Research for Maximum Yield in Harmony with Nature

Satellite Symposium Sponsored by PPI

Transactions

15th World Congress of Soil Science
15 Bodenkundlicher Weltkongress
15ème Congrès Mondial de la Science du Sol
15° Congreso Mundial de la Ciencia del Suelo
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To the readers:

The Transactions of the 15 World Congress of Soil Science consist of 16 books. Volume 1 contains the Inaugural and the State of the Art Conferences. Volumes 2a to 8a contain the papers presented in the Symposia corresponding to Commissions I to VII, respectively. Volumes 2b to 8b contain the Extended Summaries of the papers presented at the poster sessions corresponding to Commissions I to VII, respectively. Volume 9 is a supplement containing papers not included in previous books.

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International Society of Soil Science
ACKNOWLEDGMENT

The Symposium was sponsored by
the Potash & Phosphate Institute
and the Potash & Phosphate Institute of Canada
through the Western Economic Diversification Program.
Maximum yield research (MYR), maximum economic yields (MEY), and best management practices (BMP) are all goals in today's production agriculture. Each term has a very specific meaning and audience, and should be used accordingly. Lack of acceptance of these concepts, usually comes not from the concepts themselves, but rather with the fuzzy definition in some minds of what they are and how they relate.

Maximum yield research generates information that farmers may use in developing BMP systems that are highly efficient and productive, and produce near MEY. High utilization efficiency of production inputs is compatible with environmental goals and is, therefore, in harmony with nature.

The first international symposium on maximum yield research (MYR) was held in New Delhi, India, November 16-18, 1988. This was followed by a second one in Kyoto, Japan, as a Satellite Symposium of the 14th Congress of the International Society of Soil Science, on August 17, 1990. A Third International Symposium on Maximum Yield Research (T1SMYR) was held on September 6-8, 1992 in Beijing, China. This latter symposium was sponsored by the Potash & Phosphate of Canada (PPIC), Ministry of Agriculture of China (MOA), and the Chinese Academy of Agricultural Sciences (CAAS). Each of the above were highly successful events. It is the hope of those of us associated with this present symposium, "Maximum Yield Research in Harmony with Nature", that it too will be as successful as its predecessors.

Deep appreciation is expressed to our Mexican and international friends who have made this symposium possible.

Albert E. (Al) Ludwick
Western Director & Mexico
Potash & Phosphate Institute

Juan Velázquez-Mendoza
Nutrición Vegetal, Edafología
Colegio de Postgraduados
Research for Maximum Yield in Harmony with Nature

Convener: Albert E. Ludwick
Co-convener: Juan Velázquez Mendoza

Welcome Address. Juan Velázquez Mendoza.  
Maximum Yield Research. Albert E. Ludwick.  
Producing Maximum Economic Yield. E. Malavolta, J. Peres Romero, and T Yamada  
Cotton Yield Increases through Advancements in the United States. A. H. McCarty, and W. R. Thompson  
WELCOME ADDRESS

I wish to express my appreciation to the Potash & Phosphate Institute and the Western Economic Diversification program of Canada for accepting to co-ordinate the symposium on *RESEARCH FOR OPTIMUM ECONOMIC YIELD IN HARMONY WITH NATURE*, at this satellite symposium of the 15th. International Congress of Soil Science. I would also like to thank all the participants who made this symposium possible.

Initial findings of agriculture were about ten thousand years ago and soon after human beings learned that the continuous use of the land causes it to decrease in crop production ultimately it had to be abandoned and a new settlement started on new land. Time passed and man learned that by restoring nutrients and organic matter to the soil it was possible to maintain crop yields to some extent and there was no need to leave the land. Today this paradigm needs to consider not only those two factors - nutrients and organic matter - to maintain soil productivity and to continue biomass production at highly efficient rates, but also the environment as a whole.

This symposium is concerned with the techniques of management over crop production, adjusting the level and type of energy input into perennial and annual crops incorporating current knowledge. It is thought that the papers presented will contain valuable information for optimum economic yield in harmony with nature.

Juan Velázquez-Mendoza
Maximum Yield Research: Friend of the Environment

Albert E. Ludwick. Western Director & Mexico, Potash & Phosphate Institute, Mill Valley, California, USA

Abstract. Higher yields are necessary to feed a growing world population. Dr. Norman Borlaug, Nobel Peace Prize recipient, observes, "The only way for agriculture to produce sufficient food to keep pace with population and to alleviate the hunger of the world's poor is to increase the intensity of agricultural production in those ecological conditions which lend themselves to intensification while decreasing the intensity of production in the more fragile ecologies."

Maximum yield research (MYR) is the study of one or more variables and their interactions in a multidisciplinary system that strives for the highest yield possible for the soil and climate of the research site. The purpose is to gather information spanning the entire yield curve under optimal production conditions so that input efficiencies may be better understood and production opportunities defined. This information is essential for developing farm plans embracing systems of best management practices (BMPs) which in turn lead to the production of maximum economic yields (MEY).

If the resultant BMPs produced through a MYR program do not benefit the environment or at least safeguard it then it is not a BMP system. Examples of how intensified crop production systems improve plant nutrition, increase nutrient use efficiency, increase water use efficiency, and build soil organic matter are discussed. Benefits to the environment include protection of surface and ground waters and control of soil erosion.

Introduction. Question: Why maximum yield research (MYR)? Answer: To gather information to feed a growing world population.

The above response may seem simplistic, but it is fact none-the-less. Yet many continue to question the merits of MYR as if there were viable alternatives to feed our world.

Dr. Norman E. Borlaug was awarded the Nobel Peace Prize for his work in plant breeding and improvement; he is considered a leader of the "Green Revolution" which brought tremendous increases in wheat and rice yields in Asia beginning in the 1960s. He is presently Senior Consultant, International Maize and Wheat Improvement Center (CIMMYT), and President of the Saskawa Africa Association (SAA). Dr. Borlaug and Dr. Christopher R. Dowswell, Director for Program Coordination of SAA, presented the keynote address at the 61st Annual Conference, International Fertilizer Industry Association (IFA), May 1993, in New Orleans, LA, US. The authors observed (4):

"The only way for agriculture to produce sufficient food to keep pace with population and to alleviate the hunger of the world's poor is to increase the intensity of agricultural..."
production in those ecological conditions which lend themselves to intensification while decreasing the intensity of production in the more fragile ecologies.

Most of the yield increase in food production needed over the next several generations must be achieved through yield increases on land now under cultivation. Moreover, these yield increases must be achieved through the application of technology already available or well advanced in the research pipeline. This will not only lead to economic development but it will also do much to solve the serious environmental problems that come as a consequence of trying to cultivate lands that are not suited for crop production. Fortunately, many of the more-favored agricultural lands currently under cultivation are still producing food at yield levels far below their potential.

Cassman (5) points out that world population is expected to double in the next 45 to 50 years. Also, there is little potential arable land to bring into production except for the acid-infertile grazing lands and rain forests of the tropics. Therefore, food production must be doubled in the next 50 years with much of the added production coming from the intensification of existing crop land to produce greater yields per unit of land area:

"The need to double global food output without a large increase in land under cultivation presents a formidable challenge. To achieve this goal, nutrient inputs to and outputs from existing farm land must increase accordingly because crop nutrient requirements are quite rigid. A two-fold yield increase will remove two-fold more nutrients at harvest."

Cassman continues, "The greatest challenge, however, is to understand how soil fertility management affects soil quality, and to apply this knowledge to integrate all aspects of crop management to optimize yield and input utilization efficiency over the long term. Soil fertility management governs plant nutrition, which in turn influences susceptibility to disease, plant growth, and yield."

Substantial progress has been made over the past several decades in improving our crop production systems as reflected in increased yields. Research has provided farmers with the necessary tools to keep pace with demand and to even improve per capita food availability (5, 16). For example, world food production doubled from 1963 to 1988 while population increased about 60 percent, from 3.2 to 5.1 billion (3). However, cereal grain production slowed during the 1980's and the actual per capita consumption was less in 1990 than in 1980.

**Maximum Yield Research (MYR) in Perspective.** Maximum yield research is the study of one or more variables and their interactions in a multidisciplinary system that strives for the highest yield possible for the soil and climate of the research site. It is an approach to research that attempts to take into account the overall production system. The purpose is to gather information spanning the entire yield curve under optimal production conditions so that input efficiencies may be better understood and production opportunities defined.
This information is essential to create meaningful farm plans embracing best management practices (BMPs).

Maximum yield research does not and should not imply that farmers should attempt to produce maximum yields. It is widely recognized that maximum yields are not the most efficient level of production and are not, therefore, in harmony with nature. Maximum yield research is for researchers and maximum economic yield (MEY) is for farmers. They are very different concepts, but they are too frequently confused and the terms improperly used interchangeably. The MEY is that yield level where net profit is maximized in response to both appropriate inputs and management.

Maximum economic yields are achieved through the lowering of unit costs of production as yields are increased. Crops are sold and profits (and losses) are calculated on the basis of production units (e.g., $/ton, $/kg, etc.), not on the basis of land area used for production. It should be noted, however, that the lowest unit cost of production is not necessarily at the point of highest net return (net profit), but the two values do occur in close proximity. Murphy and Dibb explore MYR and MEY in further detail (8).

Maximum yield research benefits the environment through the development of more efficient and intensified cropping systems. The goal of such research is not just higher yields, but higher yields through improved input efficiencies and precision crop management. In this way inputs are not wasted through careless or inappropriate use, but they are utilized to their maximum. Maximized utilization by crops result in minimized amounts left in the environment following harvest. This is economically advantageous to farmers and environmentally desirable for us all. Potential benefits of MYR include improved plant nutrition, increased water use efficiency, increased nutrient use efficiency and higher soil organic matter content. Such benefits translate into ground water protection, erosion control and improved nutrient supplying power of the soil. Specific examples are given later in this paper under the section entitled "Environmental Benefits of BMP Systems".

Sustainable Agriculture. In recent years there has been much said and written about sustainable agriculture. Concerns over the environment have led to suggestions by some that agriculture is too dependent on chemical inputs. Low input sustainable agriculture (LISA) became the focus of many environmentalists. Frequently the arguments were based on emotion rather than scientific evidence. Sustainability and environmental issues continue to be of concern and rightly so. However, LISA has lost much of its following simply because a growing world population can not be fed on a diminishing food supply. Dr. Robert Fox, the eminent soil scientist from the University of Hawaii tells the old Turkish story about Nazri Din Hodjia, a famous teacher (15). In the story Nazri experiments with feeding a donkey less each day, expecting that ultimately the animal would not require any food at all. The experiment went very well in the initial few days, but unfortunately the donkey eventually died. Dr. Fox asks, "Do we need to continually repeat the Nazri Din Hodjia donkey experiment? We are dealing with matters far more important than donkeys." In the long run sustainability will be judged by performance,
that is, what systems get the job done. This will undoubtedly mean more, not less, fertilizer and other inputs. The research focus will be on intensification of the farming system and increasing efficiency.

Sustainable innovations in crop management are a continuously evolving process. They are an integral part of conventional agriculture and contribute to greater yield potential. A few examples follow (12):

- Conservation tillage -- Various types of reduced tillage systems have been in place for many years and are expanding in usage. New systems and equipment continue to be evaluated. Motivation has been the concern over soil erosion and the potential contamination of surface water supplies.

- Crop rotations -- The Morrow Plots at the University of Illinois have been demonstrating the value of rotating crops since their establishment in 1876. Control of crop pests is improved, usually with the use of less protectants.

- Soil and tissue testing/fertilizer application systems -- Adjusting rates of fertilizer based on soil and tissue testing and changing methods of application based on environmental conditions enhance the efficiency of utilization and lower unit costs.

- Computerized records and applications -- Innovations in computer equipment and software allow for sophisticated analysis of fields, including variation within fields, of physical characteristics, yield responses, management problems, etc. Rates of application can be changed "on the go" for very site specific management.

- Varietal/hybrid improvements -- Estimates are that 30-50% of increased yields over the past 50 years are due to plant improvements. Improvements have been made in insect and disease resistance leading to less pesticide use, as well as improvements in root development, water use efficiency and physiological activity.

- Integrated pest management (IPM) and integrated crop management (ICM) -- The systems approach is developing complete management programs (BMPs) to make best use of available farm resources, and to work toward the goal of maximum profitability and minimum environmental impact.

Environmental Benefits of BMP Systems. If benefits or at least environmental safeguards are not part of a production system, then it is not a BMP system.

*Organic Matter*

Intensive crop production does not necessarily mean that soil organic matter levels are destined to dramatically decline. Soil and residue management are important factors in determining long-term soil organic matter trends and crop productivity.
The Morrow Plots at the University of Illinois, the oldest crop management experiment in the United States and Canada, continue to provide information on the long-term benefits of crop rotation and sound fertilizer management as part of a BMP system for maintaining productivity and profitability of crop production (Figure 1).

**Figure 1.** Organic matter content of various treatments in the Morrow Plots as affected by fertilizer since 1955 (13).

Reetz et al. (13) have summarized data over a 113 year period illustrating that improved fertilization and the resultant higher yields improve organic matter content and reverse its decline. They conclude:

- Without soil fertility treatments, crop production reduces soil productivity.
- Crop rotations without addition of fertilizers help maintain soil organic carbon and N levels, but do not maintain high productivity.
- Treatments of manure, lime, N, P, and K are necessary to maintain nutrient levels and soil productivity.
- When nutrients have been depleted, addition of adequate fertilizers can reverse the trend of soil organic matter depletion.
- A combination of crop rotation and fertilization supports the highest corn yields. Fertilizer addition does not completely offset the effect of crop rotation.
- Crop rotation plus fertilization produce the highest crop yields and maintain the highest soil N and organic matter levels.
Erosion Potential

The intensification of crop management systems can result in higher yields and improved protection of the soil when proper BMPs are use. Reducing tillage and maintaining a residue cover increased water storage and reduced erosion potential by 70 percent or more in studies by Peterson et al. (9) in the low rainfall area of the Central Great Plains of the US. Yields and profits were increased with a more intensive management system which increased surface crop residues from around one ton/ha to more than 5 ton/ha.

Reduced tillage and cover crop systems are being developed across the Cotton Belt in the US. Research trials have shown that cotton can be grown in reduced and even no-till systems and produce equal or higher yields than in conventional (clean tilled) systems (Table 1). Systems are highly varied due to the diversity of soils, weather, pest problems, and farmers across the area and the need to be site specific.

<table>
<thead>
<tr>
<th>Location</th>
<th>Years evaluated</th>
<th>Avg. lint yield kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louisiana -Sharkley clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>4</td>
<td>1,282</td>
</tr>
<tr>
<td>No-till (no cover crops)</td>
<td>4</td>
<td>1,338</td>
</tr>
<tr>
<td>Ridge-till (wheat cover)</td>
<td>4</td>
<td>1,333</td>
</tr>
<tr>
<td>Tennessee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>10</td>
<td>1,001</td>
</tr>
<tr>
<td>No-till (no cover crops)</td>
<td>10</td>
<td>1,019</td>
</tr>
<tr>
<td>Conventional</td>
<td>12</td>
<td>949</td>
</tr>
<tr>
<td>No-till (wheat cover)</td>
<td>12</td>
<td>971</td>
</tr>
<tr>
<td>Texas High Plains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>7</td>
<td>766</td>
</tr>
<tr>
<td>No-till (wheat cover)</td>
<td>7</td>
<td>820</td>
</tr>
</tbody>
</table>

Quicker plant establishment and canopy cover and more extensive rooting systems associated with higher yields are also credited with better soil erosion protection.

Dr. A. L. Black, USDA-ARS, Mandan, North Dakota, notes the relation of P nutrition with residue management (11): "Long-term studies in North Dakota have shown beneficial effects of adequate available P from one-time high rate broadcast applications of P fertilizer to grain and residue yield. The key to soil resource conservation from the
hazards of wind and water erosion is crop residue production and maintenance on the soil surface during fallow or idle periods between crops."

Watershed studies involving tillage systems with natural rainfall were summarized by Fawcett (6). Mulch-till systems reduced soil erosion by 68 percent and no-till reduced it by 93 percent compared with moldboard plow systems. Pesticide movement off site was reduced by 70 percent using mulch-till and no-till comparing 38 treatment-site-years of data. Crop residue management continues to grow in popularity with US farmers. In 1992 mulch-till and no-till was practiced on 34.6 million hectares or 30 percent of the annually planted farmland, a 24 percent increase over 1989.

Water use Efficiency (WUE)

Intensified crop management and higher yields can substantially increase water use efficiency (WUE) in both dryland and irrigated conditions. Peterson (9) increased WUE from 60 to 100 percent by switching from a wheat-fallow system to wheat-corn-fallow and wheat-corn-millet-fallow systems. The higher crop residues in the latter systems contributed to WUE rising from about 30 kg grain/ha/cm of water to about 62 kg grain/ha/cm.

Irrigation is an important tool in BMP systems in arid and semi-arid regions. An advantage over rain-fed systems is that yield goals may be selected with greater confidence because soil moisture is controlled rather than left to nature. Higher yielding crops utilize more total water such as in the following example from Arizona (Table 2). However, WUE is substantially increased. Water lost by evapotranspiration in this experiment was replaced for each treatment when available profile moisture reached 70 percent depletion (14).

Table 2. Higher wheat yields increase water use efficiency.

<table>
<thead>
<tr>
<th>Fertilizer N kg/ha</th>
<th>Grain yield kg/ha</th>
<th>Water applied cm</th>
<th>Water use efficiency kg/ha/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3,820</td>
<td>59.5</td>
<td>64.2</td>
</tr>
<tr>
<td>84</td>
<td>6,500</td>
<td>68.0</td>
<td>95.6</td>
</tr>
<tr>
<td>168</td>
<td>8,080</td>
<td>74.3</td>
<td>108.7</td>
</tr>
<tr>
<td>252</td>
<td>8,560</td>
<td>78.2</td>
<td>109.5</td>
</tr>
<tr>
<td>336</td>
<td>7,930</td>
<td>79.8</td>
<td>99.4</td>
</tr>
</tbody>
</table>

Arizona

Nitrate Accumulation

Efficient uptake of nitrogen by crops has been an important consideration in fertilizer management for many years. It is important from both the standpoints of production economics and the environment. Maximizing nitrogen uptake by crops minimizes the
opportunity of residual nitrate migrating into water sources where it could potentially be a hazard to humans or animals.

There are a number of management techniques available that promote greater N use efficiency. These should be part of a system of BMPs that integrates N management with other management aspects to lower unit cost of production to the point of highest net return for the existing soil and climatic conditions. Nitrogen management techniques may include (11):

- Split or multiple applications
- Delayed applications
- Cover crops to take up residual N
- Accurate and efficient application and placement
- Field trials to correlate yield response at BMP levels
- Soil sampling to credit residual N
- Tissue sampling and correlation with yield
- Nitrification inhibitors
- Nitrogen form applied and timing of each form
- Credit for any N from legumes and manures

Many of the above items are "tried and true" practices proven over numerous years of research and farmer experience. Perhaps less appreciated are how other practices not directly related to N fertilizer itself can impact on its efficiency. Balanced fertilization which contributes to more yield than when N is applied alone is one example, as seen in Table 3 (10). Applying appropriate rates of NPK resulted in substantially more yield and no net nitrate addition to the soil profile; both N and P efficiencies were substantially improved. Where P or K was deficient, there was a net residual N in the profile.

Table 3. Balancing nutrients benefits corn yield and nutrient efficiency.

<table>
<thead>
<tr>
<th>Fertilizer rate</th>
<th>Grain yield</th>
<th>Efficiency</th>
<th>Unused N¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>kg/ha</td>
<td>P₂O₅</td>
<td>K₂O</td>
</tr>
<tr>
<td>0</td>
<td>67</td>
<td>101</td>
<td>2.57</td>
</tr>
<tr>
<td>202</td>
<td>67</td>
<td>0</td>
<td>6.02</td>
</tr>
<tr>
<td>202</td>
<td>0</td>
<td>101</td>
<td>6.96</td>
</tr>
<tr>
<td>202</td>
<td>67</td>
<td>101</td>
<td>8.97</td>
</tr>
</tbody>
</table>

¹Unused N is the amount of applied N not accounted for in the above ground portion of the crop, based on N uptake of 2.3 kg/100 kg of grain.
Dr. Ardell Halvorson, USDA-ARS, Akron, Colorado, confirms the importance of nutrient balance (11): "Adequate levels of soil P and /or K are needed to optimize the use of available N supplies by both dryland and irrigated crops. Therefore, maintaining adequate levels of available P or K will improve N use-efficiency by the growing crop and reduce the potential of NO$_3$-N loss by leaching, assuming good irrigation and N fertilization management practices are used."

Nitrogen efficiency is also affected by management decisions or inputs not directly involving fertilizer materials. Variety selection, plant population, planting date, irrigation timing, pest control, and others have an important impact. In fact, anything that affects ultimate yield will affect N use efficiency. Response to N fertilization was more than doubled in a California study (Table 4) when the plant population was increased to above 60,000 plants per hectare (1). It can be assumed that the additional yield removed more N, thereby leaving less in the environment following harvest. Unfortunately, residual N was not evaluated in this study.

Table 4. Plant population, a "low cost" input, influences irrigated corn yield and fertilizer use efficiency.

<table>
<thead>
<tr>
<th>Fertilizer N kg/ha</th>
<th>Population, plants/ha</th>
<th>Grain yield, t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>44,500</td>
<td>10.5</td>
</tr>
<tr>
<td>200</td>
<td>64,259</td>
<td>12.9</td>
</tr>
<tr>
<td>84,000</td>
<td></td>
<td>15.7</td>
</tr>
</tbody>
</table>

**Sacramento Valley, California**

A problem with at least some past soil fertility research is lack of detailed observations of all important parameters affecting yield and environment. Many trials involved gathering yield data and little else. The attitude among policy makers in the US during the 1960's, 70's and early 80's was that food production was ample (even excessive) and therefore, research dollars should be spent elsewhere. The result was a lack of resources to thoroughly evaluate evolving production systems. Fortunately, the recent emphasis on MYR and on developing BMPs is resulting in much more in-depth studies of the entire production system, including long-range implications relative to environment and production sustainability.

The data in Table 4 also indicates that not all MYR innovations are exclusively for the wealthy, developed farmer. Many inputs add little or nothing to the cost of production. Timeliness of operations such as planting date, irrigation frequency, and scheduling of
various field operations are "no cost inputs". Others, such as improved variety, splitting N applications, and increased plant population are "low cost" inputs in that they contribute little additional cost over the present system. These and other practices can be utilized by farmers of any economic or technological level to increase yield and production efficiency.

**Summary.** The growing world population demands that maximum yield research (MYR) continue and, in fact, that it accelerate. Dr. Norman Borlaug, recipient of the Nobel Peace Prize, points out the importance of increasing the intensity of agricultural production in those situations ecologically suitable so that we may keep pace with the growing population and so that we may also decrease the intensity of production on more fragile lands. The goal of MYR is development of best management practices (BMPs) with which farmers can produce maximum economic yields (MEY).

Maximum yield research is a friend of the environment and is, therefore, in harmony with nature. Through it are produced:
- Higher yields
- Improved input use efficiency
- Lowered production costs per unit
- Higher net profit
- Environmental protection

There is much yet to learn. Beaton et al. (2) point out the areas in plant nutrition needing continued research focus include ammonium nutrition, cultivar/hybrid nutrient interactions, nutrition of magnesium, sulphur and chloride, critical nutrient concentrations at early growth stages of plant development, and a better understanding of plant nutrient uptake throughout the growth cycle. Other items could be justifiably added to the list. The research challenge is greatly magnified when it comes to integrating this information into specific cropping systems.

**Literature Cited.**


(6) Conservation Technology Information Center (CTIC). Undated. Crop residue management...Gaining ground in the '90s. Pamphlet. Conservation Technology Information Center, West Lafayette, IN.


(11) Potash & Phosphate Institute (PPI), Undated b. Nitrogen management and the environment. Pamphlet (Reference #93009), Potash & Phosphate Institute, Norcross, GA.


Producing Maximum Economic Yields of Coffee in Brazil

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Introduction

Yield formation is the result of the action and interaction, both positive and negative, of several factors, that is

The subject of MEY as related to coffee was recently dealt with in detail by MALAVOLTA (1993, p. 136-159). In this paper, however, only the role of fertilizers and amendments will be discussed. Thus, the general equation will become:

$$y = f(S)$$

wherein

- **S** = soil physical and chemical characteristics, fertilizer amendments for acidity
- **Pl** = plant variety, spacing, pruning
- **Cl** = climate conditions rainfall, temperature, light
- **Cp** = cultural practices weed control erosion control, subsoiling
- **Pd** = pests and diseases
- **M** = man decision making and operations harvesting and processing book keeping and sale obtention of the Maximum Economic Yield (MEY)
In other words, all the other factors will be considered as constant and non-limiting. The justification for this reasoning is as follows.

Low average coffee yields in Brazil are chiefly due to three causes: the number of trees per hectare is still low, although the traditional 1,000 plants/ha are the exception; pruning to renew the vegetation which will produce fruit in the next season is not a well known practice to most growers; fertilization and lime and gypsum use (to correct surface and subsurface acidity) are inadequate in several aspects such as rates, timing and placement of application.

Continuous high yields, however, can be obtained when fertilization is adequate and the remaining factors are not neglected. This will be demonstrated in this paper with several case studies under different ecological conditions. All of them have in common the utilization of an approach to the practice of fertilization which is more comprehensive than the traditional programs used in the country and elsewhere (see MALAVOLTA, 1981, p. 138-194; HARDING et al., p. 499-519).

By taking into account three variables, namely, potential yield, soil and leaf analysis, the concept allows for a more precise adjustment of the rates of fertilizer to be used. This way excessive, often non economical rates, are not applied and less nitrogen and potash are leached and less phosphorus is subject to runoff. On the other hand, the raise in production per unit area reduces the need of expanding the acreage planted to coffee and thereby increasing the proportion of land available for growing food, fiber and renewable energy.

Material and Methods

- **The module of fertilization**

  The main points involved in the use of the concept of modules of fertilization are the following:

  (1) one module is defined as the quantity of nutrients needed for the vegetation and production equivalent to 10 (ten) bags of 60 (sixty) kg of clean coffee per ha, roughly the average Brazilian yield;

  (2) rates are given in kg/ha rather than g/tree;

  (3) doses obey a lower and an upper limit;

  (4) before planting surface and subsurface acidity should be corrected and when available P and K are too low, the level should be raised;

  (5) total rates of N and K\textsubscript{2}O are split into 3-4 application; P\textsubscript{2}O\textsubscript{5} may be split when convenient;

  (6) total rates are calculated in function of soil analysis and projected yield;

  (7) the first and second application (in case of more accumulated experience, only the first one) are fixed, whereas the remaining, when made at all, are variable, depending upon the results of leaf analysis and another evaluation of the yield potential which would determine adjustments in either direction in the balance of the dosage.

  Figure 1 shows an outline of the procedure.
In order to begin the procedure, the rates to be applied were established by combining the literature with personal experience (MALAVOLTA, 1981, p. 138-194). During several years field trials with various doses were carried out and the results thereof were used to make adjustments.

- **Soil analysis**

The following criteria were set up for sampling:

1. time - either before harvesting or prior the operation of collecting fallen leaves, dirt and other residues in rows between the trees;
2. place - in the dripline or middle of the fertilization band;
3. depth - yearly at 0-20 cm; every other year both at 0-20 and 21-40 cm; deeper sampling also made in between the tree rows;
4. number - in uniform areas of up to 50 ha, 10 subsamples make a composite sample.

Soil from high yielding plantations (average 4-year production from 30 to 50 bags per ha) was analysed to provide standards for comparison.

Lime requirement (L.R.) is calculated with the equation:
\[ L.R. = \frac{T (V_2 - V_1)}{RPTN} \cdot p \]

in which

- \( L.R. \) = lime requirement in tons per hectare
- \( T \) = meq/100 cm\(^3\) of exchangeable \( H + Al + K + Ca + Mg \)
- \( V_1 \) = \( S/T \cdot 100 \) (\( S = \) meq/100 cm\(^3\) of \( K + Ca + Mg \))
- \( V_2 = 60\% \)
- \( RPTN = \) Relative Power of Total Neutralization of the limestone to be used, average = 75\%
- \( p = \) factor for depth of incorporation of the limestone = 1 for 0-20 cm, 0.5 for 0-10 cm.

Phosphogypsum is recommended when Ca\% of the effective cation exchange capacity is below 40 and aluminum saturation is above 20\%, both at the 21-40 cm layer. For each one meq of Ca to be raised or of Al to be "lowered" 2.5 tons of phosphogypsum per ha should be applied. Maximum rates per year: 2.5 tons on clayey soils and 1.5 on sandy soils.

**Leaf analysis**

Sampling with the purpose of assessing the need of making adjustments in the program of fertilization is made usually 4-6 weeks after the first application of fertilizers. The berries have reached one fourth to one third final size. The third or fourth (or both) pairs of leaves are collected from fruit bearing branches located at middle height of the canopy. Eight pairs of leaves are taken per tree, each quadrant supplying two. Ten trees are sampled in uniform areas having from less than one up to 50 hectares.

The change in leaf composition throughout the year was ascertained by sampling eleven high yield plantations, during 4 successive years; this allows for adjustments to be made in the fertilizer program in other periods of the year.

**Plantations**

All the plantations which supplied data and information to be discussed next are located in the State of Minas Gerais which is the leading producer of coffee in Brazil. The original soil and vegetation were typical of the "cerrado" ecosystem. Total area covered by "cerrados" amounts to 2.0 million square km (see Figure 2), nearly one fourth of the total area of Brazil. Oxisols are the prevailing soil type. They are usually very deep, topography is flat or gently rolling, physical conditions are adequate for most crops. Rainfed agriculture is the rule. The soil is very acid, low in bases and phosphorus (for details see LOPES, 1983). Nutritional disorders (deficiencies of most elements, toxicity of aluminum and manganese) are common as described in detail by MALAVOLTA & KLIEMANN (1985). Thanks, however, to the application of lime, phosphogypsum and mineral fertilizers (particularly phosphatic) the cerrado area in the Brazilian Central Plateau has become in the past quarter of century a great producer of grains, meat, coffee and other products. Its potential for food production was recently pointed out by BORLAUG & DOWSWELL (1993).

**MEY Project**

Several leading coffee producers in the States of São Paulo and Minas Gerais have recently committed themselves to the "MEY Project", "Projeto CEM", in Portuguese. "CEM" stands for...
"Colheitas Econômicas Máximas" (Maximum Economic Yields), and not coincidentally, means also 100, as one hundred per cent, for instance. The sigla was coined 10 years ago (see MALAVOLTA, 1990). The chief points of the "MEY Project" are the following:

1. Improvement of soil physical and chemical characteristics through liming, phosphogypsum application, erosion control, contour planting, broadcast applications of P₂O₅ and K₂O before establishment;
2. High density planting (up to 24,000 trees per ha);
3. Fertilization by modules;
4. Minimum use of pesticides and weed killers, (both as consequence of good fertilization and high density planting);
5. Possibility of obtaining 200 bags of coffee in the first three harvests;
6. Replacement of the entire plantation by a new one after 5 years, or reduction of the density by cutting part of the trees in given time intervals; this would allow for mechanization if the land is level.

Figure 2. The distribution of the "cerrado" ecosystem in Brazil.
Rates

Table 1 presents the doses of primary macronutrients corresponding to 1 (one) module and which vary according to soil analysis data.

Table 1. Rates of primary macronutrients per module (kg/ha).

<table>
<thead>
<tr>
<th>Application</th>
<th>Organic matter %</th>
<th>N</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 1.5</td>
<td>1.5-4.0</td>
<td>&gt; 4.0</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>1st</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>2nd</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>3rd</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>4th</td>
<td>30</td>
<td>20</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Several points should be mentioned.

(1) the figures for available P refer to the extraction procedure involving the use of anion exchange resin (RAIJ et al., 1986); should Mehlich 1 be the extracting solution, the corresponding levels are, respectively, less than 6, 6 to 12 and higher than 12 (GUIMARÃES, 1987); available K is given as percentage of the cation exchange capacity (CEC) determined at pH 7.0.

(2) a minimum of 1 module is used for yields equal or less than 10 bags/ha and after severe pruning (1.20 m or lower); a maximum of 4 modules are generally applied for yields of up to 60 bags/ha; for production levels still higher not more than 6 modules should be used, and, in these cases 4 applications are required.

(3) the third and fourth application can be modified (sometimes the second, third an fourth) or even cancelled, depending upon the results of leaf analysis and of the new evaluation of the expected yield.

The rates of secondary macronutrients and of the micronutrients B and Zn are shown in Table 2. It should be mentioned:

(1) rates of Ca are not given since this element is always present in the liming material, phosphogypsum and in some phosphatic fertilizers;

(2) although Cu deficiency is rather common, the element is supplied as fungicides used for rust control;

(3) S-SO$_4$ levels are obtained by using acetate-PO$_4$ extractant; B is extracted with 0.05 N HCl and Zn is determined in Mehlich 1;

(4) sprays of 0.3 percent boric acid and 0.6 percent zinc sulfate are used whenever the results of leaf analysis disclose concentrations lower than 50 and 10 ppm, respectively; zinc uptake is increased by adding 0.2% KCl to the solution which may contain also 0.5% urea.
Table 2. Rates of some secondary macronutrients and of micronutrients per module (kg/ha).

<table>
<thead>
<tr>
<th>Application</th>
<th>Mg % CEC</th>
<th>S-SO₄ ppm</th>
<th>B ppm</th>
<th>Zn ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 6</td>
<td>6-12</td>
<td>&gt; 12</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>1st</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>2nd</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>15</td>
</tr>
</tbody>
</table>

The first application is usually made before flowering, late August or early September. This coincides with the beginning of the rainy season which lasts until April or May. Within this period the remaining applications are made with an interval of about 2 months between one and the next.

The fertilizers are applied in the surface of the soil as a band which is as wide as the radius of the canopy. About two thirds of the total should be placed under the canopy and one third outside the dripline (MALAVOLTA et al., 1960; NEPTUNE et al., 1974).

- Soil analysis

The chief chemical characteristics of a soil adequate for coffee production, that is, capable of continuous high yields are summarized in Table 3. Soil physical conditions should also be kept in mind especially depth (no less than 1 m), texture (30-40% clay) and apparent density (1.2-1.4).

Table 3. Characteristics of a soil adequate for coffee growing.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>0-10 cm</th>
<th>0-20 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>P µg/cm³ (resin)</td>
<td>30-40</td>
<td>15-20</td>
</tr>
<tr>
<td>S-SO₄ µg/cm³</td>
<td>10-15</td>
<td>15-20</td>
</tr>
<tr>
<td>K % CEC (pH 7.0)</td>
<td>3.5-4.5</td>
<td>3.5-4.0</td>
</tr>
<tr>
<td>Ca % CEC</td>
<td>45-55</td>
<td>35-45</td>
</tr>
<tr>
<td>Mg % CEC</td>
<td>10-15</td>
<td>10-15</td>
</tr>
<tr>
<td>V % (base saturation)</td>
<td>60-70</td>
<td>50-60</td>
</tr>
<tr>
<td>B ppm</td>
<td>1.0-1.2</td>
<td>0.6-1.0</td>
</tr>
<tr>
<td>Cu ppm</td>
<td>2-3</td>
<td>1.2</td>
</tr>
<tr>
<td>Zn ppm</td>
<td>5-7</td>
<td>4-6</td>
</tr>
</tbody>
</table>

- Leaf analysis

Figures 3 and 4 show the variation in the concentration of macronutrients during the year. The lowest values, except in the case of Ca are found in July when fruits have reached maximum development. Significant correlations between pairs of elements were disclosed only in the cases of N and K (r = 0.9581) and Ca and Mg (r = 0.8862), both positive.
Figure 3. Evolution of the concentration of N, K, and Ca in coffee leaves of high yielding trees (each point average of 44 determinations).

Figure 4. Evolution of the concentration of P, Mg and S in coffee leaves of high yielding trees (each point average of 44 determinations).
The variation in the concentration of micronutrients is given in Table 4.

Table 4. Variation in the leaf concentration of micronutrients during the year (ppm).

<table>
<thead>
<tr>
<th>Element</th>
<th>January</th>
<th>March</th>
<th>May</th>
<th>July</th>
<th>September</th>
<th>November</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>50-90</td>
<td>60-80</td>
<td>50-70</td>
<td>40-70</td>
<td>50-60</td>
<td>50-80</td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td></td>
<td>-10-15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>120-200</td>
<td>110-300</td>
<td>200-400</td>
<td>250-300</td>
<td>250-300</td>
<td>120-250</td>
</tr>
<tr>
<td>Mn</td>
<td>100-150</td>
<td>100-200</td>
<td>110-180</td>
<td>110-250</td>
<td>170-240</td>
<td>70-200</td>
</tr>
<tr>
<td>Mo</td>
<td></td>
<td></td>
<td>0.10-0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>10-20</td>
<td>12-20</td>
<td>10-20</td>
<td>8-12</td>
<td>10-18</td>
<td>10-15</td>
</tr>
</tbody>
</table>

Table 5 shows the modifications which are introduced in the program in function of the leaf analysis.

Table 5. Adjustments in the rates of N, K₂O, B and Zn.

<table>
<thead>
<tr>
<th>Element</th>
<th>Leaf concentration</th>
<th>Adjustment</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>N%</td>
<td>&lt; 2.5</td>
<td>1.5 x rate</td>
<td>3rd &amp; 4th application</td>
</tr>
<tr>
<td></td>
<td>2.5-3.5</td>
<td>1.0 x rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 3.5</td>
<td>0.0 x rate</td>
<td></td>
</tr>
<tr>
<td>K%</td>
<td>&lt; 1.75</td>
<td>1.5 x rate</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td>1.75-2.25</td>
<td>1.0 x rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 2.25</td>
<td>0.0 x rate</td>
<td></td>
</tr>
<tr>
<td>B ppm</td>
<td>≤ 50</td>
<td>2 foliar sprays</td>
<td>October-March</td>
</tr>
<tr>
<td></td>
<td>&gt; 50</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Zn ppm</td>
<td>≤ 10</td>
<td>2 foliar sprays</td>
<td>October-March</td>
</tr>
<tr>
<td></td>
<td>&gt; 10</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

- A leading farm: Rio Verde Farm, Conceição do Rio Verde-MG

A particular plot of 13 hectares planted to the variety Catuafí is representative of the farm. Spacing is 3.80 x 2.00, with two plants per site. Due to the slope no mechanization is done. Pruning is done in 4-6 years interval by cutting the plagiotropic branches 20-30 cm from the trunk. Rust control is minimal probably due to the fact that plants are well fed. Table 6 gives the yields obtained in the past 9 years as well as the 4-year mobile averages. A few points should be mentioned:
the continuous average of 60 bags/ha which showed up starting in the year 1990 corresponds
to 6 times the Brazilian average;

(2) zero production in the years 86 and 92 were due to pruning the year before;

(3) after the exceedingly high yields of more than 100 bags/ha, production next year was drastically
reduced, very likely as a consequence of exhaustion of carbohydrates and mineral reserves in
the tissue, particularly of N and K as discussed by MALAVOLTA et al. (1958) and RENA &
MAESTRI (1986); it is possible that with higher density of planting, average yields even larger
could be obtained because overbearing would be avoided to a large extent; economic returns,
however, could be higher if yields above the 100 bags were obtained every other year being
succeeded by zero yields next season, provided, of course, the same mobile averages were
maintained; this would occur because of the reduction in cost of production represented by the
harvest of just a few bags per ha.

Table 6. Coffee yields, "Catuai da Serra", section, Rio Verde Farm (1) (bags/ha).

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>Four year mobile average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>89</td>
<td>41</td>
</tr>
<tr>
<td>86</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>87</td>
<td>109</td>
<td>50</td>
</tr>
<tr>
<td>88</td>
<td>6</td>
<td>51</td>
</tr>
<tr>
<td>89</td>
<td>116</td>
<td>58</td>
</tr>
<tr>
<td>90</td>
<td>4</td>
<td>59</td>
</tr>
<tr>
<td>91</td>
<td>120</td>
<td>62</td>
</tr>
<tr>
<td>92</td>
<td>0</td>
<td>61</td>
</tr>
<tr>
<td>93</td>
<td>121</td>
<td>61</td>
</tr>
</tbody>
</table>

(1) Data courtesy of Eng. Gustavo Fernandes, owner, Rio Verde Farm.

• MEY Project: Boa Vista Farm

One of MEY projects was set up in the Boa Vista Farm, Patrocinio Country, Minas Gerais, in a
soil previously cultivated with coffee. The variety Catuai Vermelho was planted with the spacing of 1.25
x 0.50 m. Table 7 presents the results of soil analysis before planting and 3 years later. By comparing
tables 3 and 7 it becomes clear that soil conditions at the Boa Vista Farm are adequate indeed in general
terms. The levels of P and B are rather low. Available Mn also seems to be on the low side which is
unusual in the cerrado soils wherein the opposite occurs. MATIELLO & VIEIRA (1992) have found
Mn deficient plantations in soils with 5 ppm of manganese extracted by Mehlich 1. Since in the case of
the Boa Vista Farm the pH is below neutrality and the Ca level is not too high (4.7 meq/100 cm³) it is
possible that the low Mn concentration in the soil is due to low total content. Nevertheless it seems that
Mn deficiency is not a limiting factor in this case judging by the yields which have been obtained. Figure
5 shows yields and economic returns obtained so far. Data for the year 1994 are based on realistic
estimates. The first harvest of 39 bags of clean coffee per ha provided a net return of US$ 536.23; the
second one gave a profit of US$ 6,195.69. Only direct costs were considered. The value of the bag of
coffee was US$ 79.00.
### Table 7. Results of soil chemical analysis, Boa Vista Farm, Patrocinio-MG.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Before planting</th>
<th>3 Years later</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-20 cm</td>
<td>0-20 cm</td>
</tr>
<tr>
<td>pH (CaCl(_2))</td>
<td>5.7</td>
<td>5.8</td>
</tr>
<tr>
<td>Organic matter %</td>
<td>2.7</td>
<td>3.2</td>
</tr>
<tr>
<td>P (resin) µg/cm(^3)</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>S-SO(_4) µg/cm(^3)</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>K% CEC</td>
<td>4.9</td>
<td>4.4</td>
</tr>
<tr>
<td>Ca% CEC</td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>Mg% CEC</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>Al meq/100 cm(^3)</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>CEC meq/100 cm(^3)</td>
<td>9.8</td>
<td>7.5</td>
</tr>
<tr>
<td>S meq/100 cm(^3)</td>
<td>7.6</td>
<td>5.9</td>
</tr>
<tr>
<td>V%</td>
<td>77</td>
<td>78</td>
</tr>
<tr>
<td>B ppm</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Cu ppm</td>
<td>2.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Fe ppm</td>
<td>60</td>
<td>42</td>
</tr>
<tr>
<td>Mn ppm</td>
<td>7.0</td>
<td>10</td>
</tr>
<tr>
<td>Zn ppm</td>
<td>4.3</td>
<td>16</td>
</tr>
</tbody>
</table>

![Figure 5. Results obtained in the MEY Project, Boa Vista Farm, Patrocinio-MG (data courtesy Eng. Ag. Rubens E. de Carvalho).](image)

23
MEY Project: Pero Farm

The Project MEY in the Pero Farm, Ouro Fino-MG, was installed in a very hilly situation. It was necessary to prepare terraces by cutting the slope which exposed the raw subsoil, very poor and acidic. During three years, 1987-89 in order to build up fertility, amendments (calcined limestone, phosphogypsum) and fertilizers (ordinary superphosphate, ulexite, a boron source, and zinc oxide) and K rich, coffee hulls were broadcasted and turned in. Wheat and barley were sown and their residues incorporated to raise the organic matter content and improve soil physical conditions. Wind breaks of *Pinus patula* and *P. taeda* were also planted. Catuaí Vermelho variety was planted in January 1990 at the spacing of 0.8 x 0.8 m. Table 8 shows how the fertility was improved except in the case of B whose level was not affected. Figure 6 shows the expected evolution of yields and the economics of the project. The first harvest, equivalent to 18 bags of clean coffee per ha took place in the year 1991. In 1992, 95 bags were harvested, followed by another very high yield of 99 bags, a clear indication that overbearing was prevented. The estimates for the next three years are a bit optimistic. In the period of no yield in part of which investments were made in soil fertility, land preparation and erosion control, the total accumulated expenditure was US$ 19,281, much more than in the case of the Boa Vista Farm wherein land had been previously occupied by well treated coffee. A net profit of US$ 7,647 per ha will occur in the 1996 cropping year. In the previous case the cost of the first 2 years (1990-1) amounted to US$ 2,482. The net return in 1992 was US$ 536. By 1993 and 1994, after paying for the previously accumulated expenditures, the accumulated net returns would be, respectively, US$ 6,195 and 9,595 considering the entire period of 1990 to 1994.

Table 8. Results of soil chemical analysis, Pero Farm, Ouro Fino-MG.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>1987</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (CaCl₂)</td>
<td>4.2</td>
<td>5.9</td>
</tr>
<tr>
<td>Organic matter %</td>
<td>3.5</td>
<td>3.6</td>
</tr>
<tr>
<td>P (resin) μg/cm³</td>
<td>12</td>
<td>196</td>
</tr>
<tr>
<td>S-SO₄ μg/cm³</td>
<td>-</td>
<td>89</td>
</tr>
<tr>
<td>K% CEC</td>
<td>2.6</td>
<td>3.7</td>
</tr>
<tr>
<td>Ca% CEC</td>
<td>9.0</td>
<td>70.1</td>
</tr>
<tr>
<td>Mg% CEC</td>
<td>5.1</td>
<td>12.6</td>
</tr>
<tr>
<td>Al meq/100 cm³</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>CEC meq/100 cm³</td>
<td>7.7</td>
<td>13.4</td>
</tr>
<tr>
<td>S meq/100 cm³</td>
<td>0.31</td>
<td>11.6</td>
</tr>
<tr>
<td>V%</td>
<td>17</td>
<td>87</td>
</tr>
<tr>
<td>B ppm</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Cu ppm</td>
<td>-</td>
<td>2.4</td>
</tr>
<tr>
<td>Fe ppm</td>
<td>-</td>
<td>60.0</td>
</tr>
<tr>
<td>Mn ppm</td>
<td>-</td>
<td>12.0</td>
</tr>
<tr>
<td>Zn ppm</td>
<td>4.1</td>
<td>12.6</td>
</tr>
</tbody>
</table>
Figure 6. Results obtained in the MEY Project, Pero Farm, Ouro Fino-MG.

- **MEY Project: Ipanema Agroindústria (Alfenas-MG) and Promissão Farm (Cambuquira-MG)**

Figure 7 compares the productivity in two leading coffee plantations with the Brazilian average. In both cases the all known best management practices are used to sustain yields which are 3-4 times the country average. Chief among these practices are pruning and fertilization by module. The large plantation is almost entirely mechanized, including pruning and harvesting. Fluid, home made blends are used which allows for more adequate placement. It is worth considering the soil chemical characteristics existing in the larger farm, Ipanema Agroindústria S.A., Alfenas-MG today in comparison with the original ones. This is shown in Table 9. It is clear that soil chemical conditions were changed. Two of the main components of the original cerrado ecosystem were modified: the primitive vegetation of native grasses and xeromorphic, sparse wood, was replaced by high yielding coffee; the acidic, infertile soil was transformed into a substrate capable of continuous and profitable crop production.
Figure 7. Average yields in two leading after plantations compared to Brazilian productivity.

Table 9. Results of soil chemical analysis, Ipanema Agroindústria S.A., Alfenas-MG.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Before planting</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (CaCl₂)</td>
<td>4.5</td>
<td>5.4-5.9</td>
</tr>
<tr>
<td>Organic matter %</td>
<td>2.3</td>
<td>2.5-3.0</td>
</tr>
<tr>
<td>P (resin) μg/cm³</td>
<td>5</td>
<td>20-30</td>
</tr>
<tr>
<td>S-SO₄ μg/cm³</td>
<td>6</td>
<td>15-20</td>
</tr>
<tr>
<td>K% CEC</td>
<td>1.7</td>
<td>3-5</td>
</tr>
<tr>
<td>Ca% CEC</td>
<td>21</td>
<td>41-50</td>
</tr>
<tr>
<td>Mg% CEC</td>
<td>7</td>
<td>12-18</td>
</tr>
<tr>
<td>Al meq/100 cm³</td>
<td>0.7</td>
<td>0.0-0.3</td>
</tr>
<tr>
<td>CEC meq/100 cm³</td>
<td>7</td>
<td>8-10</td>
</tr>
<tr>
<td>S meq/100 cm³</td>
<td>2.1</td>
<td>4-6</td>
</tr>
<tr>
<td>V%</td>
<td>30</td>
<td>60-70</td>
</tr>
<tr>
<td>B ppm</td>
<td>0.1</td>
<td>0.3-0.6</td>
</tr>
<tr>
<td>Cu ppm</td>
<td>0</td>
<td>1-2</td>
</tr>
<tr>
<td>Fe ppm</td>
<td>30</td>
<td>50-60</td>
</tr>
<tr>
<td>Mn ppm</td>
<td>39</td>
<td>20-30</td>
</tr>
<tr>
<td>Zn ppm</td>
<td>0.6</td>
<td>4-6</td>
</tr>
</tbody>
</table>
Summary

Coffee yields are the result of action and interaction of several factors: the plant itself (variety), soil fertility (physical and chemical characteristics, amendments and fertilizers), climatic conditions (rainfall, temperature, light), cultural practices (density of planting or spacing, weed and erosion control), pests and diseases. Man is the factor responsible for decision making, operations, book keeping, processing and selling of the final product.

Three factors are considered as the main responsible for the low average productivity in Brazil, preventing the full realization of the yield potential of the improved varieties: small number of trees per hectare; lack of pruning and inadequate use of amendments (limestone, phosphogypsum) and mineral fertilizers.

A program of fertilization by modules was developed and put into practice. The rates of fertilizer to be used are based on soil analysis and on the pending or potential yield. The total doses are split into 3-4 applications. The initial application or the first two are fixed and the remaining are adjusted according to the results of leaf analysis and a new yield evaluation. One module is defined as the quantity in kg/ha of N, P₂O₅, K₂O, Mg, S, B and Zn which are required for the production of 10 bags of sixty kg of clean coffee. A minimum of 1 and a maximum of 4 (exceptionally 6) are used.

By applying the concept together with all the best management practices several coffee plantations, varying in size from 150 up to 3,000 hectares have been capable of obtaining coffee yields which are 3-6 times the Brazilian average.

Several leading farms are engaged in the "MEY Project" (Maximum Economic Yields or, in Portuguese, Projeto CEM, Projeto Colheitas Econômicas Máximas) which has several main features: very high planting density (from 15,000 up to 24,000 trees per hectare, which is 6-10 times the traditional); fertilization by modules; goal of 200 bags per ha as the sum of the first three harvests; possibility of renewal of the entire plantation after 5 years or of continuing with or without reduction in the number of trees per ha. Results obtained so far seem to point out to the fact that the production goal is being achieved.

Either in the case of the leading farms or in Project MEY, soil fertility has been increased and, through the adequate nutrition, the need for pesticides has been much lower. On the other hand, the examples of such higher productivity show that more coffee could be obtained in less land which therefore could be put into other uses such as grain, fiber, sugar, milk or meat and renewable energy production.

Literature Cited


MAXIMUM ECONOMIC RICE YIELD IN COSTA RICA

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Introduction. Rice production in Costa Rica is a highly relevant activity due to its social and economical importance. It is socially important because it generates employment and economically so because of its significant contribution to the GNP. It produced 1.54 % of the GNP during the 1991-1992 period. The production of high rice yields is also important as a food supplying activity because rice consumption in Costa Rica is one of the highest in the region, with 45kg/person/year (10).

The rice growing areas of the country are located in ecological zones that allow high yields. The soils of these areas are classified as Inceptisols, Mollisols and Vertisols. Rice yields have been increasing during the last 30 years, form national average yields of 1 t/ha to the present average of 4 t/ha, both in upland and paddy rice. Yields as high as 11 t/ha have been obtained experimentally (10).

The increment of rice productivity in Costa Rica has been associated to the search of maximum economic yield. To reach this goal, rice production was located on the best soils of adequate ecological zones and the management practices were improved. Among the improved management practices are the use of semi-dwarf varieties of high productivity and the use of balanced fertilization.

The objective of this paper is to discuss the relevant research data generated by the studies conducted for fertility diagnosis and improvement of soils cultivated with rice in Costa Rica to obtain maximum economic yield.

Rice production in Costa Rica. Total rice production and rice yield per unit area in Costa Rica have been affected by many different factors. Among the most important are total planted area and productivity. The changes in total planted area are the product of governmental policies, while the changes in rice yield per unit area have been influenced by agronomic research, the main goal of which was to obtain maximum economic yields, while at the same time being careful with the environment. The actual average national rice yield of 4 t/ha, which is apparently low, is very significant because around 70% of it comes from upland rice.

The production trends in Costa Rica though the years is presented in Figure 1. The total harvested rice production in 1960 was 47,394 tons compared with 185,791 tons in 1992. In general, total production increased through the years, but there are years where production is very high as a product of significant increases in planted area. On the other hand, there are also years of low production due to drought or flooding that affected mainly the upland production.
Rice production per unit area, a measure of agronomic efficiency, has increased consistently during the last three decades. In 1960 the national rice yield averaged 1 t/ha and in 1992 it increased to 4 t/ha. The productivity line in Figure 1 is divided in three sections with each representing a period of time. The period from 1960 to 1970 was characterized by the predominance of North American and Surinam varieties which had low nutritional requirements, but also low yield potential.

Starting in 1970, important changes that affected rice production took place. The variety IR8 was introduced in the country and the farmers started utilizing the semi-dwarf varieties selected in Costa Rica (CR varieties). These varieties have high productivity and respond very well to the application of fertilizers, particularly N (6). At the end of the period from 1970 to 1983 the national average rice yield was 3 t/ha.

During 1983 the government developed irrigation infrastructure and implemented polices to promote rice cultivation under this system. In spite of government encouragement of flooded rice production, the total area planted as paddy rice contributes only 30% of the total planted area. The national rice yield average for 1992 was 4 t/ha.

**Climate of the rice growing areas of Costa Rica.** The rice growing areas in Costa Rica, both upland and paddy rice, are located on alluvial land, river estuaries and coastal flat land of the Pacific coast, in 4 main regions: Chorotega, Central Pacific, Brunca and North Huetar.

The Chorotega rice region has well defined wet and dry seasons, with a mean rainfall of 1450 mm. The Central Pacific region is characterized by a wet climate with a monsoon influence. The mean rainfall in this region is 3500 mm. The Brunca region also has a wet climate with monsoon influence and the annual mean precipitation is higher than 3500 mm. The North Huetar region is characterized by a wet climate, and a mean annual precipitation of 2500 mm. The rainfall distribution in the different regions is presented in Figure 2.

**Soils of the rice growing areas of Costa Rica.** Rice cultivated in Costa Rica, both upland and paddy rice, are generally located on fertile soils of flat land. These soils are divided into 4 groups: 1) Well drained alluvial soils (Udolls, Ustolls y Tropepts), 2) Moderately drained alluvial soils (Tropepts and Aquepts), 3) Poorly drained alluvial soils (Aquepts) and 4) soils of lacustrine origin (Usterts
and Uderts). Most of the rice soils in Costa Rica are classified as Inceptisols, Mollisols and Vertisols but it is possible to find rice operations in Alfisols and Andisols (7).

The high rice yields obtained in Costa Rica are the product of the use of high yielding varieties well adapted to the crop ecosystems and the knowledge of the soil qualities and limitations. This has allowed the rational use of the soil while maintaining high fertility and high yields.

Most of the fertilizer recommendations are based in soil analysis. This diagnostic tool is supported by solid research on correlation and calibration (11, 8). The critical levels for rice in Costa Rica are shown in Table 1. The extracting solution is NaHCO₃ + EDTA (modified Olsen solution), but other extracting solutions, such as Mehlich III, are being studied with promising results (4, 5, 19, 20, 17).

Soil testing has also contributed to the identification of copper (Cu) toxicity in rice. For approximately 20 years (1936-1956), banana plantations used high rates of copper sulphate to control sigatoka. When these soils were planted to rice the excess of Cu reduced yields drastically (15, 22). It has been demonstrated that the toxic concentration of Cu in the soil is 40 mg/L, extracted with modified Olsen solution (Table 1).

Table 1. Soil critical levels of different nutrients for rice cultivation in Costa Rica.

<table>
<thead>
<tr>
<th>NUTRIENT</th>
<th>VERY LOW</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
<th>TOXIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>P mg/L</td>
<td>&lt; 5</td>
<td>6-10</td>
<td>&gt; 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K cmol(+)L</td>
<td>&lt; 0.1</td>
<td>0.11-0.2</td>
<td>&gt; 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn mg/L</td>
<td>0-1.5</td>
<td>1.6-3</td>
<td>3.1-6</td>
<td>&gt; 6</td>
<td></td>
</tr>
<tr>
<td>Mn mg/L</td>
<td>&lt; 5</td>
<td>5-50</td>
<td>&gt; 50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S mg/L</td>
<td>&lt; 6</td>
<td>7-12</td>
<td>&gt; 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu mg/L</td>
<td>&gt; 40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SALINITY=CEcm/siemens/cm</td>
<td>&gt; 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P, K, Zn y Mn extracted with modified Olsen solution; S extracted with CaH₂PO₄. 31
Soil salinity is another problem of rice production. Research has demonstrated that the critical toxic level for rice in Costa Rica is 2 msiemens/cm (3).

The knowledge these soil parameters have contributed toward the goal of obtaining high rice yields using fertilizers in a rational and efficient way.

**Rice fertilization and soil management.** Commercial high yields are possible using semi dwarf varieties of high tillering potential. These varieties have higher yielding potential but they also have higher nutrient demand, particularly nitrogen (N). The need of these nutrients is partially supplied by the soil and complemented by fertilizers which are supplied to the crop during the periods of higher requirement. Nutrient management, along with pest, disease and weed control are management practices which reduce nutrient competition and allow the production of maximum economic yield.

**Nutrient removal by the rice variety CR-1821.** The productivity of any rice variety is a function of soil, climate, management and its own genetic characteristics, including nutrient requirements. Several studies have quantified nutrient removal by the common varieties in use in Costa Rica (13, 16, 9). These studies have demonstrated that crop nutrient removal is different for different varieties and that it is necessary to apply nutrients in the appropriate amount and timing according to the variety.

Among the varieties used in Costa Rica, the CR-1821 rice variety produces the highest yields and, consequently, results in the highest nutrient uptake. This variety tested in semi-commercial conditions under irrigation has produced a total dry mater yield of 20.3 t/ha. From this total yield, 9.3 t/ha correspond to grain and 11 t/ha to straw. Figure 3 shows the nutrient uptake of this variety. The crop takes up 200 kg N/ha, 265 kg K/ha and 41 kg P/ha. It is worth noting the high N and K uptake. This variety also takes up 22 kg S/ha to get high yields, but this nutrient is not generally applied as fertilizer to the soil (13).

**Nitrogen fertilizer management for maximum economic yield in harmony with nature.** The rice response to N fertilization is a function of the variety, the cropping system and the N requirements according to the growth stage.

All the rice varieties planted in Costa Rica respond to N application. Typical responses are presented in Figure 4 (8) with 2 lines representing 2 different times, genetic material and cropping systems. It
can be observed that the variety CR-1821 has a greater yield potential than the variety CICA-4. The maximum yield was obtained with 180 kg N/ha with the variety CR-1821 under irrigated conditions and with 150 kg N/ha for the variety CICA-4 under upland cultivation.

Nitrogen losses in Costa Rica are high due to the elevated temperature and high rainfall common in the rice growing areas. Research was conducted to determine fertilizer N application methods that could reduce N losses and minimize the potential of N contamination. This research has focused on split N applications based on the growth stage of the crop and nutrient needs. The results of these studies indicated that the best yields are obtained by applying 20% of the total N at planting time, 20% at tillering and the remaining 60% at flower initiation. Field research has also demonstrated that equal or higher yields are possible with N applications in 4 fractions, but the additional cost of application increases the total cost of production. Results of these studies with the variety CR-1821 are shown in Figure 5.

Slow release N sources have also been studied. Results indicated that rice yields obtained with the use of slow release urea were slightly superior to the yields obtained with straight urea. These responses are associated to an apparent higher N recovery (Figure 6). It was also demonstrated that when all N is applied at seeding, the fertilizer efficiency is scarcely 18%. It was also demonstrated that N recovery is higher under irrigated conditions (40%) than under upland conditions (35%).

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Figure 4. Rice response to N application at 2 different study times (9).

Figure 5. Grain yield response of the CR-1821 rice variety to split application of 180 kg N/ha under irrigation, in Guanacaste, Costa Rica (unpublished data).
Phosphorus fertilization of rice for maximum economic yields. Eventhough most of the soils in Costa Rica are phosphorus (P) deficient, responses to the application of this element are lower than the responses to N, potassium (K) and zinc (Zn). It is possible to find responses to P applications when the P soil test is lower than 5 mg/L (modified Olsen solution). Phosphorus availability increases after flooding and responses to P application are less frequent.

In the last 10 years farmers have enriched their soils with P, substantially reducing deficiency of this nutrient. This situation is evident when a comparison is made in a rice growing area planted in the same Andisols divided by the border between Costa Rica and Panama. The Costa Rican side has been planted to rice for more than 15 years and it is difficult to find P deficiencies in the field. On the other hand, on the Panamanian side, rice exploitation started in 1985 and P deficiencies are common in the field. Application of 100 kg P2O5/ha controls this deficiency (1). The response, under upland conditions, of the variety P-1048, to P application in an Andisol that fixes 80% of applied P is presented in Figure 7.

Management of potassium fertilizer for maximum economic yield and recycling of crop residue. Potassium rates that need to be applied to rice in Costa Rica are related to soil K availability, crop K requirement and yield goal. The K requirement of the CR-1821 rice variety is shown in Figure 3. The total dry mater yield of 20.3 t/ha removes a total of 265 kg of K from the soil. From this amount, 23 kg of K are removed in the harvested grain. On the other hand, 242 kg of additional K can be lost if the rice straw is taken out of the field. If the rice straw is incorporated in the field it is
possible to recycle the K. It therefore can be used in the following crop, avoiding high K extraction from the field. An example of this balance is presented in Figure 8.

Potassium correlation and calibration studies have established K rates needed in rice production (11, 8). Potassium critical level was set at 0.1 cmolc/L. When the soil test is equal to or lower than this value applications of 30 to 60 kg K2O/ha are recommended depending on the K extracting capacity of the varieties. The use of the K critical level is a very useful tool to the farmers, but there are cases when it is also advisable to consider the Ca + Mg/K ratio. This parameter is important in Vertisols and in associations of Vertisols and Mollisols with high Ca and Mg content. In these cases an imbalance with K can develop and even at K contents as high as 0.2 cmolc/L, a response to K application is expected. This is particularly true when the Ca + Mg/K ratio is higher than 204 (16) (Figure 9). This situation has been confirmed by Cordero (unpublished data) demonstrating rice responses to applications of 80 kg K2O/ha in a Vertisol with a K content of 0.15 cmolc/L and a Ca + Mg/K ratio of 273 (Figure 10).

Figure 8. Relation between K removal and soil K with CR-1821 variety yielding 20.3 t/ha of biomass (9.3 t/ha of grain and 11.0 t/ha of straw) in a Mollisol from Costa Rica.

Figure 9. Effect of the Ca + Mg/K ratio on exchangeable K in 3 rice soils of Costa Rica (16).
Rice response to zinc. Zinc deficiency is common in soils cultivated to rice in Costa Rica. The deficiency is related to low Zn availability of these areas (2). The Zn critical level for rice is 3 mg/L (modified Olsen solution).

Zinc deficiency can be corrected in 2 manners. One requires the application of zinc sulphate to the soil and the second calls for foliar applications of Zn, preferable in a quelated form. Responses to Zn applications to a Vertisol with a Zn content of 1.4 mg/L are presented in Figure 11 (23). Molina and Cabalceta (21) documented responses to Zn foliar applications to rice growing on a Vertisol with a Zn soil test of 2.1 mg/L. Foliar Zn increased rice yields by more than 1 t/ha in this study.

Rice response to sulphur. The use of urea in upland rice and the use of urea and ammonium nitrate in paddy rice has led to sulphur (S) deficiencies in Costa Rica (12). Correction of these deficiencies is achieved with the application of 30 kg S/ha. This recommendation was adopted based on the data from a greenhouse experiment presented in Figure 12.

Balanced fertilization in rice growing in Costa Rica to obtain maximum economic yields, minimizing the potential of contamination. The fertilizer recommendations for rice growing in Costa Rica are related to the cropping system, variety, yield goal and soil test. Farmers want to achieve maximum economic yield and maintain high soil fertility at the same time. For this reason most of the farmers practice balanced and timely fertilization. The management of rice fertilization in Costa Rica is the product of field research that has studied the responses of rice to different nutrients, value of soil testing,
crop requirements and fertilizer efficiency. Table 2 shows the nutrient recommendations for the CR-1821 rice variety, with a yield goal of 6.5 t/ha, under flooded conditions. There are 9 possibilities in this table which depend on the soil test value of P and K. The amount of N needed at different growing stages of the crop is also presented. In the same way, there exists recommendation tables for the different rice varieties in Costa Rica. The objectives of these recommendation tables are: to maximize fertilizer use efficiency, to obtain maximum economic yields and; to reduce the potential of N contamination.

Figure 12. Effect of S application on rice dry mater relative yield grown on an Eutropept from Jaco, Costa Rica (12).

Table 2. Fertilizer recommendations for the CR-1821 rice variety under flooded conditions.

<table>
<thead>
<tr>
<th>PHOSPHORUS (mg/L)</th>
<th>POTASSIUM cmol(+)/L</th>
<th>LOW &lt;0.10cmol(+)/L</th>
<th>MEDIUM 0.10-0.20cmol(+)/L</th>
<th>HIGH &gt;0.20cmol(+)/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>180-0-60</td>
<td>180-0-60</td>
<td>180-0-60</td>
<td>a) 250 kg/ha 12-24-12</td>
<td>b) 65 kg/ha urea</td>
</tr>
<tr>
<td>180-0-30</td>
<td>180-0-30</td>
<td>180-0-30</td>
<td>a) 250 kg/ha 12-24-12</td>
<td>b) 65 kg/ha urea</td>
</tr>
<tr>
<td>180-0-0</td>
<td>180-0-0</td>
<td>180-0-0</td>
<td>a) 100 kg/ha 0-0-60</td>
<td>b) 98 kg/ha urea</td>
</tr>
<tr>
<td>6-10mg/L</td>
<td>10-9</td>
<td>10-9</td>
<td>c) 98 kg/ha urea</td>
<td>d) 196 kg/ha urea</td>
</tr>
<tr>
<td>65 kg/ha urea</td>
<td>65 kg/ha urea</td>
<td>65 kg/ha urea</td>
<td>c) 98 kg/ha urea</td>
<td>d) 196 kg/ha urea</td>
</tr>
<tr>
<td>98 kg/ha urea</td>
<td>98 kg/ha urea</td>
<td>98 kg/ha urea</td>
<td>c) 98 kg/ha urea</td>
<td>d) 196 kg/ha urea</td>
</tr>
<tr>
<td>196 kg/ha urea</td>
<td>196 kg/ha urea</td>
<td>196 kg/ha urea</td>
<td>c) 98 kg/ha urea</td>
<td>d) 196 kg/ha urea</td>
</tr>
</tbody>
</table>

a)= SEEDING  b)= TILLER INITIATION  c)= TILLERING  d)= FLOWER INITIATION
Bibliography


COTTON YIELD INCREASES THROUGH TECHNOLOGY ADVANCEMENTS IN THE UNITED STATES
by
W. H. McCarty and W. R. Thompson*

In 1982 the Cotton Production Conference of the National Cotton Council's Beltwide Conferences was asking "What is happening to cotton yields". Prior to 1936 there were few technological improvements in cotton production or yield. Cotton yields began an upward trend in 1936 that averaged 9.3 pounds/acre/year (10.4 kg/ha). During the period 1936 to 1961 there were technological improvements in fertilizer and pesticide use, mechanization, and new varieties. (Meredith, 1982).

Meredith (1982) stated further that starting in 1961 and continuing into the 1970's that there was a gradual decrease in cotton yields in the United States. This yield loss averaged .82 pounds/acre/year (.92 kg/ha). During this time cotton acreage shifted westward to more productive areas, and within states there was a shift to more productive regions.

Starting in the mid- to late 1970's and continuing to today, cotton yields in the United states have increased. These yields are shown in Figure 1. These data come from the Annual Production Summaries published by the National Agricultural Statistics Service of the United States Department of Agriculture. The yield data for the United States and three states, California, Texas and Mississippi, were selected to study. These three states represented 54 percent of the harvested acres of cotton in 1992.

These reported yields and the represented yield increases came from several technological improvements in cotton production practices including; higher yielding, short season varieties, improved insecticides, including the synthetic pyrethroids, improved producer management ability, better fertilization practices, more efficient herbicides, improved equipment, and others high yield producing practices.

In 1982 Dr Brooks Taylor, Arizona Extension Cotton Specialist, produced 2612 pounds of lint cotton (5.44 bales) per acre in a maximum yield research study. This compared to an Arizona state average yield of 1118 pounds of lint per acre. The record yield was produced using drip irrigation, that reduced needed water by 40 percent, and 350 pounds of nitrogen per acre applied in 49 separate applications. A conventional furrow irrigated field would require 60 acre inches of water. The reduced water usage allowed for greater salinity control in the test plots, and this contributed to the higher yields (Taylor, 1982).

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Taylor (1982) recommended the following practices for consistently, higher, more profitable yields: 1) early planting, 2) take extra care in preparing a good seedbed, 3) use a systemic insecticide, 4) base insecticide program on an earlier-than-average threshold count, 5) use more fertilizer than is usually believed necessary, in split applications, 6) provide plenty of water and irrigate later into the fall than most growers do, and 7) start picking later, but finish earlier.

In reviewing the latest recommendations and advances in cotton production technology the following list gives inputs that can increase yields on a consistent basis:

- Modern cultivars have: a high fruit or harvest index, earliness, higher lint turnout, higher quality, and improved pest resistance.
- Improved pest management
- Improved fertilization efficiency, especially with nitrogen and potassium.
- More grower knowledge and management ability on; planting dates, populations, plant monitoring and plant modeling.
- Use of narrow row (30 inch) production.
- More and improved use of irrigation.
- Machinery advances in; planters, pickers, boll-buggies and modules.
- Use of plant growth regulators, PGR's, like Pix, that increase earliness and reduces rank growth.
- Improved seed quality.
- Better tillage and management.
- Expanded pest eradication programs, such as the boll weevil.

One way to discuss technology advances is to set up a check list. Adoption of these advancements can lead to increased lint yields and quality. Economic considerations will be prudent, because many of these practices will lead to capital expenditures for such things as machinery like modification of old or purchase of new planters and pickers for 30 inch row production technology.

**COTTON PRODUCTION CHECKLIST.**

**Soil testing and fertilization.**

The correct soil pH and fertility programs can increase and maintain lint yields and quality. Modern cotton cultivars can require and utilize higher nitrogen and potash rates than did cultivars of the 1950's to the 1970's. Care must be exercised to make certain that nitrogen levels are optimum and not excessive. The best practice is to follow recommendations for the specific soil and cultivar. Each bale of yield potential requires about 50 pounds of supplemental nitrogen. Potash deficiency is widespread over the cotton belt. Recent research by several workers found that modern cultivars are removing more potash, about 18 to 22 pounds per harvested bale. A soil testing and plant analysis program will pick out fields with potash needs and furnish recommendations to correct the problem. Soil testing and plant analysis remain the best tools available to determine
phosphorus, sulphur and micronutrient needs. A soil test is the only way to accurately determine soil pH and lime needs. Petiole monitoring remains a viable tool for assessing efficiency of fertilization programs, especially nitrogen, potash sulphur and phosphorus.

Prepare land well.
Insure uniform stands with a good seedbed that will allow seed to be planted at the proper depth. Know subsoiling needs for specific soils, as some soils do not respond to subsoiling.

Variety selection.
Yield and lint quality are important when selling cotton. These characteristics are imparted by more adapted varieties. Short season varieties mature 2 to 4 weeks earlier than full season varieties. This provides many benefits from insect control considerations to earliness of harvest. Variety trials are excellent sources of information to aid in variety selection. Variety test information includes yield history, areas of adaptation, disease resistance, lint turnout lint characteristics, and much more. Consult state variety test results and select varieties that perform well in specific localities and soil types.

Planting considerations.
Plant certified seed to insure high quality to give fast seeding growth. Time of planting is critical to get a complete, uniform stand there will produce top profit yields. In the South plant cotton after April 1 when the soil is 68 degrees at 4 inches deep for 3 days in a row. Use a recommended fungicide to prevent seed rot and seedling diseases. Plant to get a stand of 3 to 4 plants per foot of row in 38 to 40 inch rows. In 30 inch rows plant to get a stand of 1.8 to 2 plants per foot of row. Final stands should be about 45,000 plants per acre in a range of 35,000 to 50,000 plants per acre. Avoid high density stands, because these can reduce yields and cause harvesting problems. Calibrate planters to drop the correct number of seed. Early plantings will require that more seed be planted to insure proper stands. Later plantings, when the soil is warmer and more conducive to quick seed germination and early seedling growth, will need fewer seed planted to get the proper stand.

Pest management.
Pest management is essential for profitable cotton production. Pest management has economic and environmental considerations. Integrated pest management is a best management (BPM) practice. Begin pest management early in the growing season, especially insect control measures.

Irrigation.
Use irrigation to increase cotton yields and quality. Do not use irrigation to mask mistakes in other inputs or practices.

Narrow row (30 inch) production.
Narrow row production offers an 8 to 10 percent increase in yield potential. There are several factors to consider in changing to narrow row production, variety selection,
nitrogen requirements, plant density, use of Pix, and water management. New or modifications of equipment for use in narrow rows will be necessary, especially for planting and harvesting.

**Harvest practices.**
Defoliation and harvests are important segments of a production program. After growing and protecting a crop, do not lose it at harvest time. A good production program will be important at harvest time, but knowledge of harvest aids and boll openers are important. Short season cotton varieties are usually ready for harvest 2 to 4 weeks earlier than full season varieties.

**Grower knowledge and management capabilities.**
Many new recommendations and computer programs are available to producers today. These tools can offer many recommendations for farmers to aid them in decisions on practices like irrigation, nitrogen management, and others. Gossum-comax is a popular management program that helps farmers with their management decisions. Plant mapping is an excellent aid to management decisions. It will be to advantage of producers to become familiar with all management tools available.

**Summary.**
Cotton production throughout the cotton belt has made giant strides in increasing yields and lint quality in the past 10 to 15 years. Adoption of the many technological advances is slowly coming about. In the future yields will continue to increase at levels above present increases, especially as producers adopt the use of increased numbers of technology advancements.

**References**


United States
Cotton Yield

Yield

1,400 1,200 1,000 800 600 400 200

Year


USA + Calif. * Texas - Miss.
MAXIMUM YIELD RESEARCH STUDIES IN RICE-WHEAT SYSTEM AND SOIL PRODUCTIVITY - THE INDIAN EXPERIENCE.

R.S. NARANG, U.S. TIWANA AND G.DEV. Punjab Agricultural University, Ludhiana/Potash & phosphate Institute of Canada-India Programme, Gurgaon, India.

Introduction. Soil nutrients exploitive cereal-cereal, 2 crops-a- year, rice-wheat cropping system (CS) had been adopted in the Indo-Gangetic Alluvial Plains on nearly 10 million ha. Such highly intensive cropping system causes heavy removal (600-700 kg NPK/ha/annum) of nutrient, at Maximum Yield Realisation Levels (Narang et al 1990). Therefore, the fertilizer use efficiency of applied nutrients is also generally very low in rice and wheat areas, due to heavy nutrient losses, raising doubts in sustaining productivity under such highly intensive and exploitive system, for long, where all the above ground organic residue is removed in manually harvested crops.

Green manure besides contributing directly to the build-up of organic matter and being good source of N, also helps in recycling of the mineral nutrients (from deeper layers) and hence sustaining of the soil productivity. Research work on integrated nutrient management in rice-wheat CS to develop suitable crop- nutrient management strategies with maximum yield realisation of the goal, has been rather limited. The present study was undertaken to assess the sustainability of MYR technology evolved for rice-wheat system. The other objective of this study was to scale-down the earlier identified high nutrient levels to MEY ((Maximum Economic Yield) level to make the technology economically viable and competitive; and increase fertilizer use efficiency and reduce NO$_3^-$ pollution chances.

Materials and Methods

The investigations were carried out in an on-going field experiment on Maximum Yield Research (MYR) studies on rice-wheat cropping system, being conducted since 1989 at the same site with the same treatments. Changes in soil productivity parameters were monitored in 0-180 cm rhizosphere, layer-wise, treatment-wise, since-after the harvest of third crop of rice in 1990 and thereafter at the end of each crop season, over 5 seasons stretching from kharif 1990 to rabi 1992, so as to perform an indepth analysis of the long-term effects of Maximum Yield Research production practices evolved on soil productivity and crop nutrients requirements.
The MYR treatments involved the use of heavy fertilisation dosages to both rice and wheat (referred in terms of N-P$_2$O$_5$-K$_2$O, kg/ha) raised under high plant population stands (+ 33 per cent). The fertilizer doses tested for rice were: 120-30-30, 180-30-30, 180-45-45, 240-60-30, 240-60-60 and 240-60-60 + Plant Growth Regulator (PGR), CCC and Kinetin. For wheat the respective levels were 120-60-30, 180-60-30, 180-90-45, 180-90-60, 240-90-60 and 240-90-60+PGR. Fertilizer treatments of wheat were superimposed on fertilizer treatments of rice, to generate MYR levels. For higher population stands (+33) both rice and wheat were raised under close crop geometry of 15 cm x 15 cm for rice (44 seedlings/m$^2$) against 33 seedlings/m$^2$ under the recommended practice of 20 cm x 15cm, while the wheat was sown at 15 cm row spacing instead of conventional spacing of 20 cm. PGR applications comprised foliar spray of CCC; cone, lg/1 at 45 days (d) followed by Kinetin spray; cone. 50 mg/1 at 80 d, to both the crops. The quantity of water used per spray was 500 l/ha.

Fertilizer application was applied through two streams viz. i) chemical fertilizer alone (cfs); and ii) partially through green manure and partially through chemical fertilizers to rice (gms). The following wheat crop in sequence to rice always received all the fertilizers through chemical fertilizers alone. Green maturing to rice accomplished by raising of dhaincha (Sesbania aculeata L.) after the harvest to wheat, under irrigation. For green manuring Sesbania aculeata L., sown in April end (seed rate 50 kg/ha) was burried at 45 d (biomass 20-25 t/ha) nitrogen equivalent of 60 kg/ha. In green manured plots the remaining N was made up through chemical fertilizer. The sources of N, P, K and Zn were urea, single superphosphate, muriate of potash and zinc sulphate, respectively.

The experimental site was loamy sand, classed as Typic ustochrept, deep alluvial, low in OC and available N, and medium in available P and K.

Forty days old seedlings, of rice (cv PR 106 during 1990 and 1991 and PR-110 during 1992) was transplanted in the mid June after puddling at 15 cm x 15 cm spacing. Full doses of P and K according to treatments were applied at transplanting (TP). Nitrogen was applied in 3 equal splits at 0, 3 and 6 weeks after TP. All other practices like irrigation, weed and post management etc. were uniformly applied to all the plots.

During 1990 and 1991, crop remained free from disease and insects. But during 1992 due to extremely dry weather there was epidemic level attack of rice leaf folder and subsequently it also was damaged by late storm and suffered severe yield losses. Rice crop was harvested manually and all the produce removed out of field, dried, threshed and rice yield expressed at 12% moisture in unhusked grains.

Wheat cv/2329 was used. It was applied full dose of P and K and N in 2 splits, 1/2 at sowing and 1/2 at 4 weeks with the first irrigation. Wheat too was harvested manually around 15 April, produce (straw and ears) removed and grain yield recorded at 8% moisture.
The soil productivity changes in respect of organic carbon, total-, available-, and ammoniacal- N; available-, P and K were tested in 0-180 cm rhizosphere, layer-wise, treatment wise, over 5 crop seasons during 1990 through 1992. Standard procedures given were followed.

Results and Discussion

Grain Yield:

The highest grain yields of rice and wheat was at 180-30-30 & 180-60-30 to rice/wheat crops in the CS. These yields were significantly higher than those obtained at normal fertilizer level (NFL) of 120-30-30/120-60-30 used for rice-wheat CS in this area. The grain yields were higher by 16.2% for rice and 13.5% for wheat.

Further increases in fertilizer levels to 1/2 and 2 times the NFL levels did not result in any appreciable yield improvement over 180-30-30/180-60-60-30 level of rice/wheat CS. It rather decreases the yield in some cases. Thus based on yield performance, fertilizer levels of 180-30-30/180-60-30 was identified as the Maximum Economic Yield level. Nambiar and Anrol (1989) reported that 150 per cent NPK increased the grain yield of wheat by 10.0 per cent and of rice by 8.6 per cent over normal recommended NPK (120-30-0/120-60-30). This shows that 180-30-30/180-60-30 could be considered mean economic fertilizer level for obtaining maximum economic yield (MEY) in rice/wheat.

The highest grain yield of 8.6 t/ha was obtained under gms with 120-30-30 + green manuring (gm) which was equal to 180-30-30 of cfs (8.4 t/ha). This shows that gm made contribution of about 60 kg N/ha equivalent. Narang et al (1988) and Meelu et al. (1992) also reported economy of 60 kg N/ha with green manuring to rice. Higher levels of P and K over 30 kg P2O5 or K2O/ha each did not give any increase in grain yields of rice and wheat, showing the absence of response to higher levels of P and K.

Organic Carbon:

Organic carbon content showed a sizeable increase in the top 0 to 30 cm and 30 to 60 cm layers with different fertilizers levels over 5 crops seasons (Table 2, Fig. 1). The organic carbon in 180-30-30/180-60-30 (MEY levels for rice/wheat) treatment in 0-30 cm layer increased over 5 seasons from 0.34 to 0.40 per cent under chemical fertilizer series (cfs) and 0.37 to 0.45 per cent under green manure series (gms). The organic carbon also increased during corresponding period from 0.34 to 0.38 per cent under cfs and from 0.37 to 0.43 per cent under gms with 120-30-30/120-60-30. A marginal increase of about 0.04 to 0.05 cm layer. The increase in lower layers, however, was negligible. Narang et al. (1990), Kumar (1992) and Siddeswaran (1992) noticed that organic carbon content increased with increase in N levels. It can be postulated that more production of root biomass and their subsequent decomposition have increased the organic carbon status in the soil as also reported by Chaudhary et al (1981). Sharma et al. (1993) reported that 80% of the total rooting prevailed in the surface (0-20 cm) layer in wheat. The root density (g cm⁻³) of rice in the 0-30 cm layer was 97% as observed in these studies.
Fig. 1: Changes in soil organic carbon, available N under NFL and MEYL with depth.
Available N:

Soil available N in 0-30 cm layer increased from 78.4 to 103.0 µg g⁻¹ at 180-30-30/180-60-30 under cfs and from 84.0 to 113.87 µg g⁻¹ at 240-60-60/240-90-60, while with the recommended level of fertilizer input to rice (120-30-30) and wheat (120-60-30), there occurred a marginal reduction (9 µg g⁻¹) in the soil available N under cfs. Green manuring to rice in rice-wheat CS resulted in higher soil available N than cfs. It also helped maintain the soil available N status of the soil at the recommended level of fertilizer (120-30-30 in rice and 120-60-30 in wheat) at high level. In the subsurface layers, the increasing trend was maintained but the magnitude of increase decreased sharply with depth (Fig. 1). The increase in soil available N may be attributed to higher doses of N application to both rice and wheat and greater amount of underground crop residues left in soil after crop harvest as also observed by Sood (1988). Hegde and Dwivedi (1992) reported a negative balance of N, P and K in the soil with recommended fertilizer use as observed here-in. It is because all the above-ground biomass is removed under manual harvesting of rice and wheat.

Higher levels of P and K did not influence the soil available N significantly. Similar results were also reported by Chaudhary et al. (1981) and Chhillar and Swarup (1984).

Total Soil N:

In 0-30 cm layer, the total N content ranged between 490 to 550 µg g⁻¹. The values in the 30-60 cm was just 1/2; in 90-120 cm layer 1/3r; and in 120-180 cm layer, just 1/5th of the ones observed for 0-30 cm. The 180-30-30/180-60-30 level showed a build up of 50 µg g⁻¹ in 0-30 cm layer as compared to 31 µg g⁻¹ with 120-30-30/120-60-30. Moderate but progressive increase (with time) was also visible in the 30-60, 60-90 and 90-120 cm layers. The rate of build up of total N was more in gms than cfs. Higher levels of P and K did not influence the total N. Build up of total N with high dosages of N has also been observed by Macrya and Ghosh (1972) and Halepyato and Sheelavantar (1990).

NH₄⁺ - N:

NH₄⁺ - N content in 0-30 cm layer increased from 4.28 µg g⁻¹ to 5.76 µg g⁻¹ with 180-30-30/180-60-30 as compared with 4.25 to 5.6µg g⁻¹ at 120-30-30/120-60-30 under cfs over 5 crop seasons. Green manuring to rice showed slightly larger values for NH₄⁺-N than the chemical fertilizer series (cfs) Singh and Singh (1986) reported that NH₄⁺-N losses were 0.8 and 0.9 percent in 0-60 cm soil which received N through urea at the rate of 60 and 120 kg N/ha, respectively. Sawant and De Datta (1980) noticed that leaching losses of fertilizer-N as NH₄⁺ in rice decreased (i) with puddling; (ii) with split application of N fertilizer; (iii) ammonium volatilization (10 to 60%) losses from wetland rice soils; and (iv) fixation of ammonia in soil (which ranged from 6.3 to 23.5% of total adsorbed NH₄⁺).
In wheat, in contrast where oxidized conditions prevail throughout the life cycle, the N in the form of NO$_3^-$, gets lost into deeper soil layers with irrigation water, while some is lost due to denitrification, particularly from top layer. That is why perhaps the NH$_4^+$-N fixation after harvest of wheat, also tends to vary nearly similar to that availed after rice (which in itself is rather very low and stabilized NH$_4^+$-N level).

**Available P:**

Sizeable build up of available P was noticed for the 0-30 cm and 30-60 cm, the layers accounting for most of the active roots of rice and wheat. The available P content in soil with 180-30-30/180-60-30 (MEY level) increased from 10.5 to 11.00 µg g$^{-1}$ under cfs, 10.47 to 12.00 µg g$^{-1}$ under gms. The fertilizer level 120-30-30/120-60-30 increased the soil available P from 10.50 to 11.83 µg g$^{-1}$ under cfs and from 10.50 to 12.83 µg g$^{-1}$ under gms. The magnitude of increased available P was 4.8 per cent at MEY level and 12.7 per cent at the recommended level under cfs. In 30-60 cm layer, increase in available P ranged between 7.0 to 11.7 per cent under different fertilizer levels. In lower layers, the available P was not influenced by fertilizer levels (obviously due to its high fixation and low mobility).

With continuous application of P to each crop in rice-wheat rotation, build-up of P in the soil has been reported by many workers in this region (Kolar and Grewal, 1989; Dang et al., 1989; Jaggi and Minhas, 1989; and Narang et al., 1990). Chillar and Swarup (1984) observed less build-up of P at higher levels of N because of enhanced dry matter production and consequent high uptake of P by crops at higher levels of N.

**Available K:**

A Status quo position was maintained with respect to available K under the gms for MEY level. A declining trend with respect to available K status, however, was noticed under the cfs; and this was equally well-marked both for the NFL and MEYL receiving 30 kg K$_2$O/ha each to rice and wheat. Almost similar trend was discerned for the treatment receiving 45 kg K$_2$O/ha application each to rice and wheat. But distinct and well marked build-up of available K was obtained under high input level of K of 60 kg K$_2$O/ha each to rice and wheat. The order of decline in available K over 5 crops seasons was 12.3 µg g$^{-1}$ at 120-30-30/120-60-30 and 15.6 µg g$^{-1}$ at 180-30-30/180-60-30 over their respective initial values. Singh and Nambiar (1986), Narang et al., (1988 and 1990), Roy et al (1990) and Rai et al. (1991) reported that higher application of K improved the available soil K while Swarup and Singh (1989) and Hegde and Dwivedi (1992) observed that extractable-K declined over time with higher fertilizer levels (due obviously to higher uptake than annual accruals). This suggests that over time, application of K might have to be enhanced i) to restore the K-balance and sustain the production of MEY fertilizer level under cfs, the chemical fertilizer application series.
Fig. 2: CHANGES IN SOIL NH\textsubscript{4}–N, AVAILABLE P AND K UNDER NFL AND MEYL WITH DEPTH.
Literature Cited


Table 1. Grain yield (t ha\(^{-1}\)) of rice and wheat in rice-wheat system

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Rice</th>
<th>Wheat</th>
<th>CD 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-P(_2)O(_5)-K(_2)O (kg ha(^{-1}))</td>
<td>1990</td>
<td>1991</td>
<td>Mean</td>
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<tr>
<td><strong>Rice</strong></td>
<td><strong>Wheat</strong></td>
<td><strong>Green manure series</strong></td>
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<tr>
<td>120-30-30</td>
<td>120-60-30</td>
<td>9.1</td>
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<tr>
<td>180-30-30</td>
<td>100-60-30</td>
<td>8.6</td>
<td>7.5</td>
</tr>
<tr>
<td>180-45-45</td>
<td>100-90-45</td>
<td>8.6</td>
<td>7.4</td>
</tr>
<tr>
<td>240-60-30</td>
<td>180-90-60</td>
<td>8.4</td>
<td>7.2</td>
</tr>
<tr>
<td>240-60-60</td>
<td>240-90-60</td>
<td>8.4</td>
<td>7.6</td>
</tr>
<tr>
<td>240-60-60+GR*</td>
<td>240-90-60+GR</td>
<td>8.5</td>
<td>7.6</td>
</tr>
<tr>
<td><strong>Chemical fertilizer series</strong></td>
<td></td>
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</tr>
<tr>
<td>120-30-30</td>
<td>120-60-30</td>
<td>7.6</td>
<td>7.2</td>
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<tr>
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<td>7.4</td>
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<tr>
<td><strong>CD 5%</strong></td>
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<td>0.40</td>
<td>0.84</td>
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Table 2. Effect of maximum economic yield fertilizer dose on soil productivity under rice-wheat rotation over 5 crop seasons

<table>
<thead>
<tr>
<th>Fertilizer series V</th>
<th>Soil depth (cm)</th>
<th>NFL</th>
<th>MEYL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
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</tr>
<tr>
<td>gms</td>
<td>0-30</td>
<td>0.37</td>
<td>0.39</td>
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<td></td>
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<td>Available nitrogen (µg g⁻¹)</td>
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</tr>
<tr>
<td>gms</td>
<td>0-30</td>
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<td>69</td>
<td>71</td>
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<td></td>
<td>30-60</td>
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<tr>
<td>NH₄-N (µg g⁻¹)</td>
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<tr>
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</tr>
<tr>
<td>gms</td>
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<td></td>
<td>30-60</td>
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<tr>
<td>Available P (µg g⁻¹)</td>
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<td></td>
</tr>
<tr>
<td>gms</td>
<td>0-30</td>
<td>10.5</td>
<td>11.0</td>
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<td></td>
<td>30-60</td>
<td>6.3</td>
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<td>cfs</td>
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<td></td>
<td>30-60</td>
<td>6.3</td>
<td>6.3</td>
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<td>Available K (µg g⁻¹)</td>
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<td></td>
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<td>gms</td>
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<tr>
<td></td>
<td>30-60</td>
<td>46</td>
<td>47</td>
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</table>

Fertilizer dose (N-P₂O₅-K₂O, kg ha⁻¹)
Rice: 120-30-30 180-30-30
Wheat: 120-60-30 180-60-30

Dr. Federico Kocher¹ and Dr. Harold F. Reetz, Jr.²

INTRODUCTION.

Changes in Mexican agriculture are beyond simple explanation. What was expected to remain working for years to come has stopped; what was thought to not be possible is happening today. Scientists and technicians need to take charge now of the opportunities derived.

We can no longer talk of small steps toward change at some time in the future. Big steps are needed now with new production practices for farmers so they can integrate various independent pieces of know-how which already exist into complete management systems to improve their crop yield.

We used to assume that work done on MEY production on a few thousand hectares in Jalisco was something significant. Today we have to talk about thousands upon thousands of hectares as a small beginning; millions are awaiting.

Training technical personnel to become production agronomist consultants for MEY production has become vital to the operations of AGRONEGOCIOS INTERNACIONALES, which works in several states in Mexico. Early emphasis has been on those production factors that result in little or no increase in total costs: Tillage, rotations, drainage, crop variety, seed quality, planting date, row spacing, plant population, and weed, insect, and disease control. Special emphasis has now been placed on soil fertility, because, even though cost per hectare for fertilizer become significant, returns can be greatly increased when soil tests indicate a need for nutrients.

All of these changes are occurring in less than three growing seasons, without a major formal program. Today, growing two good crops a year as a minimum in the coastal region of Nayarit is a must.

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² Midwest Director, POTASH & PHOSPHATE INSTITUTE, Monticello, Illinois, U.S.A.
Institutions like FIRA, the Potash & Phosphate Institute (PPI) cooperating with FIRA, private banks, and consulting firms are clearly showing their open willingness to cooperate and participate. As a part of this dynamic process, AGRONEGOCIOS INTERNACIONALES has offered postgraduate courses in high productivity linked to MEY production and management for consulting firms.

The need to move ahead faster has also required adjustments in our understanding of consultants' activities. They need more involvement in private production research and demonstration, together with a better understanding of the working environment.

It is most appropriate to introduce our presentation today with some selected paragraphs from a speech by Dr. Norman E. Borlaug at the 61st Annual Conference, International Fertilizer Industry Association (IFA), May 1993, in New Orleans, Louisiana:

"The only way for agriculture to produce sufficient food to keep pace with population and to alleviate the hunger of the world's poor is to increase the intensity of agricultural production in those ecological conditions which lend themselves to intensification while decreasing the intensity of production in more fragile ecologies."

"Most of the increase in food production needed over the next several generations must be achieved through yield increases on land now under cultivation. Given present scientific know-how, the use of chemical fertilizers must be expanded two- to three-fold in developing countries over the next 20 years if the world is to feed herself."

Some of the basic steps that will affect agricultural efficiency have already been taken in Mexico. Minimum tillage is not at all new to people who 5000 years ago developed corn under a conservation tillage system.

Because almost 85% of Mexican agriculture is rain fed, exercising in a conscious and scientific way the action of harvesting water, constitutes one of the most important steps in moving agricultural efficiency forward. Best management practices for water must include efficient use of nutrients and concern for protection of the environment.

Because of rich local supplies of hydrocarbons, mechanical energy can be used to replace chemical use in seedbed preparation and weed control. This will allow for farmers to make enormous increases in productivity, and give them the potential to take a technological leap of centuries in only a few years.

No one can deny the advantage that better soil management can bring to Mexican agriculture in a very short time, and no one can prevent this from
happening. There is a need to increase the use efficiency of fertilizers, as well as their amounts, in the immediate future. Without efficient fertilizer use, it will be impossible to develop the vertical growth in production needed in agricultural soils. Luckily Mexico is a major exporter of ammonia. For the time being, imports of potash and phosphate fertilizers must be considered an important investment in making nitrogen use efficiency a reality.

Most protection against soil erosion is made by well-fertilized crops. Strong roots and healthy canopies protect the soil against the force of tropical rains and also result in increased soil organic matter content.

In general, it can be said that Mexican environments favor the adoption of MEY production and conservation tillage systems in a stronger manner than in the cooler Northern Hemisphere latitudes. All reported findings up to now call attention to the speed of responses obtained in terms of time and economy. Steps taken in the use of living mulches, plus responses to balanced fertilization, together with chemical weed control, water efficiency, and machinery adaptations are already pointing to a much better efficiency in the immediate future.

HOW DID ALL OF THIS HAPPEN?

Years of training FIRA's production consultants at their own working sites provided solid background for making MEY production and best management practices the working goal for advisers. It took no time to put FIRA's needs, our knowledge in on-farm research, and PPI's experiences together. The following discussion will focus on how to transform needs into working goals, and our findings from this cooperative experience.

ANALYSIS of the TECHNOLOGICAL PACKAGES.

One characteristic that has obscured most farmers' technical needs has been the fact that their management systems have been developed from a narrow "technological package", which has involved "changes in only one factor at a time" once implemented. The technological know-how was mostly reserved to the official banks. They focused on developing a "financial package", designed to replace the need for more technology. Most of the technological know-how has been provided by the farmers themselves, with some assistance from distributors of agricultural and animal inputs.

The advent of private consulting into production agriculture has greatly expanded the need for technical data, in a market not very rich in detailed technical information. In very specific terms, private consulting is supporting maximum economic yield (MEY) production goals with best agronomic
management practices available worldwide. This is the shortest way to increase productivity today.

For this presentation several hundred cases were reviewed in five municipalities in the estate of Nayarit: Rosa Morada, Santiago, San Blas, Tecuala, and Tuxpan. The area involved is over 4,000 hectares of agricultural land that is preferentially sowed with dry bean as the autumn-winter crop.

OPERATIONAL BASES ASSUMED BY PRIVATE CONSULTANTS IN DEVELOPING THEIR WORK IN HIGH PRODUCTIVITY.

Short- and Long-Term Goals for Consultants:

1. Production of individual diagnoses for each field. The field is the "patient" to be treated in the first term.

2. Start the long road towards MEY in all fields advised.

3. Production of individual animal-agricultural production systems sustainable and in permanent growth.

4. Permanent evaluations and future projection.

5. Keep farmers up-to-date in relation to best technological alternatives available.

6. Use each crop cycle as a base for planning the following one.


8. Program the use of inputs in relation to the pre-established goals.

9. Perform all necessary studies and analyses in behalf of the administrator.

10. Organization of study banks derived from ACRE and MEY records.

Agronomic Characterization REgister (ACRE).

The confrontation with on-the-job consultation on MEY production using best available agronomic practices, requires first of all a good registration system to keep all available data up to date and organized in such a way that it will allow immediate retrieval and computer storage.
ACRE was first started with the help of FIRA Jalisco technicians, being modified later because of new working experiences gathered by AGRONEGOCIOS INTERNACIONALES technical staff.

This tool was needed because little was known about the real production farmer. It must be remembered that the most detailed agricultural information was kept by banks' agricultural divisions, which relate mostly to commercial transactions, and that most "technical packages" are not used by farmers working with private banks or others. Up to now the most important "package" has been a more or less uniform "financial package", which greatly determines the amount of agricultural loans for most agricultural enterprises.

Analyses of ACRE records for Jalisco gave us the first understandings of variability at work in small and large regions, as well as between fields under the same administration. These variations had gone unnoticed because of the economic background in which each farmer used to work, and because their production goals had been frozen mostly to responses of "low-cost technologies" tied to excellent breeding research.

ACRE IN NAYARIT.

In 1992, AGRONEGOCIOS INTERNACIONALES took the responsibility to assist a few thousand hectares cultivated with dry bean in Nayarit. In developing the work, over 700 ACRE's were filled, each corresponding to separate fields. Records were taken throughout the growing season, together with financial evaluations for each individual enterprise. In 1993, the same work was conducted over a larger area, this time filling the ACRE records prior to sowing dry bean.

Production goals were established for each field with fertilizers and other inputs for yield increases larger than 100%. Partial results of background findings are presented to help illustrate the complexities and enormous potential available for Nayarit farmers and others willing to accept the use of the best agronomic practices know today, adapted to fit MEY production goals.
NUMBER OF FIELDS, ADMINISTRATORS, AND TOTAL LAND AREA.

The Nayarit work was conducted in five municipalities: Rosa Morada, Santiago, San Bias, Tecuala, and Tuxpan.

For practical reasons farm sizes were divided into four categories: >1 ha; >10 ha; >20 ha; >75 ha. (Fig. 1, 2, 3, 4, 5)

Figure 1. Average size of fields, number of fields, number of enterprises & administrators, and total land area (ha) involved in farms in the 1992 Rosa Morada diagnosis.

All municipalities totaled 1301.8 ha in the >20 ha category, with 258 individual fields averaging 4.7 ha; in the >10 ha category, 479.7 ha were divided into 123 individual fields averaging 3.9 ha; in the >1 ha category, there 326.5 ha in 57 fields averaging 3.67 ha.

The grand total of 637 individual fields implied that a little over 700 ACRE forms were filled in in order to get a clear picture of the characteristics of each field larger than 5 hectares.

The total non-ponderated area per field was 4.85 ha; the total number of administrators is 136; and the total land area under analysis was 3034.2 ha for 1992. The 1993 data for San Bias cover approximately 1200 ha.
Figure 2. Farm category, average size of fields, number of fields, number of enterprises & administrators, and total land area (ha) involved in farms in the 1992 Santiago analysis.

<table>
<thead>
<tr>
<th>Category Enterprise (ha)</th>
<th>Average Size (ha)</th>
<th>Number of Fields</th>
<th>Total ha/category</th>
<th>Enterprises &amp; Administrators</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1 ha</td>
<td>&gt;10 ha</td>
<td>&gt;20 ha</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Average size of fields, number of fields, number of enterprises & administrators, and total land area (ha) involved in farms in the 1992 San Blas analysis.
Figures 3 and 4 show that only San Bias and Techuala had 11 enterprises in category 4 (>75 ha), totaling 1031.2 ha of land and 199 individual fields with an average size of 7.2 ha.

Figure 4. Average size of fields, number of fields, number of enterprises & administrators, and total land area (ha) involved in farms in the 1992 Tecuala analysis.

Figure 5. Average size of fields, number of fields, number of enterprises & administrators, and total land area (ha) involved in farms in the 1992 Tuxpan analysis.
Three important points are shown by these figures:

1. Actual field sizes are very close to the maximum size for the diagnosis proposed—5 hectares. The task became more difficult in about 60% of the sites because of their smaller sizes. For the time being, this distribution cannot be avoided and contributes enormously to elevating costs of field work.

2. Few marking points are present, making locating fields difficult.

3. Enterprises are made up of many little fields.

**MEASUREMENT OF pH in WATER and CALCIUM CHLORIDE.**

Measurement of $pH_w$ and $pH_s$ in general showed lowering of the values when 0.01 M CaCl$_2$ was used. Differences between municipalities and fields belonging to the same administrator are significant. The scattering of values obtained show the need to study individual fields if MEY production is the goal.

Values of $pH_w$ 6.0 and $pH_s$ of 6.0 to 5.5 are considered deficient for many crops. At $pH_s$ of 5.5 to 5.0, Ca is deficient; at $pH_s$ of 5.0 to 4.5, Ca is very deficient, unsatisfactory for most crops. The numbers speak for themselves, showing independence when studied for the first time.

Rosa Morada

If pH 6.0 is used as a divider between soils with possible negative effects on potential productivity, 93% of the $pH_w$ readings were over 6.0. When measured in 0.01 M calcium chloride, 72.5% were over 6.0. (Fig. 6, 7).

Santiago's fields were the one with fewer pH below 6.0 and only 2% when measured in salt. (Fig. 8,9)
San Blas

San Blas fields sampled in 1993 showed that most soils had pHw below 6.0 (6% >6.) and 100% below 6.0 in pHs. The scattering of the values is significant, confirming that Ca
t values are low. Possibilities of strong...
responses to Ca applications are high, particularly in crops like dry bean.. (Fig. 10,11)

Sixteen percent of the soils had pHw below 6.0 and 36 percent had pHs below 6.0. (Fig. 12,13)


**FIGURE 13.** Measurements of pHs [salt] in Tecuala soil samples, analized after sowing dry bean, 1992.
Tuxpan

In Tuxpan pH\textsubscript{w} showed that almost all fields had pH\textsubscript{w} over 6.0, when measured in salt almost 50 percent of soils showed pH\textsubscript{s} below 6.0. The scattering of values is big. (Fig. 14. 15)

**FIGURE 14.** Measurements of pH\textsubscript{w} [water] in Tuxpan soil samples, analyzed after sowing dry bean, 1992.

![Graph showing pH\textsubscript{w} values in Tuxpan soil samples](image)

**FIGURE 15.** Measurements of pH\textsubscript{s} [salt] in Tuxpan soil samples, analyzed after sowing dry bean, 1992.

![Graph showing pH\textsubscript{s} values in Tuxpan soil samples](image)
For the record it must be known that very seldom lime has been used in the state of Nayarit, in this particular municipality dry bean yields had steadily decreased throughout the years.

In diagnosing and interpreting soil conditions for plant growth, it is of value to determine both pHw and pHs. The difference between the two values reflects the salt content of the soil, low pHs in comparison to pHw values suggest highly leached and infertile soils. This findings had been very useful in explaining low nitrogen efficiency, lowering of yields in dry bean crops, physical problems in soils, and development of technological alternatives with goals close to MEY.

**ELECTRIC CONDUCTIVITY MEASUREMENTS**

![Electric conductivity (μmhos/cm) of Rosa Morada soil samples, analyzed after sowing dry bean, 1992.](image)

In all five municipalities; Rosa Morada, Santiago, San Blas, Tecuala, and Tuxpan (Fig. 16, 17, 18, 19, 20) electric conductivity readings are found between 100 and 600 μmhos/cm, with a tendency towards low values related in some way with lower pHs already presented. Higher values were found in fields in which the ocean is close to the fields. Scattering of measurement values show the independence of each value from site.
Figure 17. Electric conductivity (μmhos/cm) of soil Santiago samples, analyzed after sowing dry bean, 1992.

FIGURE 18. Electric conductivity (μmhos) of San Bias soil samples, analyzed after sowing dry bean 1992.

POTASSIUM MEASUREMENTS


FIGURE 22. Quantity of soil K [cmol/kg] from Santiago soil samples, analyzed after sowing dry bean, 1992.
Analytical values for K are shown in Figures 21, 22, 23, 24, and 25. If a critical value for available K of 0.20 cmol kg\(^{-1}\) is used, samples from Santiago (Fig. 22) are the only ones above it. In all other four municipalities most values are below the 0.20 cmol kg\(^{-1}\) values (Fig. 21, 23, 24 and 25).
If a grand CEC average for this region goes along 20 cmol kg\(^{-1}\) with a lower point of about 14 cmol kg\(^{-1}\) and high values of 27 cmol kg\(^{-1}\). That gives per cent saturation values of 1.4% for the low CEC and of 0.7% K saturation for soils with higher CEC. Almost all values found are too low to help in MEY production. Most crops growing in this region develop important K deficiency symptoms quite early in their development.

The K needs for the 2.5 to 3.0 tones yields needed to make dry bean an economic crop, are quite superior to the one found in the analyzed soils. Some fields can reach yields over the five tonne mark, if well managed and with adequate nutrition.
SOIL NITRATE

Detailed data for nitrates present in the soil top 20 cm belong to San Bias (Fig. 26) 1993 samples and Tecuala (Fig. 27). Most of the values are between almost zero and 20 kilos/ha, this can be attributed to the fact that during the rainy season weeds are the only plants present, and the fact that they are controlled by harrowing in wet. The numerous instances of "plow-pans" in these soils is also attributed to this practice. In general fields with high nitrate readings belong to a rotation tobacco-dry bean, practiced in the region.

SOIL CALCIUM AND RELATIONSHIPS

Soil calcium in San Blas (Fig. 28) samples is low as total content and as a percentage of the CEC, and variations between samples are present. Soil calcium in Tecuala samples are much higher in terms of absolute content and percentage of the CEC.
The Ca/Mg relations for San Bias 1993 samples (Fig. 30) considering the value 1.2 as critical level are good; just the opposite happens in Tecuala (Fig 31) where values are extreme low, ranging in the deficient level.

**FIGURE 30. Relations Ca/Mg in San Bias soil samples, analyzed before sowing dry bean, 1993.**

**FIGURE 31. Relations Ca/Mg in some Tecuala soil samples, analyzed before sowing dry bean, 1992.**
The relation Ca+Mg/K (Fig. 32 and 33) due to the low K values have the tendency to be over a possible critical point of 10.0. The scattering of the results show the difficulties in making general recommendations.

**FIGURE 32.** Relations Ca+Mg/K in San Bias soil samples, analyzed before sowing dry bean, 1993.

**FIGURE 33.** Relations Ca+Mg/K in some Tecuala soil samples, analyzed after sowing dry bean, 1992.
SOIL PHOSPHORUS

Data presented in Figure 34 shows levels of P1 present in San Blas, 1993 samples in mg/kg.

FIGURA 34. Quantity of soil P1 [mg/kg] in San Blas, analyzed before sowing dry bean, 1993.

Thirty per cent of the samples appear to be above 20 mg/kg with values as high as 45 mg/kg or "very high" with most of samples with values below 15 mg/kg or "low". The scattering that happens within the fields under the same administration, emphasized once more the benefits of a close soil sampling and individual field soil analysis interpretation to get down into the real needs for MEY production and best management practises.
SOIL TEXTURES

Soil textures found in four municipalities help explain some of the variations already described. Rosa Morada (Fig. 35) present ten soil texture classes with 61% of them being clay loam and clay textured soils.
San Blas, 1993 (Fig. 36) present eight different soil textures with 63% of them being clay loam and clay textured soils. Tecuala (Fig. 37) present ten different soil textures, clay and clay loam representing only 55% of the total and clay-loam-clay loam textures representing 84% of them.
FIGURE 38. Soil textures in Tuxpan and number of fields where they were found, 1992.

Tuxpan (Fig 38) present seven soil textures, clay and clay loam representing only 49% of the total and clay+loam+clay loam representing 98% of the. Some correlations between this numbers and CEC appear to be most promising as means to understand some of the soil analyses values, in the future with thousands of analyzed data this will be done, meanwhile, the fact that most fields had different values is real, so the need of interpreting each one of the separately is also a real necessity to keep moving ahead.
SUMMARY AND CONCLUSIONS.

Few detailed geological, soil, or hydrological surveys have been completed in the last 20 years. The comprehensive ACRE records for fields of farmers using private consultant services are helping to fill this technology inventory gap. It is time to stop thinking of the uniformity and land-abundant states, because of vastly different soils, rainfall levels and patterns, altitude, latitudes, and availability of locally adapted technology.

The message is clear, it is time to focus on individual enterprises and examine the problems unique to each one, rather than to discuss regional or state problems in idealistic terms as one homogeneous (and non-existing) land. Such broad analysis is completely inappropriate for real technical consulting work.

It is also time to stop thinking that all farms and enterprises have the same financial needs or production goals. Because of differences in initial working capital, natural resource endowments, history, and applied technologies, there are vastly different prospects for agricultural growth among individual farmers at this historic starting point.

In the long run, many farmers have the physical capacity to grow as big enterprises, given investment capital, strengthened rural institutions, and up-to-date technological consultants. Such growth will result from adding to individual field production efficiency.

This paper has examined some strategic issues in dealing with the starting needs for implementing Maximum Economic Yields and Best Management Practices in Nayarit under the guidance of private consultants. New laws and constitutional amendments have replaced old ones. The needs for more efficient production and use of land resources have become more prominent. This has led to massive short-term efforts and crash programs to increase food production efficiency. It is important to recognize that the reordering of development priorities, and giving substantially higher priority to use of agricultural consultants, has to go on for several decades.

Absorptive capacity, "a rough measure of a society's ability to employ efficiently additional capital resources" (Rostow, 1985), was avoided only a few months ago by bank and consulting people. They have to be liberated from the old idea of "helping" farmers, because it involves tolerating lower standards of performance. A credible plan to assist farmers into MEY production became a reality when the trilogy, farmer-bank-consultant each reach consensus. The failure to get the business association working will inhibit any action toward successful achievement of productivity goals.
Animal-agricultural systems development is too complex to be explained by a single factor such as a farmer’s unwillingness to perform, mishandling of loans, or increasing yield only with the aid of science-based technologies.

Retroactive technical analyses of production investments should become routine. This would stop artificially elevating the numbers of projects beyond the ability of farmers to manage them, and help farmers to achieve more effective coordination.

All the data presented point out sharply that, for the time being, there are larger-than-expected differences between production fields. This fact is true when MEY production becomes the goal. For low-yielding crops, the variations can be confounded with numerous factors, transforming technical work into a guessing game.

Gathering this type of information, of which only a small part was shown, takes much time and investment at the beginning, but we consider it the only way to reach the proposed goal.

MEY production systems with best management practices are a viable alternative to increase agricultural and animal production productivity. It is important to recognize that many obstacles must be overcome:

1. Study with most detail the main components of the farming enterprise, the fields.
2. Study the economic implications of fields’ spatial distribution as well as their technical realities.
3. The diagnostic approach has to be taken to further steps in order to gain better understanding of the financial alternatives available for each enterprise.
4. Participation of private consultants, well-equipped and with good understanding of MEY production requirements, is essential.
5. Yield goals for every enterprise must be established as a working frame.
6. Production of excellent permanent ACRE files is essential.
7. There must be good communication with financial advisers.
8. Excellent maps must be developed for fields under contract.
9. Individual technological alternatives must be identified for every field.
10. Nutrition and fertilization technologies provide an opportunity to produce fast changes in production economics.

11. Farmers' should be encouraged to move as fast as possible to use the best production technologies available.

12. Production research should be implemented *in situ* when better and more precise levels become necessary.
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