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THE DEVELOPMENT OF RICE-CORN ROTATIONS IN TROPICAL LOWLAND ENVIRONMENTS: A SYSTEMS RESEARCH APPROACH

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FOREWORD

Corn and rice are the two main cereal crops of Asia. This Bulletin discusses the reasons why they are so seldom grown in a rice-corn rotation system, in spite of the fact that most countries in the region have achieved self-sufficiency in rice while the demand for corn as livestock feed is growing steadily. The constraints to rice-corn rotation are discussed. These are particularly severe in rainfed areas. The authors point out that the constraints are complex and interactive, and can therefore best be understood through a systems research and development approach.

This approach was followed in a major project carried out by IRRI and the Philippine Department of Agriculture in the plains of Central Luzon, where irrigation by tubewells allowed two crops of rice per year. An increase in the cost of dry-season irrigation water and falling water output impelled researchers to study whether a rice-corn-mungbean rotation might be more profitable than the existing cropping system. The Bulletin describes the technology adopted, and the results of the program to date. The fact that the farm gate price for corn was higher than that for rice was an added incentive for farmers to adopt the new system. Technology for growing corn after rice in rainfed areas is also described.

Both authors are members of the team working in the project described, and their paper is based on years of practical experience in the problems of rice-corn crop rotation. This paper was first presented at an international seminar on *"Integrated Technology for Field Corn Production in Paddy Fields"*, held in the Philippines in March 1990. A highlight of the seminar was a field trip to Central Luzon to view the project in operation. The seminar was sponsored by FFTC and the Institute of Plant Breeding, College of Agriculture, University of the Philippines at Los Baños.

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(Chinese Abstract) 摘 要

在熱帶亞洲，很少有玉米種植在水田，但許多證據顯示這種情況在未來將發生改變。無論從技術或經濟上效益都有助於玉米在稻田的生產。本文主要討論玉米種植水田時所發生的一些問題，特別是土壤及水分問題，並以在菲律賓一個成功計劃爲例說明如何栽植作物，如何進行水分管理，養分管理，其結果在過去五年內使玉米產量由每公頃2.5公噸增加至6.6公噸，也引起灌溉制度的改變。

目前研究濕季中玉米生產的方法，特別強調及發展出在土壤水分過多下耕作方式及耕作後期如何保持土壤中水分。最後提出水稻——玉米生產的模式，以便農業專家來共同協助解決此一輪作所引起的複雜問題。

(Japanese Abstract) 摘 要

現在、熱帯アジアでは水稲裏作としてトウモロコシの栽培はあまり行なわれていないが将来拡大する可能性が大きい。この栽培法は技術的、経済的にも有利である。ここでは水稲跡作としてトウモロコシを植える場合の土壌の物理条件と水分供給について考える。耕うん、移植、灌水管理、養分管理（量と方法）については、圃場試験が行なわれた。その結果農家レベルで過去５年間に収量が，2.5 ton/haから6.6 ton/haに増加した。これによって乾期作イネ用の灌漑システムもトウモロコシ栽培にも利用できるようになった。

天水栽培のトウモロコシ生産についてみれば、耕うんの仕方が栽培初期の土壌水分の過剰を防ぎかつ栽培期間を通じての水分保持に大きく影響する。最後に水田跡作利用のトウモロコシ栽培のための輪作モデルを提案した。

(Korean Abstract) 초 록

열대아시아지역에서 저습논에서의 건기옥수수 생산은 거의 없다. 그러나 이러한 현실은 앞으로는 변화될 것이라는 강한 조짐이 있다. 기술 및 경제적 요인 모두가 옥수수 생산의 다양화를 촉진하기에 유리한 방향으로 진전되고 있다. 이 논문에서는 벼농사 후작 옥수수의 입모 및 생육에 관여하는 재배환경상의 복합적인 여러문제, 특히 토양의 물리성 및 함수요인에 관한 검토가 이루어 졌으며, 필리핀의 성공적인 포장이용 체계 연구결과들로 부터 개발된 관개에 의한 옥수수재배 생산기술이 분석되었고, 포장환경의 조절연구가 경운, 입모, 관개수조절(특히 관개 횟수) 및 영양조절(예를들어 비료수준 및 시비방법)이라는 관점에서 보고되었다. 본 연구에서는 5년 이상 2.5~6.6MT/*ha*의 포장수량을 낸 농부들을 연구에 고용함으로써 단계적인 포장관리기술의 향상을 직접적으로 꾀하였으며 건기 벼농사로 부터 옥수수로의 관개체계를 바꾸는 것을 유도하였다.

이와 더불어 천수답 옥수수 생산체계를 발전시키기 위한 최근의 연구도 함께 검토되었는데 특히 작기의 초기에는 과도한 토양수분을 줄이고 이후에는 계속 보존하는 경운법의 상호작용적 영향에 중점을 두었다. 끝으로 획기적인 벼-옥수수 작부체계모형이 제시되었는데 이 모형은 벼-옥수수 윤작체계에서의 여러 복합적인 문제들에 대하여 공동으로 초점을 맞출 기술과 개발연구진들에게 지침이 될 수 있을 것이다.

THE DEVELOPMENT OF RICE-CORN ROTATIONS IN TROPICAL LOWLAND ENVIRONMENTS: A SYSTEMS RESEARCH APPROACH

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ABSTRACT

Very little dry-season corn is currently produced on wetland ricelands in tropical Asia, but there are strong indications that this situation will change in the future. Both technical and economic factors are becoming favorable for accelerated diversification to corn production. This paper reviews the problem complex of the post-rice environment that challenges corn establishment and growth, particularly the soil physical and hydrological factors. The development of irrigated corn production is analyzed through the results of a successful on-farm systems research project in the Philippines. Controlled on-farm research is reported on aspects of tillage, crop establishment, water management (particularly irrigation frequency), and nutrient management (i.e. levels and placement methods). This work directly contributed to gradual management refinements employed in farmer participant research, raising farm yields from 2.5 to 6.6 mt/ha over 5 years, and induced the transformation of an irrigation system from dry season rice to corn.

Recent work to develop rainfed corn production systems is also reviewed, with an emphasis on the interactive impacts of tillage methods on alleviating excess soil water early in the season, and its conservation later on. Finally, a model is presented of the rice-corn field as a dynamic agronomic system, which can help guide scientific and development teams to jointly focus on the complex problems of this rotation.

INTRODUCTION

Corn and wetland rice are the dominant annual crops in the countries of the Asian tropics, each occupying scores of millions of hectares. Their production, distribution, and consumption are the basis for a large proportion of the total economic activity of most nations in the region. However, the two crops occupy distinctly different ecological domains in each country: different soils, landscape positions, and climatic zones. Seldom are they grown in sequence with each other on the same land.

The proportion of wetland riceland (approximately 75 million ha in South and Southeast Asia) that is under a rice-corn rotation system is probably less than 1-2%. For example, corn is produced on 3.3 million ha in the Philippines, rice on 2.8 million ha. However, the area of wetland rice that is followed by corn is estimated to be less than 25,000 ha (less than 1%).

Such a stark segregation of two crops that are both so fundamental to tropical agricultural systems clearly suggests that there are serious and complex constraints to their successful integration in crop rotations. If the constraints were not major ones, there is little doubt that farmers would have already evolved wetland rice-corn sequences on a large scale, such is the importance of, and experience with, these two crops.

A number of factors do suggest the potential for a substantial change in this situation. Most countries in the region have attained and are maintaining a position of self-sufficiency in rice production. The profitability of rice is eroding (Pingali *et al.* 1990) and there is strong economic pressure on farmers to diversify into other crops. Meanwhile, the demand for processed feeds for the livestock

industry is growing at a rate of over 20% per year in many countries in Southeast Asia. In the Philippines, the farm-gate price for corn is currently higher than for rice, a historic reversal of past trends.

The size of the average rice farm continues to decline. It is now between 0.5 and 2.0 ha in most countries in South and Southeast Asia (IRRI 1988). In both rainfed and irrigated rice areas, there is a major impetus to intensify crop production in the off-season. The installation of small-scale shallow pumps is burgeoning in many areas, giving farmers direct control over limited amounts of water for dry-season crops.

The costs of dry-season irrigation are escalating, forcing public and private pump operators to explore alternatives other than flooded rice in the dry season. The management of gravity irrigation systems is gradually becoming more sophisticated. Skills are developing in controlling and scheduling water allocations to meet upland crop requirements without causing serious waterlogging. Finally, attention is being given for the first time to developing maize technologies specifically adapted to the rice field, and their spread among farmers in key production areas.

Nevertheless, the biophysical and socioeconomic factors constraining the development of the rice-corn rotation are complex and interactive, and can therefore best be understood and overcome through a systems research and development approach. We will review the interacting determinants of the biophysical environment of rice-corn systems, and attempt to outline a research model that views the field as a dynamic system, wherein a deeper understanding of interactions is a prelude to the generation and evaluation of technical solutions.

We review experience with an integrative research program that developed components of a technology for tropical irrigated corn production after rice, and their integration into the cropping system through a farmer participatory approach. Recent research on the development of viable methods of rainfed corn production is also analyzed.

CORN IN THE TROPICAL WETLAND RICE ENVIRONMENT

At the end of the wet season the atmospheric and soil environment of a previously puddled rice field is harshly adverse to the successful establishment and growth of upland crops. In most locations in Southeast Asia, there is considerable uncertainty as to the amount and distribution of rainfall during the wet-dry transition period, during which time crops succeeding rice are established. Prolonged or intermittent saturation of the soil, and the consequent maintenance of a shallow water table in the rice field (Fig. 1), delay land preparation or may result in seedbed conditions of poor tilth. The continuation of excessive moisture after seeding subjects the seeds or seedlings to waterlogging stress.

On the other hand, the soil environment often shifts rapidly from excess moisture to water deficit. As the root zone of a fine-textured, previously puddled soil dries down, the soil strength increases sufficiently in seven days to impede root and shoot growth at a depth of 10 cm. After 22 days, the soil strength may be sufficient to prevent all rooting and kill the plants (Woodhead *et al.* 1989). The compacted plow layers in many rice soils may block root penetration almost completely as they dry.

The physical factors that constrain establishment and production of non-rice crops include (Woodhead 1989):

- Inadequate and delayed seedling establishment,
- Extremes of soil temperature,
- Restricted rooting caused by the puddling-induced compact layer,
- The persistence of rice stubble and roots after the rice harvest,
- The legacy of preceding submergence during the rice phase of the crop sequence,
- Post-seeding waterlogging,
- Post-seeding water deficit.

A remarkable feature of the post-rice environment is the highly interactive nature of the problems that control crop establishment and growth: atmospheric, soil physical, soil chemical and hydrological conditions. The severity of the combined crop limitations, and the high cost and uncertainty of manipulating them satisfactorily, has discouraged vigorous efforts to develop rice-corn rotations in the tropics.

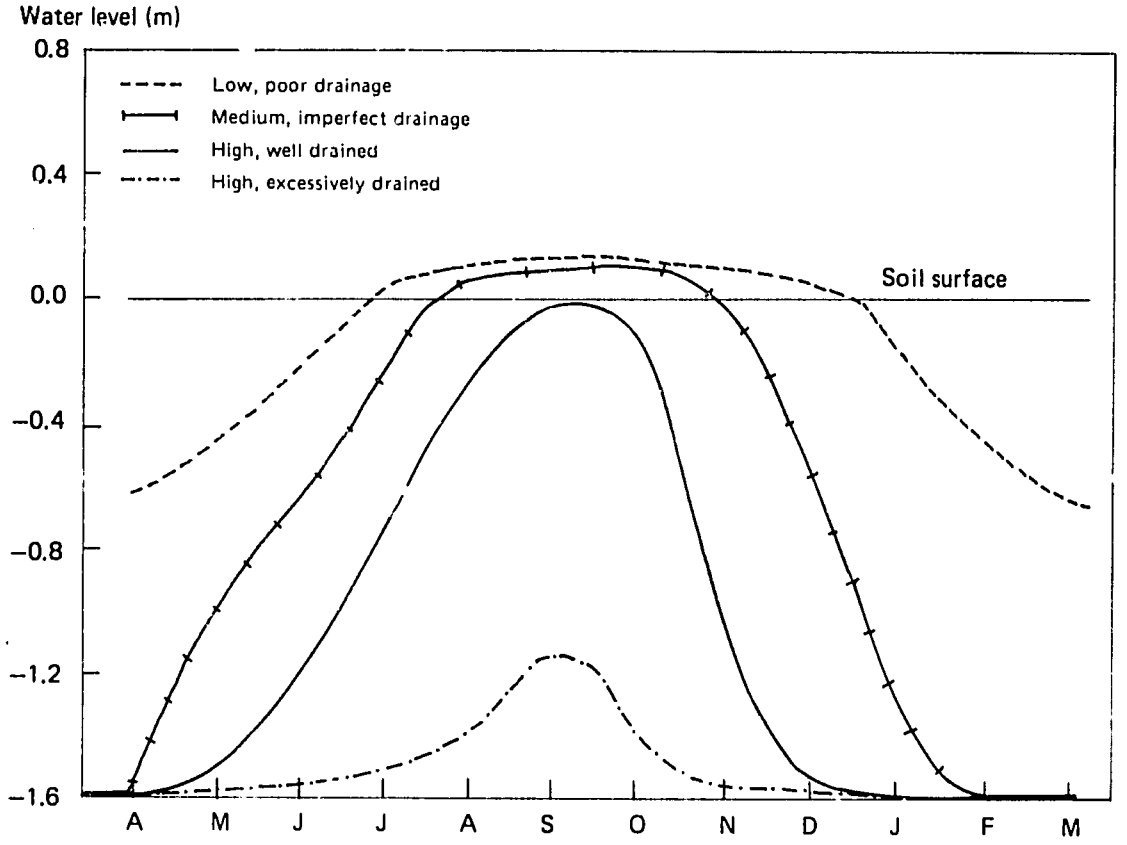


Fig. 1. Water table dynamics in different rice-growing environments

SYSTEMS OF IRRIGATED CORN FOLLOWING RICE

The potential for small-scale farmers to overcome multiple constraints and produce corn after rice efficiently and profitably became evident through experience gained by IRRI and the Philippine Department of Agriculture in an on-farm cropping systems research project in Guimba, Central Luzon (Fig. 2). The research site was the command area of a deep tube well operated by the National Irrigation Administration and irrigators' associations. The system was programmed to irrigate two crops of rice per year, and was confined almost exclusively to rice cropping.

As long as water was inexpensive and abundant in the deep tube well service area all year round, double-crop irrigated rice cropping systems were comparatively stable and productive, and managerially less demanding than other types of irrigated farming on fine-textured soils. However, the irrigation system became progressively affected by escalating costs for dry-season irrigation water, and progressively lower pump output (Fig. 3). Two rice crops often became unprofitable (Moya 1981). Also, the potential irrigable area for rice steadily declined. These concerns established the rationale to investigate the agronomic and economic viability of alternative upland crops, as a test case for many irrigation systems in the Asian tropics experiencing similar limitations.

The research team hypothesized that the productivity of the irrigation system as a whole, and the profitability of individual farm enterprises, could be more productively utilized in a rice-corn-mungbean rotation (Fig. 4). A switch to crops other than rice would make possible a large increase in the service area, and a large reduction in per hectare operating

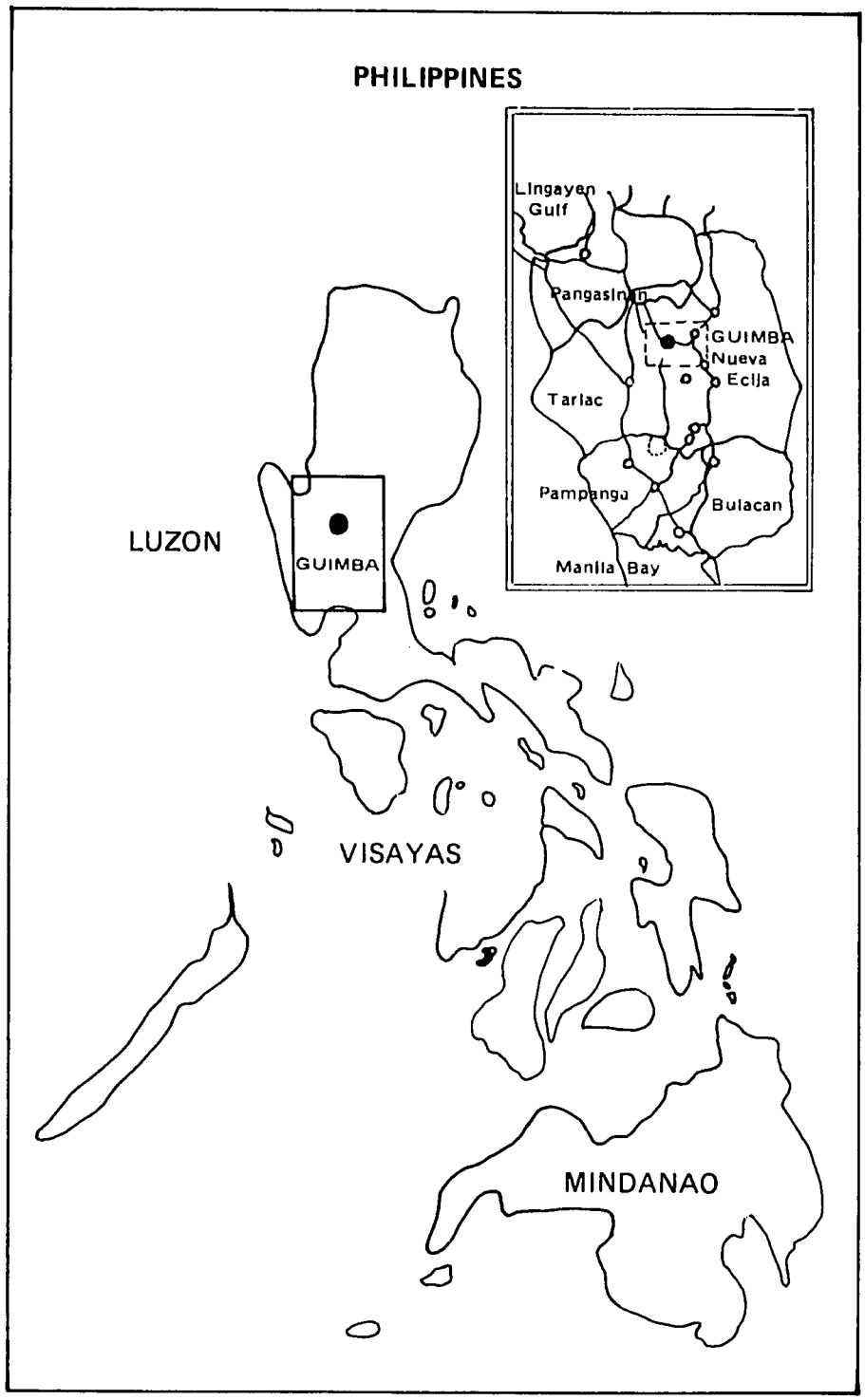


Fig. 2. Location of the key on-farm research site for the development of irrigated rice-corn rotations in Central Luzon by IRRI and the Philippine Department of Agriculture. Guimba, Nueva Ecija, Philippines

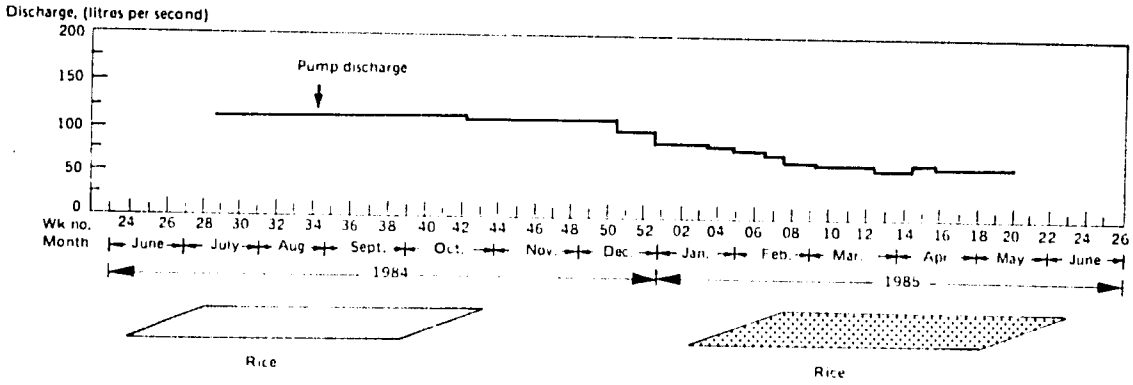


Fig. 3. Pump discharge from P-27, and duration of the traditional rice-rice pattern, in Guimba, Nueva Ecija, Philippines, 1984 wet season and 1985 dry season.
Source: Moya and Murray-Rust (1985), Water Management Department, IRRI

costs of the deepwell pump.

An onfarm systems research mode (Zandstra *et al.* 1981) was adopted to holistically identify and investigate the factors that constrained the development of this cropping system: physical, biological, social, and economic. The research team was composed of staff from the agronomic, engineering, pest management, and social science disciplines.

Corn had never before been grown in this large area of irrigated and rainfed riceland located in the middle of the Central Luzon plain. Neither farmers nor researchers in the area had any experience with this crop. Therefore, farmer-participant tests of corn after rice were initiated in the first year to obtain a baseline indication of the crop's productivity on a field scale within the prevalent management constraints.

Farmers recognize two distinct land types across the nearly level topography of rice fields: Lower fields with finer textured soils and poor drainage ('lungog'), and slightly higher fields with slightly coarser texture and better drainage ('turod'). The initial field-scale tests of corn production were confined to three groups of adjacent farms on the turod lands.

Land preparation was initiated after the rice harvest and field drainage. Wet conditions delayed tillage operations and resulted in seedbeds with poor tilth and large soil aggregate sizes. Corn seedling emergence was poor. Waterlogging severely affected fields located close to irrigation ditches. In fields far from the irrigation pump, water stress was serious. Grain yields averaged 2.59 mt/ha across 12 farms, well below the target levels anticipated for acceptable profitability.

Analysis of the problems led to a research effort into the technology used for corn production. The three major areas investigated were tillage and crop establishment, water management, and nutrient management. A program of on-farm researcher-managed trials was developed to address these issues.

Tillage and Crop Establishment

Tillage of a puddled soil at any time during the drying-out phase after field drainage tended to produce an unacceptably poor aggregate size distribution. This occurred regardless of whether tillage was by animal-drawn moldboard plow or tractor-drawn disk harrow. This appeared to be a result of the very narrow window of time between soil saturation and the development of massive surface shrinkage and high soil strength.

An acceptable tilled seedbed was obtained by allowing the field to dry out thoroughly, then flush irrigating lightly before primary tillage. This method greatly delayed land preparation, but resulted in much better

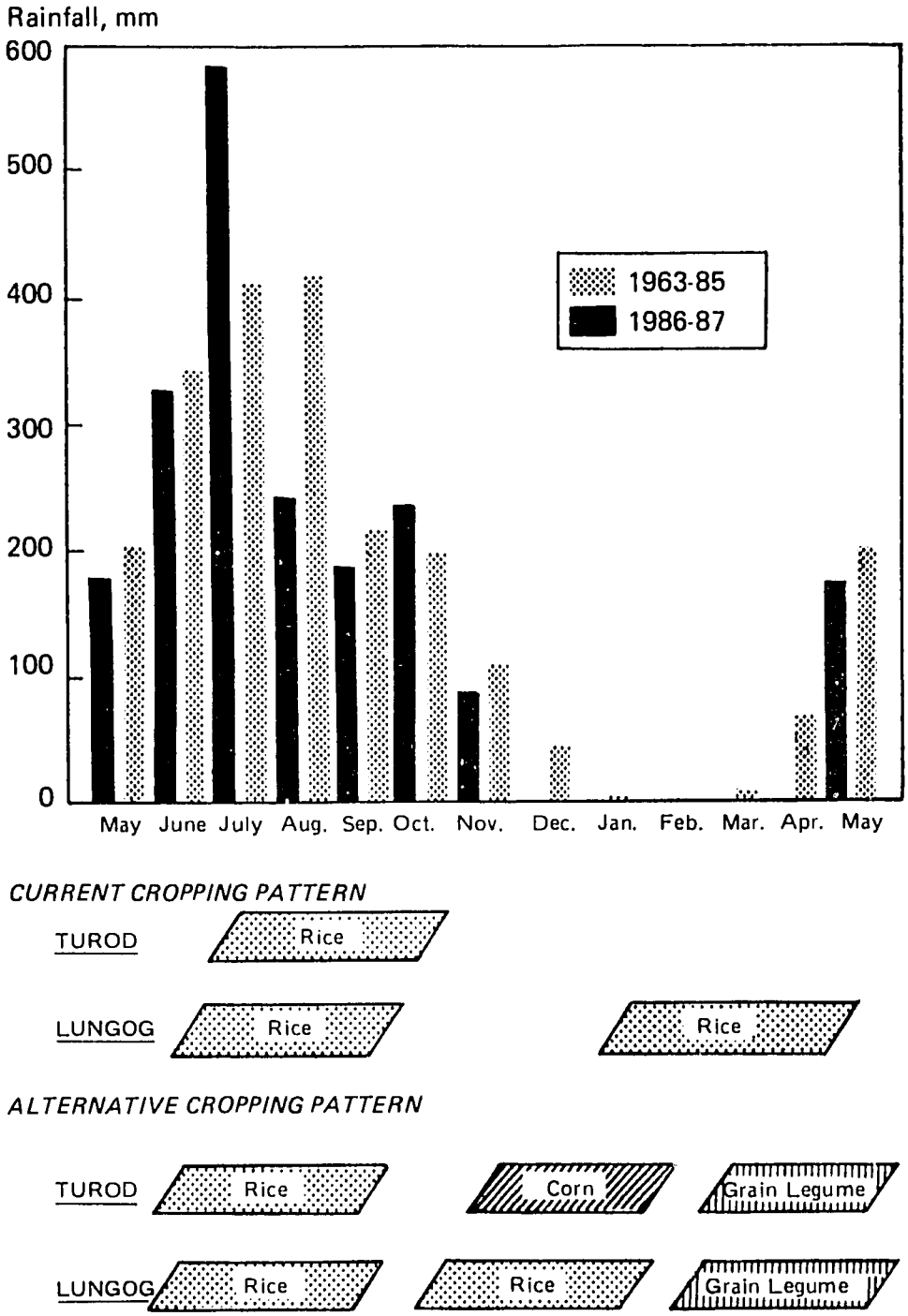


Fig. 4. Mean monthly rainfall, current and alternative cropping patterns for partially irrigated land in Nueva Ecija Cropping Systems Research Site, Nueva Ecija, Philippines. Lungog land is lower than Turod land and is therefore easier to irrigate for rice in the early dry season.

corn seedling density.

Gines *et al.* (1990) found that the seeding method used interacted with the prior tillage method in influencing corn stand density and yield. Hand planting and seeder planting were equally effective in creating a desirable plant stand when combined with zero tillage. However, when conventional tillage (plowing and harrowing) was used, or rototillage for primary tillage, seeder planting was clearly superior. These differences were observed in final grain yields.

With moderate soil tillage in preparation for corn, any of four different seeding methods performed satisfactorily (Table 1). In growing irrigated corn, the conservation of the original stored soil moisture supply is not as critical as in rainfed corn. Therefore, there is greater flexibility in scheduling tillage and seeding operations. However, optimizing seed-soil contact and moisture in the seed zone is still a major problem.

Tillage and seeding must be completed with adequate soil moisture remaining for germination and emergence, combined with an aggregate size distribution appropriate to provide that moisture to the seed. The limits in this interaction were shown by Woodhead (1990) for mungbean seeds (Fig. 5). Irrigation immediately after seeding, to correct for inadequate soil moisture or poor tilth, is often harmful because of the high crusting potential of most rice soils, and the attendant possibility of waterlogging the germinating seeds.

Table 1. Effect of seeding methods on grain yield and other agronomic characters of maize in a partially irrigated environment. Guimba, Nueva Ecija, Philippines, 1989 wet-dry transitional season

Seeding method	Grain yield (mt/ha)	Crop stand (no./12m²)	100 seed weight (g)	Ear length (cm)	Plant height (cm)
Inverted T seeder	4.37	129	27.6 b	11.7 b	199 a
Plow seeder	3.99	109	29.6 a	13.2 a	188 ab
Jab planter	4.17	102	30.3 a	13.3 a	179 b
Hand seeding	4.12	110	38.7 ab	13.8 a	194 a
Difference between treatment means	ns	ns	*	**	*
LSD (0.05)	0.8	23.0	1.6	0.9	12.3
CV (%)	12.9	12.7	3.59	4.44	4.05

Means in a column followed by the same letter are not statistically different at a 5% level by LSD

Water Management Research

Waterlogging may be the most serious constraint to the production of maize in irrigated rice areas. It is a factor over which the individual farmer may have relatively little practical control. It is manifested in several ways.

The water table may remain quite shallow in unflooded fields near rice, as a result of groundwater dynamics and seepage from irrigation ditches (Fig. 1). Because most tropical rice irrigation systems are designed for direct surface flow from field to field, and have a general lack of drainage facilities, it is costly and difficult to drain fields individually.

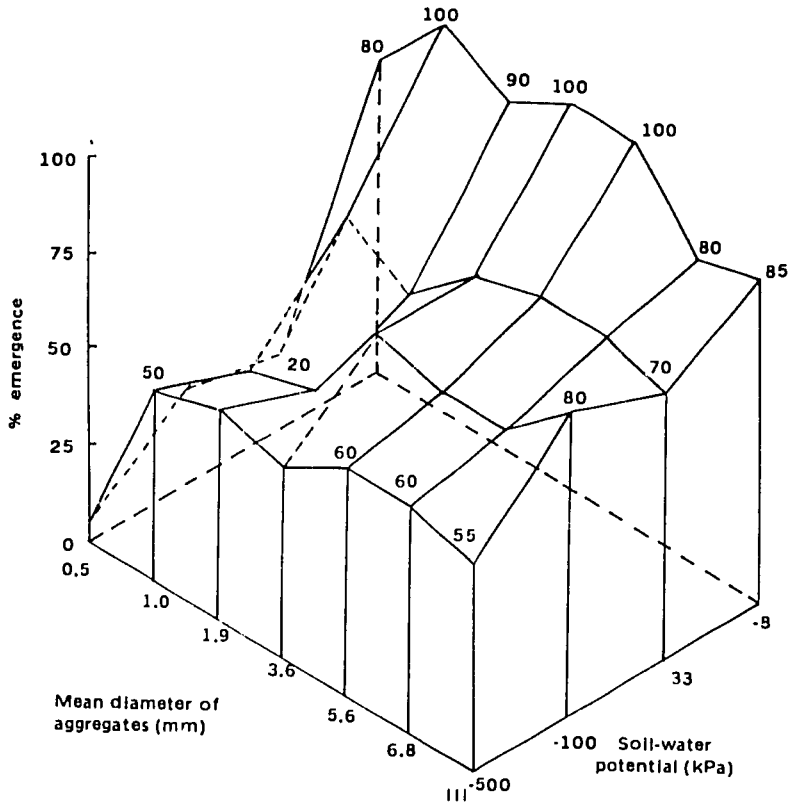


Fig. 5. Percentage emergence for CES 1d-21 mungbean at 25°C in a growth chamber, as affected by the size of soil aggregates and by soil-water potential. (The mean diameter of aggregates was obtained by mixing appropriate proportions of sieved aggregates of specific sizes).
Source: Woodhead *et al.* 1988

Prolonged oxygen stress may be created in the field at each irrigation event. Most rice soils have a compacted plow pan with very low hydraulic conductivity, inhibiting vertical water movement. When the field is irrigated, whether by flood or furrow irrigation, a temporary perched water table develops. The limited soil pore volume in the compacted subsoil layer and in the plow layer above it may remain saturated for days after irrigation. The corn root system, which is mainly confined to the upper 15 cm because of the high soil penetration resistance of the plow pan (Shen 1987), is injured or killed.

The concept of light, frequent irrigations as the basis for meeting the crop's evapotranspiration demand without inducing waterlogging, was tested. In the first year, corn responded linearly to N application and furrow irrigation frequency up to the maximum levels tested, 120 kg N/ha and 5 irrigations (Table 2).

Work by Moridis and Alagcan (1988) extended the concept to very frequent small basin irrigation. They observed a hybrid corn yield response of up to 9.17 mt/ha with nine post-plant irrigations, based on replacement of the moisture depletion from the top 0.15-0.20 m of soil (Table 3).

Such frequent irrigation requires complete

water control at the field level, which is feasible with shallow, privately owned wells. It may not be practical for larger communal or regional irrigation systems, where lack of control of water delivery may cause serious water scheduling problems. However, the high productivity achieved suggests that more serious attention should be given to developing a new class of large irrigation system management practices to interface with the efficient farm level techniques identified.

Nutrient Management

Initial fertilizer trials on corn in Guimba indicated that although corn responded to nitrogen fertilizer, the responses were not consistent across fields (Gines *et al.* 1990). Further work revealed that phosphorus and potassium were important additional nutrients. Basal application of the fertilizer at planting was very efficient, and corn responded best to frequent nutrient applications (at least three splits).

The tendency for the available phosphorus in flooded rice fields to decrease and become unavailable to subsequent upland crops is well known (Brandon and Mikkelson 1979). Muirhead (1979) observed that tissue samples from young upland crops after rice were deficient in phosphorus, despite high rates of phosphorus fertilization.

Available P was inherently low in the soils of the research site. We investigated fertilizer placement as a factor in increasing corn nutrient uptake efficiency (Gines *et al.* 1990). Placing N, P, or K in dibble holes near the base of the corn plant about seven days after emergence proved to be greatly superior to placing the same quantity of fertilizer in the seed furrows at planting (Table 4). Dibble placement was superior, both when nitrogen alone was applied (yield increase of 1.9 mt/ha), and when N was combined with P (2.6 mt/ha), and with P + K (3.16 mt/ha). This work clearly indicated that the uptake and utilization efficiency of nutrients applied to irrigated hybrid corn could be remarkably increased by rigorous attention to optimizing the fertilizer placement site, depth, and timing.

Table 2. Maize yield and yield components as influenced by N rate and irrigation frequency, Guimba, Nueva Ecija, Philippines, 1987.

Treatment	Grain yield (mt/ha)	100-grain weight (g)	Ear length (cm)
	80-30-30 kg NPK ha		
3 irrigations	3.6	20.6	10.1
4 irrigations	4.7	22.1	11.1
5 irrigations	5.0	23.5	11.5
	120-30-30 kg NPK ha		
3 irrigations	5.9	24.5	12.6
4 irrigations	6.0	23.9	13.2
5 irrigations	6.9	25.2	14.0
CV (%)	7.8	5.7	5.0
LSD (0.05)	0.01	2.0	0.9

Table 3. Evapotranspiration (ETP), desired and gross applications, overall efficiency and yield of three fields (F1, F2, F3). Guimba, Nueva Ecija, Philippines, 1988

Field	No. of irrigations	Total actual ETP (m)	Desired total application (m)	Gross total application (m)	Overall application efficiency (%)	Yield (mt/ha)
F1	7	0.284	0.300	0.330	91.1	8.08
F2	6	0.309	0.310	0.336	92.4	6.14
F3	9	0.327	0.350	0.374	93.7	9.17

Source: Moridis and Alagcan 1988

Table 4. Effect of fertilizer placement on the response of corn to fertilizer in a partially irrigated environment. Bantug, Guimba, Nueva Ecija, Philippines, dry season in late 1989

NPK (kg/ha)	Placement	Grain yield (mt/ha)	Germination count/ linear M	Total DM Yield (mt/ha)	Man-hour requirement/ ha
1. 150-0-0	Furrow[a]	2.97	74.00	13.83	23.77
2. 150-0-0	Furrow[b]	3.50	83.67	13.14	45.57
3. 150-0-0	Dibble	5.40	112.68	13.53	56.50
4. 150-30-0	Furrow[a]	3.20	75.67	14.43	22.13
5. 150-30-0	Furrow[b]	3.57	90.00	13.43	40.93
6. 150-30-0	Dibble	6.17	110.67	14.63	48.57
7. 150-30-30	Furrow[a]	4.53	79.00	14.00	23.80
8. 150-30-30	Furrow[b]	4.97	84.33	14.87	44.23
9. 150-30-30	Dibble	7.13	110.00	15.77	52.17
Difference between treatment means		**	*	ns	ns
LSD (0.05)		1.24	24.67	-	9.33
CV (%)		11.25	15.65	8.07	13.56
Orthogonal contrasts					
N vs NP		ns	ns	ns	-
N vs NPK		*	ns	*	-
NP vs NPK		*	ns	ns	-
Furrow[a] vs furrow[b]		ns	ns	ns	*
Furrow[a] vs dibble *		*	*	*	
Furrow[b] vs dibble *		*	ns	*	

[a] Apply fertilizer in furrow, plant seeds and cover by harrowing

[b] Apply fertilizer in furrow, cover fertilizer, plant seeds and cover by harrowing

Evolution of the Farmers' Corn Production System

The initial experience that most cooperating farmers in Guimba gained in corn production was not very encouraging. In addition to the serious irrigation and agronomic constraints that they experienced, there was much uncertainty about the development of a local market for the commodity. A corn market was nonexistent. Also, these small-scale farmers, each of whom was cultivating only 1-3 ha, perceived hybrid corn production as quite cash-intensive. There was concern about the availability of production credit for inputs.

Cropping pattern research continued as a cooperative venture between 12 farmers and the research team. Progressively, the farmers' refined their practices through experience and the annual infusion of research results obtained through the researcher-managed trials that were conducted at the site, a sample of which were discussed above.

Yields gradually increased (Table 5), and by 1987-88 the 10 remaining farmer-cooperators were averaging corn yields of 5.56 mt/ha. At this point, the local Land Bank was informed by the project staff of the potential for profitable diversification to irrigated corn. In 1987-88, credit was extended to a limit of US$130/ha. Commercial corn production began on a significant scale, occupying a major

portion of the higher landscape of the irrigation command area (Fig. 6).

Most farmers interested in the crop obtained their technical information concerning management practices directly from the research staff, who were based in the community. In the 1988-89 crop year, mean yields jumped to 6.69 mt/ha. The payment of irrigation fees was almost 100%. Among farmers who planted a second rice crop, which averaged 2.5 mt/ha, irrigation repayment was less than 1%.

Table 5. Yields of component crops in the rice-maize-mungbean pattern by crop year in a partially irrigated environment. Guimba, Nueva Ecija, Philippines

	Yield of component crops (mt/ha)		
Crop year	1st rice crop	2nd maize crop	3rd mungbean crop
1984-85	3.97	2.59	0.91
1985-86	4.70	4.45	1.10
1986-87	5.02	4.48[a]	1.07
1987-88	4.84	5.56	0.74
1988-89	-	6.69[b]	-

[a] Average yield of SMC 305 and IPB variety. In all other crop years, only SMC 305 was used

[b] Average yields of farmer's corn crop using SMC 305. Cropping pattern testing was discontinued from CY 1988-89

In crop year 1989-90, the operation of the deep tube well continued to be suspended, due to a shortfall in the repayment of the irrigation fees for rice. Farmers used shallow wells that they installed themselves to produce corn after rice. Over 80% of the dry season cropped area in the vicinity was planted to corn (Fig. 6), including fields in the lower landscape positions (lungog).

The current management practices employed by 20 of the local corn farmers were determined through interviews conducted in January and February, 1990, about one month after harvesting the wet season rice crop. All farmers are now hiring four-wheel tractors with a disc harrow for primary tillage. The fields are left to dry for about three weeks after disking, then flush irrigation is applied. When the soil moisture dries to below field capacity, the soil is harrowed with an animal-drawn harrow, then furrowed and seeded with a hybrid corn cultivar in 75 cm rows.

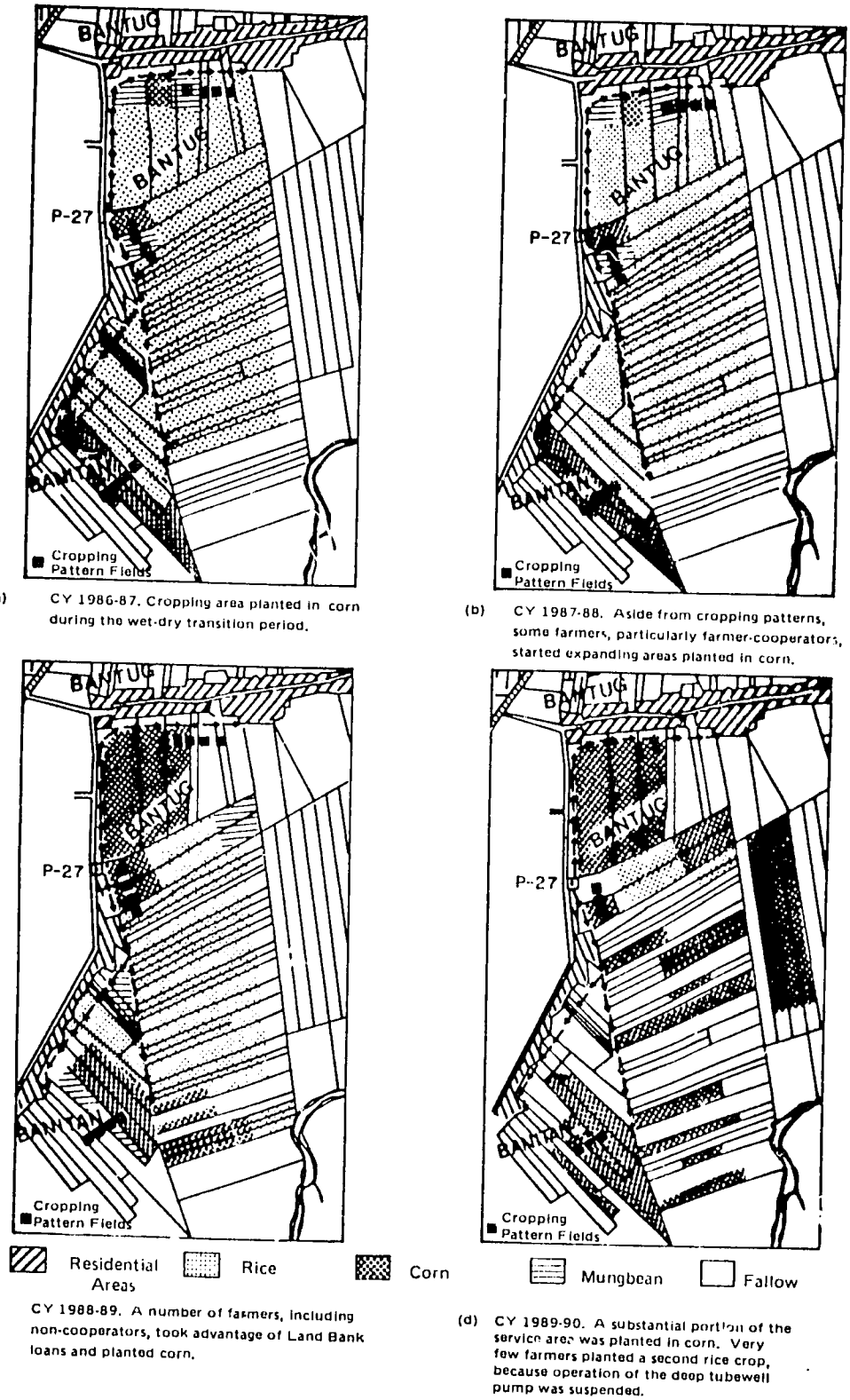
The average fertilizer rate applied by farmers was 92 kg N/ha, 20 kg P/ha, and 17 kg K/ha. All P and K and part of the N were applied basally in the furrows, together with the seed. The remainder of the N was spot applied at the base of each plant before hilling-up at about 32 days after emergence, or was drilled along the rows before hilling up.

Insect pest damage has not been significant since the crop was introduced to the location, and no pesticides were recommended. Nevertheless, all farmers applied insecticide as a preventative measure.

All irrigation water was supplied from privately owned shallow wells in the 1989-90 dry season. Farmers who did not own wells purchased water from their neighbors who did. The crop was irrigated 5 or 6 times, beginning after the off-barring operation (first cultivation), and continuing at two-week intervals until 15-20 days before harvest.

The price of corn increased from US$0.16/kg in 1988 to US$0.24/kg in early 1990. With corn prices higher than rice prices, with the development of the components of an efficient production technology for the local region, and with a critical mass of successful farmer experience with irrigated corn, current interest in the expansion of corn production after rice appears to have reached a take-off stage. Production is in fact now spreading beyond the research site. Further technical support, and financial and marketing encouragement, would be effective at this stage in expanding the production system.

A key aspect of the success achieved to date was apparently the sustained integrated research approach that was adopted. Plans are being developed to expand the research to other locations to explore the potential for replication. Of particular interest is the challenge of diversification in the command area



(a) CY 1986-87. Cropping area planted in corn during the wet-dry transition period.

(b) CY 1987-88. Aside from cropping patterns, some farmers, particularly farmer-cooperators, started expanding areas planted in corn.

(c) CY 1988-89. A number of farmers, including non-cooperators, took advantage of Land Bank loans and planted corn.

(d) CY 1989-90. A substantial portion of the service area was planted in corn. Very few farmers planted a second rice crop, because operation of the deep tubewell pump was suspended.

Fig. 6. Annual changes in the portions of the P-27 service area in Guimba, Nueva Ecija, Philippines, planted in corn and rice during the dry season, crop years 1986-87 to 1989-1990

of large reservoir-fed irrigation systems. However, in the immediate future, the greatest potential for large-scale irrigated corn development would appear to be in areas irrigated by the small-scale, shallow well systems that are being installed very widely.

SYSTEMS OF RAINFED CORN FOLLOWING RICE

The area of irrigated corn after rice in the tropics is currently modest, but there is considerable potential for expansion. In comparison, the area of post-rice rainfed corn is negligible. It is confined to very limited rice-growing areas with medium textured soils, where there is plentiful capillary rise from a shallow groundwater table. The viability of the system in more typical rice soils has not been confirmed. In the absence of irrigation or groundwater, the soil physical and hydrological constraints to the development of a stable, productive rainfed corn production system after rice have so far proven difficult to overcome.

The key to satisfactory yield in a rainfed post-rice crop is optimum husbandry of the limited supply of stored soil moisture, while at the same time avoiding the effects of waterlogging. The practical options for accomplishing this task are often at cross-purposes, and are much more limited in the absence of irrigation, since soil moisture can only be replaced by rainfall (if any) or by capillary rise from a shallow groundwater table (if any).

A considerable amount of research has been conducted on the establishment of rainfed upland crops following lowland rice over the past decade, at IRRI and by collaborating institutions in the Asian Rice Farming Systems Network. Although the majority of the work has been directed toward short-duration legumes, a significant amount of attention has been targeted to corn.

At IRRI, yields as high as 4.6 mt/ha have been obtained for rainfed corn grown under zero tillage conditions, during a dry season in which 450 mm of precipitation was received (Nadal and Carangal 1977). Pandey *et al.* (1987) reported rainfed corn yields after lowland rice of 2.63 mt/ha with 165 mm rain. With 153 mm rainfall and good land preparation, corn in Iloilo yielded 2.86 to 3.45 mt/ha (Carangal 1977). Zero tillage corn in Pangasinan receiving only 3 mm rainfall yielded 1.09 to 1.58 mt/ha at a site with a deep water table, and 2.33 to 2.94 mt/ha where there was a shallow water table. The instability of rainfed corn yields is very high. Several trials at these same sites were reported to give a yield range of 0.5 to 1.0 mt/ha or less (IRRI 1979).

Tillage and Crop Establishment

When a rice crop is harvested at the end of the rainy season, and a dry period follows during the growth stage of the succeeding corn crop, it is necessary to use a tillage method which allows planting of the upland crop shortly after the rice harvest. Such a tillage method must be able to conserve the maximum moisture possible for the later growth of the crop.

Crop waterlogging in the immediate post-rice period is a serious problem, because the internal drainage of the rice field has been deliberately destroyed. Surface drainage is ineffective, and conversion to an adequately drained upland field is very difficult. It is necessary to evaporate the excess water before or during the early growth of the corn seedlings, and then to conserve water for the reproductive phase.

Hadas and Russo (1974) found that the seedbed should be prepared in such a way that the mean soil aggregate diameter is less than one-fifth the seed diameter. However, the necessity to ensure proper seedling survival, and at the same time to conserve water by aggregating the top layer by tillage, are serious conflicting problems.

The choice of seeding method is influenced by a number of variables, including the often unpredictable weather and soil conditions at planting time. These factors influence the optimum depth of planting, and the resultant interactions are reflected in the degree of success in seedling emergence.

Seed germination and emergence are controlled by many environmental factors which in the field are difficult to manipulate. Soil compaction, nutrient status, and moisture regimes influence emergence and seedling growth. Water must be taken up for germination, and for root and shoot extension. The size of the seed determines the maximum depth at which it can be planted.

The oxygen consumption rate of corn increases as the seedling develops, a higher average oxygen diffusion rate being necessary for emergence than for germination (Wengel 1966). Local aeration conditions around the seed determine whether or not it germinates and emergence occurs.

The intensity of tillage affects the arrangement of particles in the upper soil layer, altering the movement of water in the topsoil and consequently the amount of water available to plants (Lal 1984). The coarser and less compact the seedbed, the more rapid is the loss of water.

Table 6. Tillage effects on germination, plant height and grain and straw yield of corn and mungbean

Tillage	Germination (%)	Plant height (m)	Grain yield (mt/ha^{-1})	Straw yield (mt/ha^{-1})	Germination (%)	Plant height (m)	Grain yield (mt/ha^{-1})	Straw yield (mt/ha^{-1})
Experiment 1	IRRI (Mungbean)				IRRI (Corn)			
Zero	93	0.43	0.41	0.47	90	1.3	0.6	0.8
Minimum	94	0.53	0.68	0.97	76	1.8	2.0	3.3
Conventional	91	0.56	0.78	1.01	74	1.9	2.1	3.3
LSD (5%)	NS[a]	0.08	0.20	0.32	11	0.2	0.6	0.9
Experiment 2	IRRI (Mungbean)				Bulacan (Mungbean)			
Zero	94	0.56	0.83	1.63	92	0.20	0.12	0.12
Minimum	93	0.61	0.96	2.44	90	0.23	0.16	0.28
Conventional	92	0.62	1.04	2.73	90	0.24	0.17	0.34
LSD (5%)	NS	0.04	0.09	0.35	NS	0.03	0.02	0.07

[a] NS: not significant

Zero tillage reduces the turn-around time between crops, and enables a succeeding crop to be planted earlier in a soil with a higher soil moisture content. Valuable soil moisture may be lost if thorough tillage for seedbed preparation is practiced. Herrera *et al.* (1978) observed that with low post-plant rainfall, a zero-tilled upland crop produced highest yields. However, where post-emergence rains occurred, complete tillage outyielded the zero tillage treatment.

Hundal and De Datta (1984) reported that sorghum grown after lowland rice in a clay soil at IRRI showed no significant differences in yield when zero-tillage and complete tillage were compared at three water table regimes. Khan *et al.* (1981) observed similar results with maize in West Bengal over two years.

When Sharma *et al.* (1988) grew corn on previously puddled riceland which had a shallow water table, seedling emergence was 15% higher with zero tillage than with minimum tillage. However, tillage increased the final plant height by 42%, root length by 61%, and grain yield by 242%. Zero tillage provided a more favorable soil environment at the beginning of the season, but later constrained the lateral and vertical rooting ability of the crop, seriously reducing crop growth later in the season. Such interactions make it difficult to predict the actual, as opposed to the theoretical, advantage of any given tillage treatment in a rainfed situation.

Zero-tillage is often considered superior to tillage in conserving soil moisture. How-

ever, Hundal and Tomar (1984) point out that although tillage enhances the drying of the tilled layer itself, it may reduce water movement from the layers below.

In many puddled soils, severe shrinking occurs, and deep cracks develop which greatly accelerate the desiccation of the entire plow layer. There is often only a perilously narrow window of a few days in which seeding will result in successful emergence (Fig. 7).

The concept of a very shallow, superficial post-rice tillage operation has been suggested (R.A. Morris, personal communication). This would create a thin soil mulch, disconnect cracks from the soil surface, and conserve moisture. The idea has not yet been

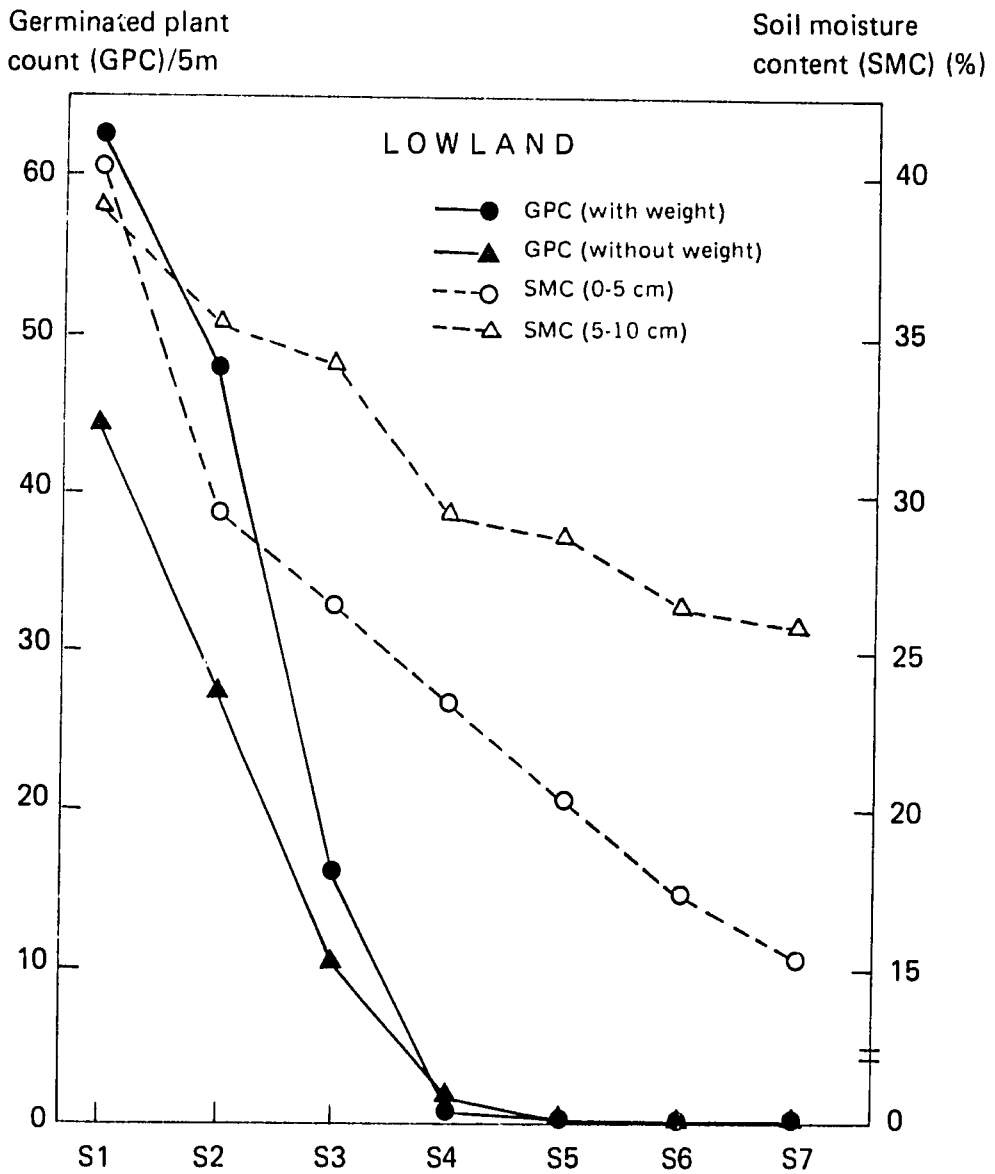


Fig. 7. Germinated plant count and soil moisture content as influenced by seeding dates. IRRI, 1982

Source: Naseem 1983

adequately tested on previously puddled soils.

The strip tillage concept has evolved to combine the separate advantages of complete tillage and zero tillage. Strip tillage is conceived as a means of optimizing soil conditions in both the seedbed and the rootbed. Excess water would evaporate faster from the tilled band, but would tend to be conserved in the untilled band for a longer period, diffusing horizontally toward the tilled band. Wittmuss *et al.* (1971), Hadas and Russo (1974), Bolton and Booster (1977), and Maghari and Woodhead (1984) found tillage in strips 10 to 15 cm wide beneficial for corn growth. However, Morel (1985) found that waterlogging damage to corn was more severe with strip tillage in the event of post-emergence precipitation than with zero tillage. The soil tilled in strips trapped and stored relatively more water than an untilled soil.

The way in which tillage is managed in the preceding rice crop also affects the response to tillage in the corn crop. These interseasonal interactions add further complexity to understanding the optimum tillage systems for rainfed corn. Syarifuddin and Zandstra (1978) examined the effects of tillage treatments given to the previous rice crop, as well as to the following corn crop. The three rice-growing systems tested were unpuddled nonflooded, unpuddled flooded, and puddled flooded. Superimposed on these were three tillage treatments on the corn: strip tillage, zero tillage, and complete tillage.

The previous rice-growing system of puddled-flooded reduced corn seedling density in the row-tillage plots. Zero tillage had the highest stand density, regardless of the previous rice-growing system. The more intensive the tillage, the lower the number of established plants. Soil puddling for rice cultivation was more detrimental to corn growth than was flooding alone. Nutrient uptake, growth and yield of corn on the puddled-flooded and unpuddled-flooded soils were better with intensive tillage than with zero tillage (Fig. 8).

Subsoiling, by opening up a narrow channel through the hardpan, has been investigated as means of improving rooting by increasing aeration and reducing the root penetration resistance of the soil immediately below the plow layer. Maghari and Woodhead (1984) found that root penetration of rainfed corn was faster and deeper in strip-tilled plots that had been tilled to a 35 cm depth than in conventionally tilled plots.

Recently, the concept has developed of seeding upland crops directly into fully saturated soils without tillage (R.K. Palis, personal communication). Since the seed is not covered, it does not suffer from oxygen stress. Complete mungbean seedling emergence was observed even from seeds of 12 to 16 cm deep (Garrity and Liboon, unpublished data). We are currently exploring this concept as a means of gaining time in establishing upland crops, before the soil drying front outpaces the root system of the developing seedling, and before increasing soil strength debilitates root growth.

Mulching with rice straw at 5 mt/ha significantly increased water use efficiency, grain yield, and nutrient uptake in rainfed corn grown after wetland rice. Residue mulching reduces soil temperatures, assists in weed control, and decreases evapotranspiration. The practical application of mulching, however, is severely restricted, since most Asian farmers either use the straw for livestock feed, or find it inconvenient to return the straw to the field from the spot where threshing occurs. Until harvest systems are developed that strip or thresh the grain where it is cut, the benefits of rice residue mulches will be unrealized.

Nutrient Management

Syarifuddin and Zandstra (1978) found that when the soil was previously puddled and flooded, the iron (Fe) content in rainfed corn decreased. As the amount of tillage prior to corn planting increased, the Fe content in the plant increased. The corn nitrogen content also increased with more intensive tillage, and was lowest when corn was planted without tillage after puddled flooded rice. Potassium, however, was not affected by different tillage treatments.

Fertilization dramatically increased rainfed corn yields, regardless of tillage treatment (Fig. 8). There was an extreme shortage of soil nutrients available for corn growth in the post-rice period, whether or not the soil had previously been puddled.

Crop Species and Cultivar Duration

There are rainfed crop options available

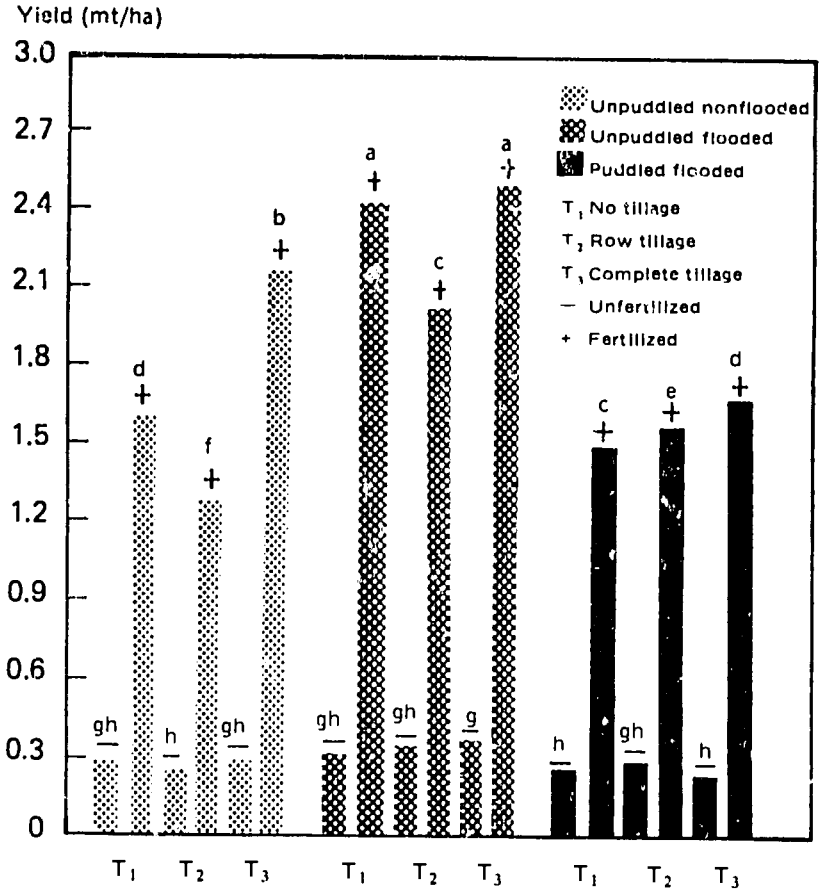


Fig. 8. Grain yield of corn as influenced by rice-growing system, tillage, and fertilizer treatment. Bars with a common letter are not significantly different at the 5% level. The fertilized plots received 60 kg N, 26 kg K/ha. International Rice Research Institute, 1978

for farmers other than corn. The grain legumes, particularly mungbean and cowpea, are attractive because of their early maturity (less than 70 days). The reservoir of available soil water is not adequate to support vigorous biomass production beyond this limit in most areas after the rice harvest. Very early maturing corn cultivars will be necessary if corn is to be fitted into this vast range of rainfed post-rice niches.

Among the full-season cereals, grain sorghum is more drought resistant than corn and will outyield it in situations where water is very limited (Samson *et al.* 1987).

THE RICE-CORN FIELD MODELED AS A SYSTEM

One factor emphasized in the above discussion is the complex nature of management decisions in post-rice corn production, particularly under rainfed conditions. We have not even attempted to discuss the implications of the wide range of post-rice climates to the choice of tillage, seeding, and fertilization practices.

The discussion does adequately signify that there is no one unique agronomic solution that is universally superior, even at a given site. Ever-changing circumstances will dictate

flexibility in the choice of technique. Therefore, as Sebillotte (1989) has argued, the underlying assumption that there is a direct relation between choice of technique and the resulting yield, that is:

Technique ———-> Yield

is overly simplistic and not a useful paradigm.

Fig. 9 is an attempt to represent the rice-corn field as a dynamic system, the soil and crop status of which responds continuously to changes in weather and hydrology, and to past and present management interventions. The state of the field's physical, chemical and biological properties is emphasized as one of constant flux. The status of these properties at the start of the corn season is represented by the variables P1, C1, and B1. Their values change with time during the season, but have a cyclic component from one year to another, as the field passes from corn back to puddled rice in the following crop year.

Weather conditions are shown to affect the field status directly at all stages through the crop season, and to influence the choice and effect of the specific management practices applied at each operation. The integrated effects of all these processes is expressed through the corn grain yield.

Such a systemic perspective provides a basis for a more sophisticated and holistic agronomic diagnosis of the problems of increasing yields, by providing a more effective evaluation of hypotheses about solutions. Table 7 shows an example of an application of this approach. The state of some important physical factors are tabulated for four experiments on tillage methods for rainfed corn after rice. The levels of the factors are indicated for two time periods during the growing season, thus isolating the interactions within discrete periods.

In the experiments conducted at IRRI, the comparative effects of the tillage methods were different within the respective growth stages. Zero tillage was superior during the establishment phase, and full tillage during the succeeding major growth to ripening phases (Table 7). The final crop performance indicators showed that full tillage was superior.

The concept proposed is one of monitoring the state of the determinants of yield across growth stages as a means of gaining greater insight into the dynamic interactions. Better quantitative relationships among these factors can then be derived, and diagnosis and predictability progressively improved.

Another device that materially assists teams of diverse disciplines to jointly focus on complex problems is the problem-cause diagram. These diagrams have been quite useful in cropping systems research (IRRI 1987), and have been successfully used by corn research teams in Asia (Dahlan *et al.* 1987). The diagram is built by specifying a major problem, and progressively identifying and isolating the contributing causes of the problem. Problems are decomposed into more and more specific causes through a flow diagram. Potential solutions are then linked with each specified cause. These provide the basis for the team's experimental research program.

Fig. 10 combines the conventional problem-cause diagram approach (Dahlan 1987) with the dynamic model of the rice-corn field over time (shown above in Fig. 9). It provides a basis for generating and examining proposed technical solutions across growing season time periods.

The growing season is divided into four phases. One overall crop-related constraint is identified in each time phase. The contribution of dominant causal factors to the problem is indicated, along with relationships between the causal factors themselves. A spectrum of potential solutions can be hypothesized as the next stage of the analysis. The growth-phase dependence of the diagram will reveal both positive and negative interactions resulting from the application of a given solution.

Although the above are still fairly crude tools, research teams are in need of such conceptual approaches to focus their combined efforts on complex interactive systems. We are attempting to develop and refine this approach in a number of our systems research projects at IRRI, and in collaboration with other centers.

We believe that a more determined theoretical framework will sharpen the analysis of constraints in both the irrigated and rainfed rice-corn rotation systems, and lead more rapidly to both technical and economic solutions to accelerate the development of this production system in tropical Asia.

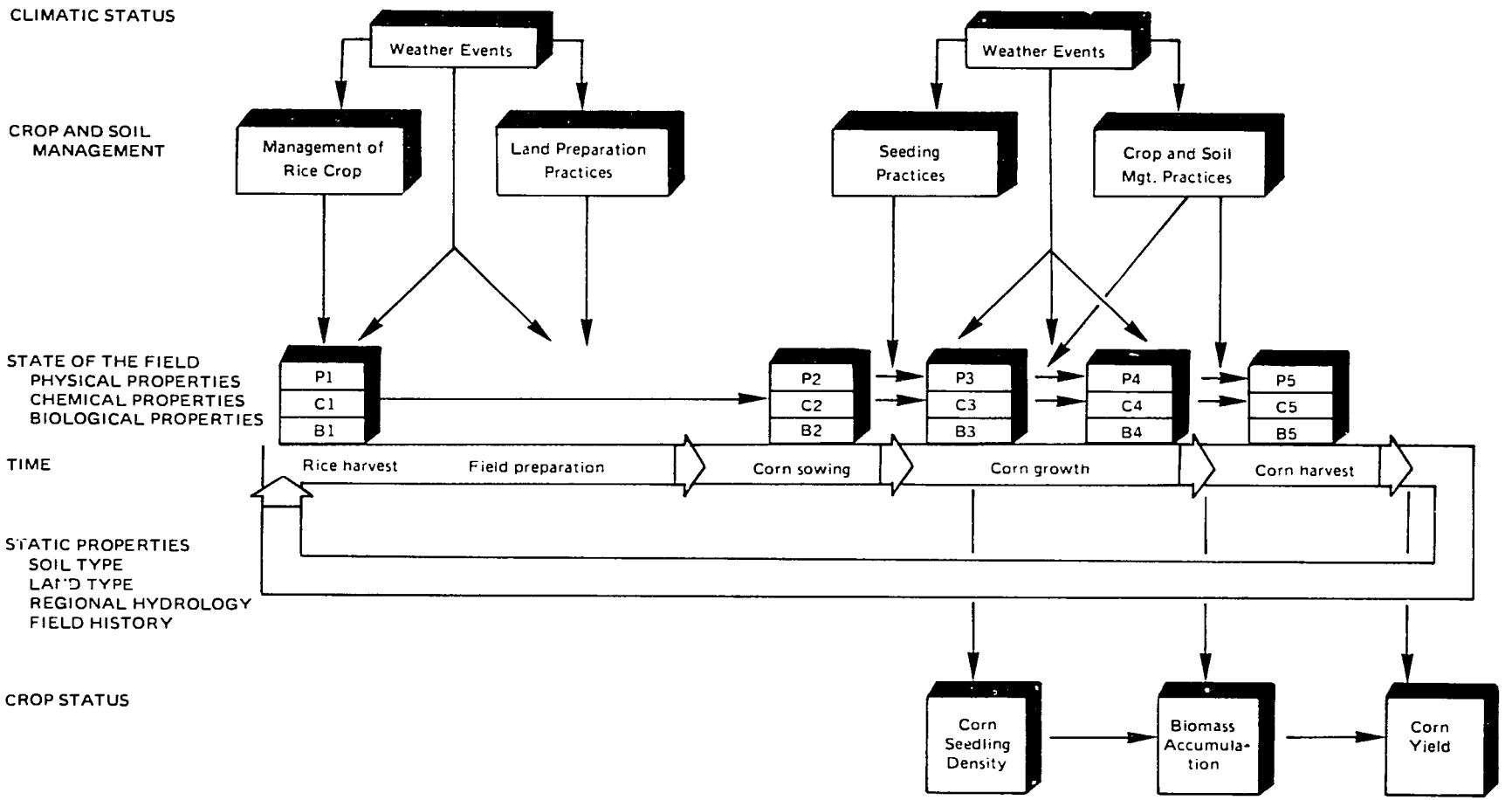


Fig. 9. The interactive relationship between management practices and corn yield

Table 7. Application of a growth stage model of field status to the determination of a superior tillage method for rainfed corn: four cases examined

	IRRI (Sharma *et al.* 1988)	IRRI (Syarifuddin *et al.* 1978)	Taitung R.O.C. on Taiwan (Shen 1987)	Wufeng R.O.C. on Taiwan (Shen 1987)
Planting/Establishment				
Rainfall to emergence	Adequate	Substantial	Substantial	Substantial
Water table	Shallow	Deep	Shallow	Shallow
Soil moisture	Near saturation	Drained	Near saturation	Near saturation
Soil strength: plow layer	Moderate	Moderate	Moderate	Moderate
subsurface	Moderate	High	Very high	Very high
Major constraint	O_2 deficiency	O_2 deficiency	O_2 deficiency	O_2 deficiency
Superior tillage method	Zero tillage	Zero tillage	Zero tillage	
Growth to ripening				
Rainfall	Significant	Significant	Significant	Significant
Water table	Shallow	Deep	Deep	Deep
Soil moisture	New saturation	Low (dry)	Drained	Drained
Soil strength: plow layer	Moderate	High	High	High
subsurface	Moderate	High	Very high	Very high
Major constraint	O_2 deficiency	Water deficient	O_2 deficiency	
Superior tillage method	Full tillage	Full tillage	Zero tillage	
Overall				
Superior tillage method	Full tillage	Full tillage	Zero tillage	Zero tillage or tillage with subsoiling

[a] Fall planting

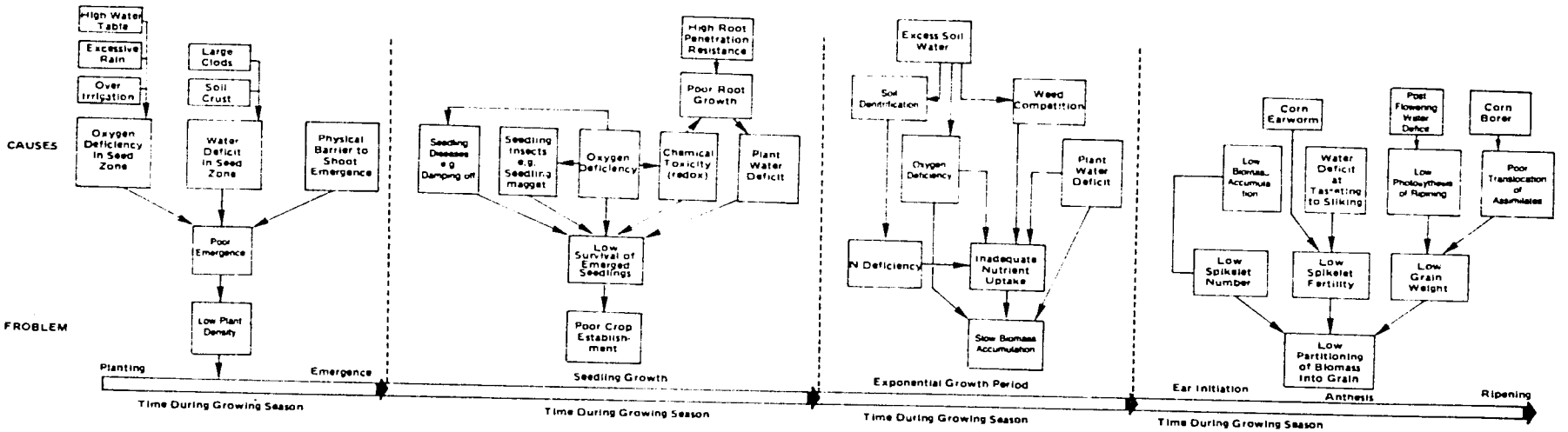


Fig. 10. Growth-stage specific model of production constraints and causes: rice/corn rotation

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DISCUSSION

Q. (Chamnan Chutkaew)
Your paper is very interesting, but the problems are obviously complex. How long do you think it will take to get a 100% expansion of the corn planting area in the Philippines?

A. It will take a long time, and may never happen. Other crops such as mungbean can also be grown after rice, and many of these have a shorter growing period and lower water requirements. It would be unrealistic to expect that corn must be dominant in all systems. I would suggest a broader approach, of increasing upland crop production with corn playing an important role.

Q. (S. Lian)
I am very impressed by the wide spectrum of considerations you have covered. When do you expect to have a simulation model?

A. This work is still in progress. What I am hoping to achieve is not a full simulation model, but a conceptual model. It is very difficult to quantify centain of the various reactions for a simulation model. In the meantime, agronomists can use a conceptual model to understand the relationships between variables, even if they cannot quantify them.

Q. What pest management practices were used?

A. The incidence of pests in the area was quite low, and there was no significant reduction in yield due to corn borer or other pests. Farmers universally apply pesticides such as chemical sprays and Furadin to their corn crops, probably because they are used to applying them to rice. Farmers tend to use these as prophylactic sprays against anticipated pest problems, rather than as a response to actual ones.

Q. (D.A. del Rosario)
There are two major problems in growing corn after rice, excess soil moisture and water deficiency. Since we have only limited personnel in the Philippines engaged in plant breeding, which problem do you think we should tackle first, and which growth stage should we emphasize? We are screening corn varieties now for tolerance to both water deficiency and excess soil moisture, but we have to establish priorities in view of our limited resources.

A. I am more familiar with the problems of water shortage, but I suspect that the genetic potential for resistance to waterlogging is better in the short term than resistance to drought, since there is more genetic variability in the extent to which corn can survive waterlogging. As far as the growth stage is concerned, waterlogging is particularly important when corn is at the seedling stage. At the reproductive stage it is drought tolerance which is particularly important. I do not know whether there is any linkage between the two traits, whether they are complementary or mutually exclusive, or whether there is no relationship at all between the two. I have not come across any work which considers both factors.

Q. I note that in experiments on fertilizer placement, dibbling gave the best results. Is dibbling a practical technique for local farmers to use?

A. Table 4, giving the number of man-hours of labor for the various types of fertilizer placement, shows that dibbling takes up to 56 man-hours per hectare, and has a much higher labor requirement than furrow placement. Whether it is practical or not thus depends partly on the availability and cost of labor. However, fertilizer dibbling can be mechanized, and given the efficiency of the response, seems to be an efficient practice with high returns.