-savings in comparison to conventional seeding: 1.7 litre of gasoline (aircraft-type) per hectare sown, against 30-40 litres of gas-oil per hectare in conventional sowing.

Nevertheless, obtaining satisfactory wheat yields in this region remains strongly subject to rainfall regime, parasites and soil fertility. Therefore, overseeding by plane must be considered only as a practice which, owing to its fast implementation, allows to take advantage of imminent rainfalls for establishing a wheat crop with maximum chance of success.

From 250 m^2 experimented in 1975, the overseeded wheat acreage expanded on more than 3.000 hectares in 1977 in the region of Dourados

More detailed information on the above experiments can be found in a paper titled "La semis aérien du blé dans le soja: trois années d'expérimentation dans le Mato Grosso du Sud, Brésil", which will be presented during the International Congress on Dryland Farming (25th August-5th September, 1980), Adelaide, South Australia. This paper will also be published in the French review "L'Agronomie Tropicale". (9)

4.2 Soil Erosion and Farm Machinery

The expert also participated and assisted in the design of experiments aimed at quantification and measurement of direct and indirect effects of soil erosion on the economy. (37) These experiments, still underway, demonstrated that:

a). productive soils are lost by water erosion to an alarming extent when conventional soil preparation (ploughing + discing) and straw burning are used, as usually. A single storm at the CNPT, caused a loss, on unprotected soil, of 34 tons per ha under a rainfall of 60 mm/hour, whereas the loss on a direct-drilled plot only amounted to 0.2 ton/ha. Graph 6, paragraph 2.3.2, shows dramatic differences in soil erosion regarding soil preparation methods under natural rainfalls.

b). Incorporating crop residues or direct-drilling (with crop residues on the top soil layer) have been demonstrated as the best means for reducing soil erosion. Direct-drilling saved also 71% of fuel, in comparison to conventional soil preparation and sowing, which is of considerable importance in terms of energy savings.

The expert also advised on the research work on farm machinery, especially for direct-drilling purposes. Before the year 1975, the research work on direct-drilling (no-tillage) was carried out with a commercial machine of long standing in Brazil. Another machine was imported to CNPT through FAO available funds for equipment. Two Brazilian companies further developed "no-tillage sowing drills". In 1978 was carried out by the CNPT an evaluation of the merits and limitations of present commercial (or near commercial) machines which are available for direct drilling of wheat.

A variety of sites were selected to take in the major representative soil types, and five machines were selected, according to their availability and the comparison which they made possible with their different systems.

When considering the differences obtained in work rate, seed placement, seed cover, undulation following properties, and economy of energy, then the introduction of the triple disc system understandably generated considerable interest in direct-drilling wheat. Subsequently, a private company in Passo Fundo developed the first Brazilian-made triple disc prototype, which is now being tested before local commercialization.

Chapter 5. RECOMMENDATIONS

5.1 Specific Recommendations on Research Lines

5.1.1) Soil Fertility

. All experiments made prior 1978 on soil fertility have been developed into the very narrow scope of wheat-soybean annual double-cropping. Therefore, all conclusions derived from these experiments only apply to this system. Since the simplistic wheat-soybean double-cropping has been recognized as detrimental for wheat production, and that new winter crops are going to be introduced into a more diversified crop rotation, all conclusions and, therefore, all official recommendations for limestone and fertilizers use must be reconsidered.

. During a lot of years, liming was erroneously considered as unique responsible for the occurrence of wheat "take-all" disease. In reality, the continuous wheat cropping, every year in the same field, is the fundamental cause of "take-all", the part of lime being only to exacerbate disease occurrence. Therefore, the correction of soil acidity and Aluminium toxicity by liming must be reconsidered within the new scope of diversified crop rotation.

. The same recommendation is made for N-P-K-fertilization, which obviously need to be reconsidered within the "new deal" brought by diversified cropping systems. All previous experiments were distorted by the complex syndrome called "wheat roots problem", partially explaining the poor response of wheat to nitrogen. Therefore, systematic experimentation on wheat fertilization in fields "cleaned" from "take-all" and H. sativum is needed for renewing the recommendations to farmers.

. There is an urgent necessity for better knowledge of the organic matter in Brazilian soils, in direct relation to nitrogenous fertilization of wheat. Most of the soils where wheat is grown have a surprisingly high content in total organic matter, but this content should be more accurately characterized by determination of the "easily mineralisable" amount of organic matter, giving so a rough estimation of the potential nitrogen supply from the soil. This is of utmost importance as far as N-fertilizers are concerned. Quantitative and qualitative estimation of the microbial life in the soil deserves also special attention. Nutrient losses by leaching should also be estimated through simple studies with lysimeters under controlled conditions of rainfalls.

. Medium- or long-term experiments should be continued or settled, aimed at better knowledge of the effectiveness and possible utilization of national rock phosphates, as well as on potash content decline of the soils under intensive double-cropping every year.

. Taking advantage of the crop rotation experiments underway, the national team working on soil fertility should draw a "nutrient balance" for each rotation followed, aiming at to estimate the total needs in N.P.K. fertilizers for a given rotation - These data are fundamental in production systems studies.

. It is recommended that the Laboratory of Soils in the CNPT be discharged of the routine work on soil analysis. This routine work heavily burdens the laboratory, and turns it away from its intended purpose which is research. Specialized other laboratories (i.e. neighbouring Faculty of Agronomy) could be entrusted with this routine work.

5.1.2) Cultural Practices

. Since most of the Brazilian soils have good properties in terms of structure and facility in working with farm machinery, it is quite surprising to find out that very heavy disc implements and powerful tractors are still in use. Lighter tine implements should be used instead of heavy discs, for many reasons: reduced weight and broader width for the same traction power (saving fuel consumption), easier servicing and repairing, cheaper cost, etc... Certainly, tine cultivation could play an important part as well as direct drilling for better crops through reduced work. This is another new research area in which Brazil needs further development.

. Special effort should be devoted by extension services for cultural practices improvement at the farmer's level. Substantial increases of wheat yields undoubtedly would be achieved through very simple improvements and more carefulness in common agricultural work.

5.1.3) Wheat Roots Problem

. Regression of the tillers and of the root system soonafter the beginning of stem elongation, leading to an abnormally low plant fertility (less than one spike per plant, in average), is now recognized as one of the most important bottle-neck hindering any breakthrough in wheat production in Brazil. To overcome this problem must be considered of overwhelming importance and top-priority in wheat research. Broadly overspread in all wheat growing regions, the syndrome does affect not only national wheat production, but also the practical results and the very effectiveness of important research areas as plant breeding and soil fertility. The best breeding programme carried out during a lot of years with the best germplasm available and the highest care, may be useless if the newly improved cultivars are grown in such conditions that the expression of accrued yield potential or disease resistance is hindered by abnormal root development. All experiments realized up to this date on wheat response to N-P-K fertilizers only reflect the reaction of plants growing under abnormal conditions of nutrient uptake because of deficient root system.

. Though two fungi have been identified as the main pathogens attacking the wheat root system, it is recommended to continue investigations on non-pathogenic factors (Al^{+++} and Mn^{+++} toxicities, micronutrient deficiencies, physiological disturbances, etc...)

dealing with root development and growth, because these factors may interact with soil borne pathogens.

. Root system studies, as already pointed out, require a multidisciplinary approach, because of their complexity, and will demand devoted and common efforts from plant pathologists, physiologists, soil scientists, agronomist and plant breeders. It is strongly recommended to promote and to foster any attempt for developing a multidisciplinary team dealing with root system.

5.1.4) Crop Rotations

The simplistic wheat-soybean double-crop system actually prevailing in Brazil means really a "double monocultivation". This system leads to a natural accumulation of soil borne organisms, some of them being pathogens.

Crop diversification is now recognized as the unique way for controlling soil borne diseases of wheat and soybeans. It has to be remembered that Rhizoctonia is becoming a very important problem in several soybean growing areas. That is why crop rotation experiments need to be extended to medium-term rotation models involving different species for cash-cropping, fodder or green manuring, grown in succession in order to break the reproductive cycle of pathogenic soil borne organisms. Although recognizing the leading part played by soybeans in the Brazilian national economy, the wheat research cannot be limited within a narrow "loophole" between two successive soybeans crops. This constraint must be overcome, because of several reasons:

- crop diversification is needed for better control of soil borne pathogens for both wheat and soybeans;
- crop diversification is a necessity as far as integrated biological control of pests and diseases is concerned;
- crop diversification is essential to any comprehensive farming system where soil erosion would be thoroughly controlled;
- crop diversification should help the farmers, especially the small ones, in obtaining more stable and safer profits.

Conclusively, special emphasis should be given to studies on diversified crop rotation patterns in which wheat plays a leading part. These patterns should be evaluated and optimized by agro-economical studies, and adapted to the different socio-economical features of the different wheat growing regions in Brazil, so leading to comprehensive wheat production systems.

5.1.5) Soil Erosion Control

Soil conservation practices must be an essential part of the comprehensive "diversified agricultural production scheme" as it was spoken above, so leading to a national planning for land use into which integrated pest control should play another essential part. Since soil erosion goes well beyond the agricultural framework (energy, transport and human life are also affected), the problem deserves a broader approach which should be taken over by the Federal Authorities, at highest national level. The National Programme of Soil Conservation, as established by the Law 6225 (1975), deserves immediate implementation, for national soil patrimony, human life in easily flooded areas and hydroelectric plants are directly and urgently concerned.

5.2 General Recommendations on Research Implementation

5.2.1) The CNPT of Passo Fundo has been initially created in order to develop agronomical researches on wheat. Summarizing the works realized in the period 1970-79 with the assistance of the Project BRA/69/535, it can be assumed that most of the wheat research work performed by the CNPT has been conducted with a very specific approach, the only associated crop being soybeans. Over the years the essential need became evident for integrated study of the wheat crop in its biological, technical and economical aspects, and its relationship to other activities of the agricultural enterprise. Now the CNPT was given a national-wide responsibility, and it has to embrace the problems which wheat cropping faces in all existing and potential wheat-growing regions in different parts of Brazil. This means a new dimension given to its activities, but also means a new approach to a more general problem dealing with regional development. The so-called "miracle" wheat-soybeans double-cropping is dead and gone (especially in the South), new diversified production systems are urgently needed, and the CNPT's Management is perfectly aware of it. It is therefore desirable that more flexible guidelines be given to CNPT (though keeping it as responsible for wheat research at national scale) in order to allow it to pay more attention to other crops than wheat (rapeseed, lupins, etc...) in so far as they interfere with wheat production into new diversified production systems.

5.2.2) This new approach, to which the Project devoted much effort in recent years, means <u>interdisciplinary research work</u>. Because of their formation and maybe of inherited individualistic standards in research work, CNPT's researchers are not yet accustomed to work in really multidisciplinary teams. Considering the complexity of the problems dealing with wheat production increase, it is essential that a given research topic be carried out by a <u>team</u>, and not by a single specialized researcher. It is then strongly recommended that CNPT develop an "interdisciplinary spirit" in the scientific team working at the Centre.

5.2.3) Since a comprehensive approach to wheat production is considered, priority should be given, from a practical point of view, to carefully selected research programmes. The selection of priorities should be detected and decided by the Management of EMBRAPA/CNPT, taking in account the Government's objectives, the structure of crop production and the farmers' needs. When determined, these "top-priority lines" should be translated in practical terms by the Deputy Technical Chief of the CNPT (with the help of some specialists of the Centre, something like an "Operations Group"), so building up well-defined "Research Projects". Each research project would be executed by an interdisciplinary team headed by the scientist whose specialization area is the most concerned. It is clear that when the selection of priorities is decided, all available resources in equipment and manpower should be given to the corresponding research projects, even if resources must be reduced to a minimum for other research areas. Obviously, no specialized research area should be dominant in the activities of the CNPT, in so far as comprehensive approach of wheat production increase is concerned.

5.2.4) Linkage between research and extension is of utmost importance. It is therefore recommended to institutionalize and implement a better and efficient coordination between EMBRAPA and EMBRATER, but also with the Wheat Cooperatives. It is imperative that research be in touch with the practical problems of the farmer, and that the false image given by the scientist working alone in his "ivory tower" be definitely broken down. Closer links with extension are strongly recommended. In order to make easier the contacts between research people, extensionists and farmers, establishing of "Centres for Agricultural Technical Studies" is particularly desirable. In Brazil, a number of CITEs (Clubes de Integração e Troca de Experiências) already exist, based on the same principles as defined in France by Bernard Poullain (1945, founder of the first French CETA), as well as in Argentina and in Uruguay where they are called "CREAs". Most of the Brazilian CITEs existing now in Rio Grande do Sul are oriented toward stock breeding. Establishing CITEs of wheat producers, first near Passo Fundo and more widely in the main wheat growing areas of Brazil would be of utmost interest. Since a CITE is a focusing point where producers, extensionists and researchers gather informally, this seems to be one of the best means for creating and further strengthening of the links between research and extension. Additionally, some large scale experiments at farmer's level could be realized through a

CITE, at lowest cost, since they are not entertained within the administrative and practical framework of the CNPT.

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(note: RACPET = Reunião Anual Conjunta de Pesquisa de Trigo)

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	pH (H_2O) 1:1		exch. Al meq/100 g		exch. Ca+Mg meq/100 g		avail. P ppm		exch. K ppm		O.M. %	
Analysis 1975	5.10		1.40		3.90		15.5		98		5.00	
Analysis 1977												
No lime	4.70	100	1.85	100	3.79	100	19.4	100	107	100	4.95	100
1/2 SMP (1975)	4.85**	103	1.37**	74	4.52**	119	19.3	99	103	96	4.88	99
Convent.preparation	4.75	100	1.70	100	4.02	100	17.3	100	98	100	4.87	100
Direct drilling	4.80	101	1.53*	90	4.29*	107	21.5**	124	112*	114	4.95	102
Burnt residues	4.78	100	1.62	100	4.11	100	19.6	100	108	100	4.89	100
Rem. residues	4.76	99	1.60	99	4.20	102	19.2	98	103	95	4.93	101
Seedrate 1	4.77	100	1.64	100	4.11	100	17.8	100	101	100	4.87	100
Seedrate 2	4.78	100	1.58	96	4.20	102	20.9*	117	109	108	4.95	102
Nitrogen N_0	4.85	100	1.58	100	4.15	100	20.0	100	112	100	4.87	100
N_1	4.83	99	1.53	97	4.20	101	19.2	96	107	96	4.90	101
N_2	4.73	98	1.66	105	4.12	99	19.1	96	101	90	4.95	102
N_3	4.68	96	1.66	105	4.15	100	19.2	96	102	91	4.92	101
	**		**						**			
General average	4.77		1.61		4.16		19.4		105		4.91	

* Significant difference ($P \leq 0,05$)

** Highly significant difference ($P \leq 0,01$)

ANNEX A.1

Evolution of soil fertility after two years - Rotation "B" - 1977

EMBRAPA-CNPT - Passo Fundo, RS - Projeto FAO/BRA/69/535

	Exch. Al^{+++}		Avail. P		Avail. K	
	(meq/100 g)	% C_i	(ppm)	% C_i	(ppm)	% C_i
Initial content (C_i) in 1975	1.40	100	17.4	100	91.5	100
Two-year rotations	Analytical results 1977					
Wheat-soybeans, wheat-soybeans	1.96	140	12.4	71	76.5	84
" , " -corn	2.24	160	16.9	97	79.5	87
" , " -sorghum	1.99	142	18.0	103	84.0	92
" , barley-soybeans	1.80	129	12.8	74	60.5	66
" , " -corn	1.64	117	18.8	108	80.0	87
" , " -sorghum	1.58	113	10.8	62	77.5	85
Wheat - corn, wheat-soybeans	2.00	143	13.3	76	93.5	102
" , " -corn	2.16	154	17.5	101	90.0	98
" , " -sorghum	1.95	139	14.6	84	85.5	93
" , barley-soybeans	1.86	133	14.8	85	78.5	86
" , " -corn	1.84	131	17.6	101	93.8	103
" , " -sorghum	1.70	121	15.8	91	80.0	87
Wheat-sorghum, wheat-soybeans	1.85	132	11.3	65	88.0	96
" , " -corn	2.05	146	16.5	95	90.5	99
" , " -sorghum	1.58	113	14.5	83	85.5	93
" , barley-soybeans	1.90	136	15.0	86	73.5	80
" , " -corn	1.70	121	18.6	107	99.5	109
" , " -sorghum	1.96	140	12.9	74	81.5	89
Barley-soybeans, wheat-soybeans	1.90	136	14.4	83	72.0	79
" , " -corn	2.09	149	17.5	101	86.0	94
" , " -sorghum	1.89	135	17.0	98	76.5	84
" , barley-soybeans	1.86	133	15.3	88	62.5	68
" , " -corn	1.61	115	13.6	78	89.8	98
" , " -sorghum	1.81	129	13.0	75	75.5	83
Barley-corn, wheat-soybeans	2.01	144	13.9	80	80.0	87
" , " -corn	2.11	151	18.3	105	84.5	92
" , " -sorghum	1.95	139	13.5	78	82.5	90
" , barley-soybeans	1.99	142	12.8	74	60.5	66
" , " -corn	1.81	129	21.5	124	94.5	103
" , " -sorghum	2.01	144	12.5	72	73.5	80
Barley-sorghum, wheat-soybeans	2.01	144	11.8	68	74.0	81
" , " -corn	1.96	140	14.8	85	121.5	133
" , " -sorghum	1.85	132	14.6	84	69.5	76
" , barley-soybeans	1.99	142	12.9	74	57.8	63
" , " -corn	1.69	121	21.5	124	105.5	115
" , " -sorghum	2.05	146	15.0	86	84.0	92
General average 1977:	1.90	136%	15.2	87%	81.9	90%

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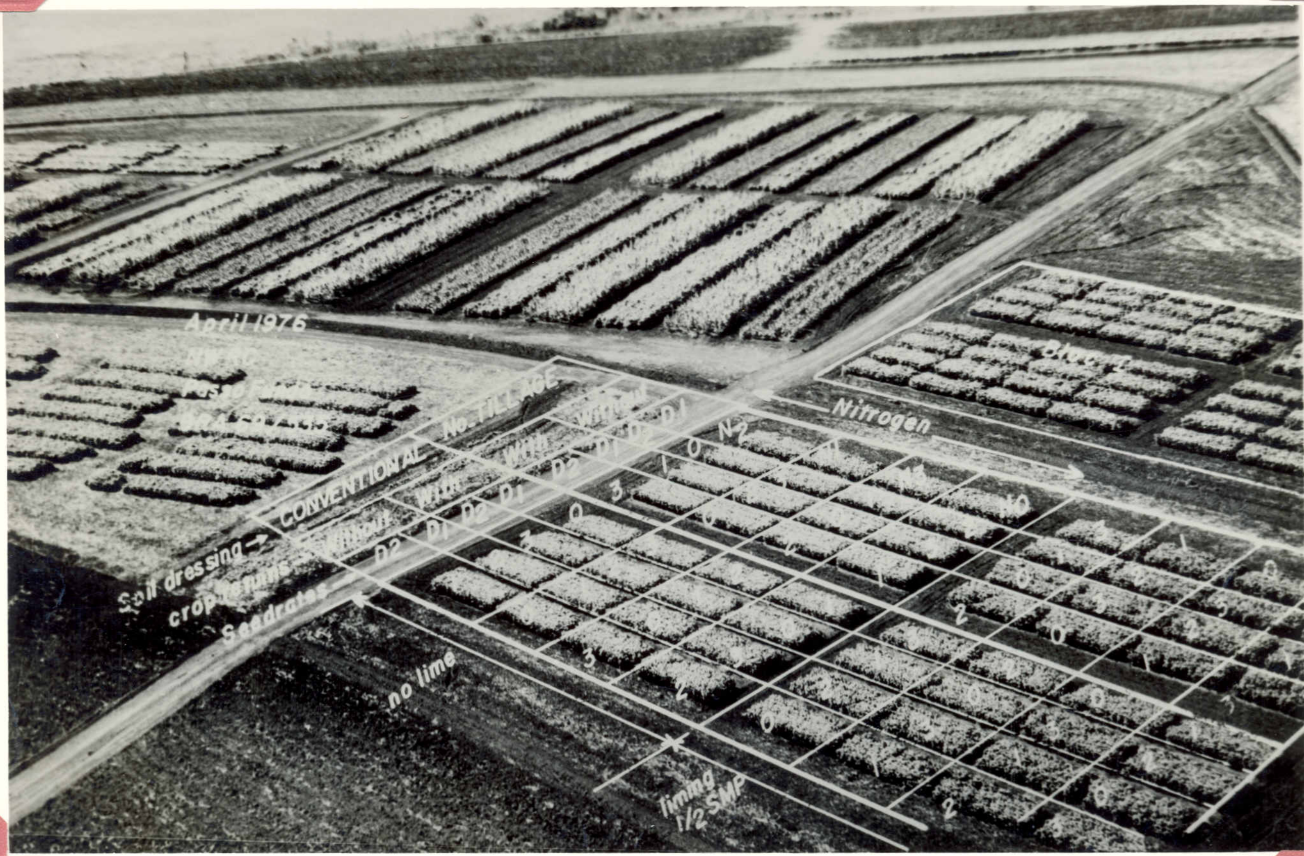

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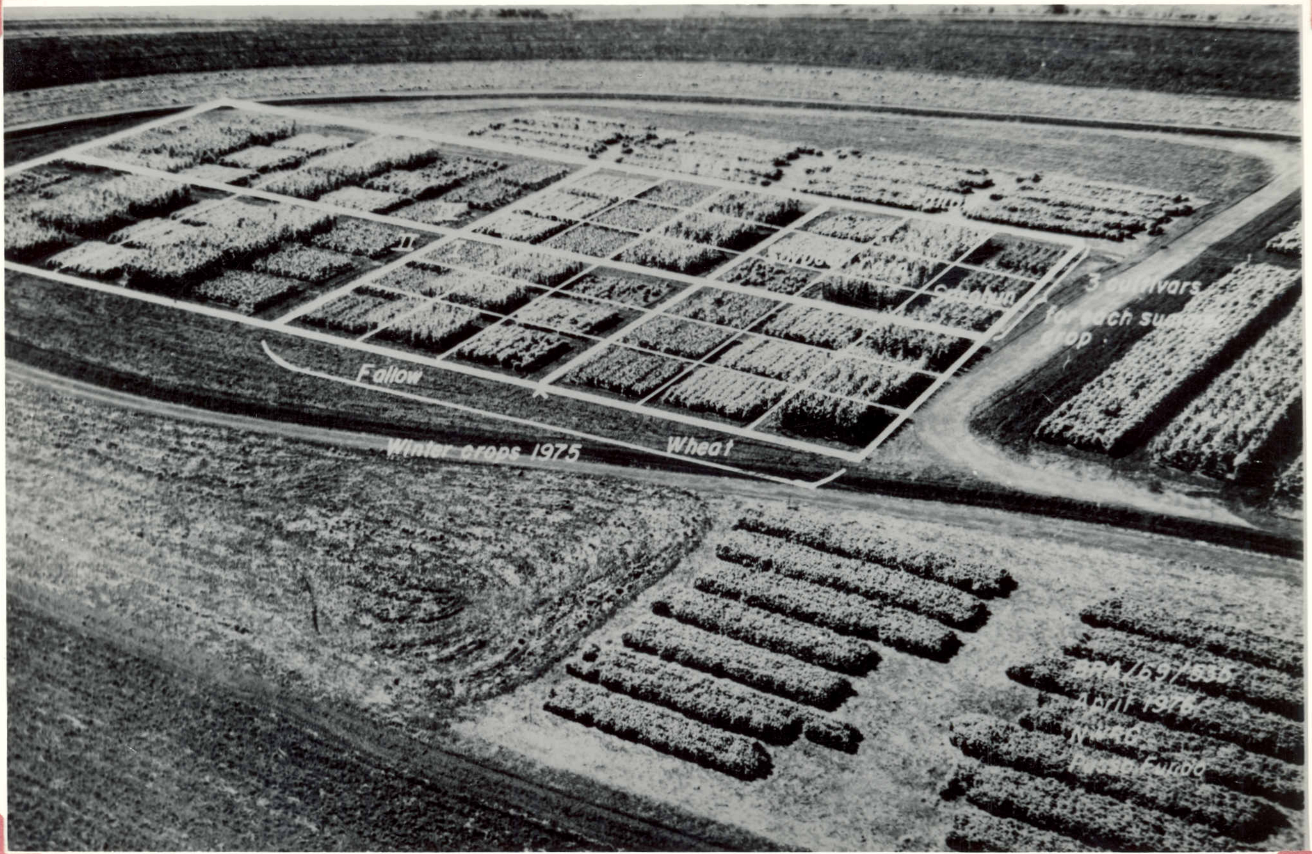

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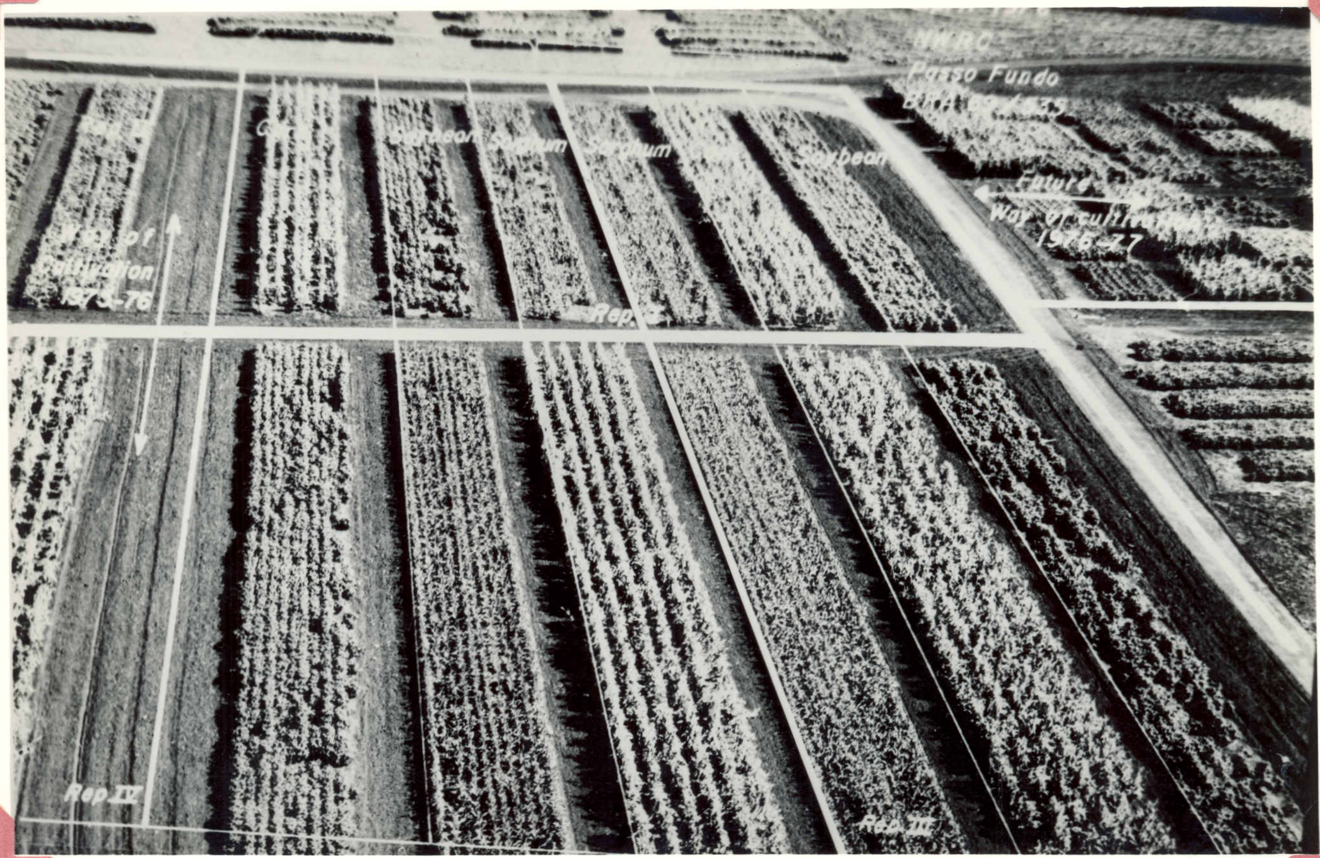

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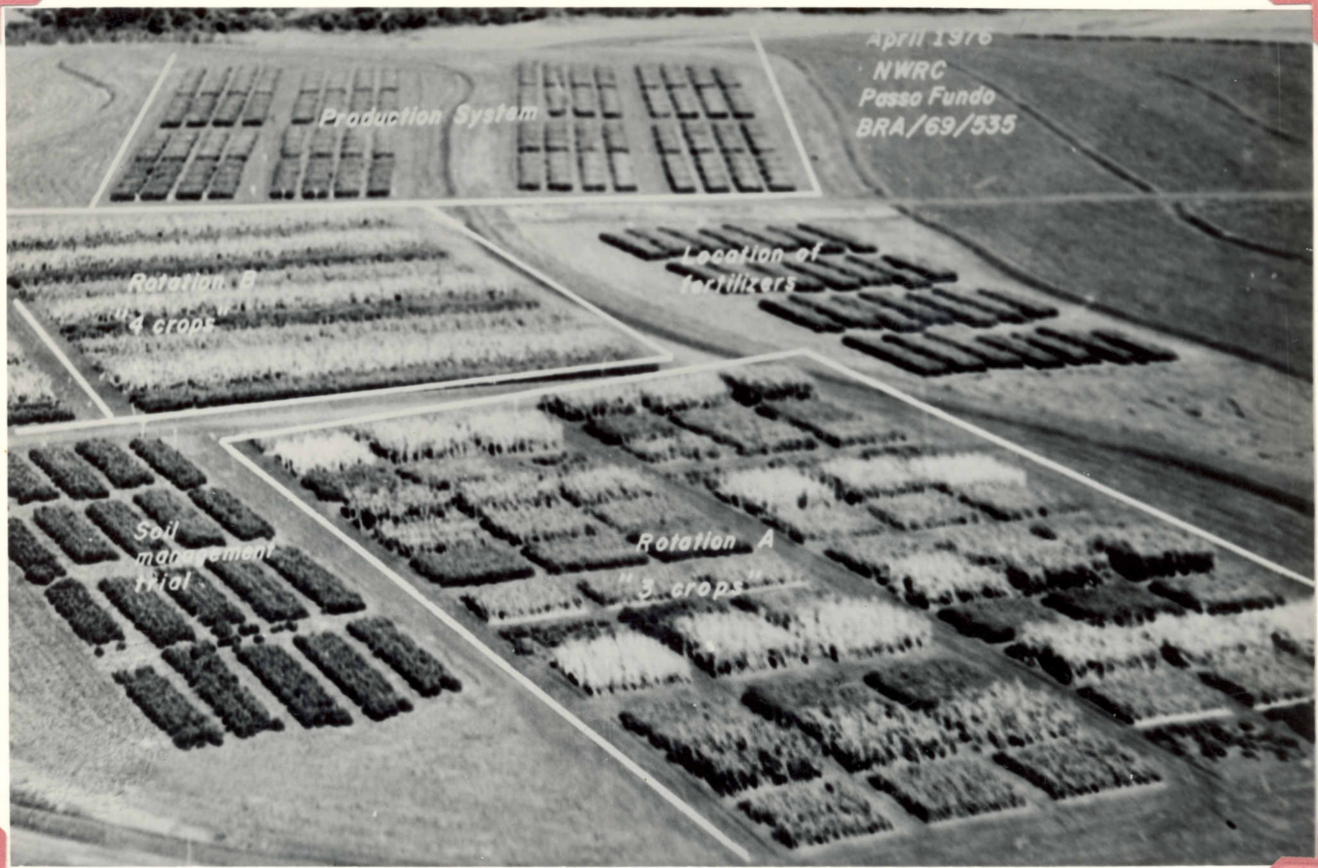

5. Aerial photograph of the experimental complex, April 1976.