Opportunities for soya beans after rice in the Philippines: an exploration by simulation

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Preface

This paper resulted from multidisciplinary studies at the International Rice Research Institute (IRRI), Los Baños, Philippines, on multiple cropping in rice-based cropping systems. After years of experimental research, exploration of new cropping systems was accelerated by adding simulation modelling to the research techniques of the Multiple Cropping Department where the authors worked together from 1988 to 1990. Several papers and theses resulted from the collaboration. This report documents one of the main models, its testing and its application. It has been written with potential users in mind of the project Simulation and systems Analysis for Rice Production (SARP), a training and collaborative research project of IRRI, CABO and TPE.

Research and documentation were almost completed by the end of 1990, when the first author moved from IRRI to CABO. However, it took until Dr J. Timsina, now in Nepal but formerly at the Multiple Cropping Department, visited CABO and completed this document. Our apologies to colleagues who waited long time for this report to become available. In this period, D. van Kraalingen removed an irritating bug from the program (by changing the variable 'RUN' into 'IRUN'), that sometimes caused the original program to hang at some computers.

All programs (in CSMP) and tools for economic analyses (in Microsoft EXCEL), plus the text of this report (in MS-WORD, but without the figures) are available.

Abstract

The potential production of soya bean crops in the Philippines under irrigated and rainfed conditions on lowland rice soils and upland soils was simulated with SOYCROS, a general crop model adapted for soya bean in partially saturated soils. The model was evaluated with field experiments. It was applied for 8 locations in the Philippines, with monthly sowings. Simulations were performed for 20 years of weather data, providing information about the average yield and probabilities of risks for each of the treatment.

Grain yields vary from 1.5 to 4.2 t ha^{-1}, the highest values being obtained at the coolest locations and on deep soils. Fully irrigated crops show little seasonality as temperatures are favorable throughout the year. Rainfed crops are productive only on deep soils in the South with favorable rainfall distribution.

We demonstrate how crop modeling can guide agricultural research. It appeared that capillary rise can be very important. To determine the production potential for dry season crops on rainfed lowland, knowledge of the water table and of the saturated hydraulic conductivity of the soil is therefore of major importance.

The model permits the economic analysis of soybean production in an MS-EXCEL program. Net profits vary from -500 to 1000 US$ (-10000 to 20000 Peso), the highest profits obtained from its cultivation in rainfed and irrigated lowlands in Baguio. Net returns from the saturated soil culture are always positive and more stable than for any other land types in all locations, suggesting that the crop can be profitably grown under such culture in all months in all the locations.

The results suggest that the SOYCROS can be used for Asian rice lands with varying moisture and water table depth regimes. Implications of the simulation results, to policy makers and planners, researchers and extension workers, and to the farmers are also discussed.

1. Introduction: why research on potentials of soya bean crops?

Consumption of soya bean in South East Asian countries is low, but growing fast. Annual consumption of soya beans plus soymeal per capita in the Philippines, for example, was only 7 kg in 1983, and it grew by 15 % annually in the preceding decade (Rosegrant et al., 1987). Most of the soya bean and all of the soymeal is used as animal feed. Only 5 % of the soya bean is produced in the country. The situation in Indonesia is similar (Bottema, 1986). In addition to providing food and feed, soya bean crops increase level and stability of farm income (Senthong and Pandey, 1989) and improve soil fertility (de Datta and Morris, 1983). Moreover, crop diversification is desirable in rice-cropping systems to break pest cycles (Pandey, 1987). The Philippine government stimulated soya bean production. As a result, the harvested area grew from 1,500 ha in 1970 to 10,000 ha in 1976, but remained constant since. Production is concentrated on the southern island Mindanao where it is a rainfed upland crop, but it is being stimulated in other parts as well. Rosegrant et al. (1987) suggest that use of inappropriate cultivars and poor seed quality cause low production. The Philippine Council for Agriculture, Forestry and Natural Resources Research (PCARRD) advocates a technology to increase soya bean yields in uplands to 1.5-2.0 t ha^{-1}. Price support for soya bean production in the seventies and eighties was significant (Rosegrant et al., 1987). The average soya bean import price was about 0.28 US$ kg^{-1}. The soya bean price at the farm gate was 50-100 % higher. With production cost at 0.15-0.3 US$ kg^{-1}, farmers netted profits of 100-150 US$ ha^{-1} per crop (Rosegrant et al., 1987; PCARRD, 1987).

The best Philippine farmers harvest 1.5-2.0 t ha^{-1} soya beans (PCARRD, 1987), but the average regional yields remained about 1.0 t ha^{-1} in the decade that the area remained constant. This average is one fifth of the highest yields attained in the tropics (5 t ha^{-1}), and much below the world average of 1.9 t ha^{-1} (Whigham, 1983). The worlds major soya bean production zone is between 25 and 45° latitude and below 1000 m elevation.

The International Soya Bean Program (INTSOY) carried out production trials with more than 20 cultivars in 47 tropical and subtropical countries (Jackobs et al., 1986). The cultivars can be grouped as early, medium and late maturing (about 90, 100 and 115 d from seeding to maturity). Trials are performed on well drained soil with NPK fertilization and management for potential production. The tropical cultivars in average, yielded 1.8 t ha^{-1} (Sulzberger and McLean, 1986).

While most soya bean production occurs in uplands with a deep soil water table, soya beans can be grown in tropical lowlands in very wet soils. Particularly as a crop following rice, it attracts attention (Pandey et al., 1987). Tedia (1988) found soya beans to yield up to 3 t ha-1 in the dry season in Los Baños. Two constraints are specific to crops in rice-based systems: the soils are usually heavy and may have a hard pan, which impede drainage and cause waterlogging, and the planting date depends on the preceding rice crop. Flooding can lead to large yield reductions in soya bean (Whigham, 1983; Carangal, 1986). But while brief periods of high soil water contents may harm the crop, some soya bean cultivars grow very well in a stable, nearly-saturated soil culture (SSC) with a water table at only 0.05-0.2 m, as recent research in Australia and Thailand demonstrates (Nathanson et al., 1984; Troedson et

al., 1986; CSIRO, 1987). Alagos (1990) obtained a yield of over 4 t ha^{-1} in conditions similar to those of Tedia (1988) with SSC.
In this report, we try to answer the questions:

- what is the yield potential of soya bean in Philippine lowlands and uplands (i.e. after problems on crop protection and agronomic practices are solved)?
- on what subjects is research needed to achieve those potentials?
- does the potential agronomic yield translate into a high financial yield for farmers?

These questions cannot be answered by experiments only. Trials would have to be repeated for many years and at many locations. A theoretical approach for establishing the potentials for soya bean production is helpful. Therefore, a simulation crop model is extended, evaluated and then applied to determine the average potential production of soya bean at several sites in the Philippines. 'Potential production' refers to the situation where the field crop is grown with good management and ample fertilizer, and where all yield reducing factors (weeds, pests and diseases) are eliminated. The potential is fully realized when there is continuously ample water. With limited water, the yield obtained is called 'rainfed potential production'. Only physiological characteristics, weather and soil characteristics determine the yield potential. Due to weather variations, the potential yield changes from year to year.
To include the notion of risk, 'potential production' will refer to the grain yield (14 % moisture) that is exceeded in 75 % of the years.

2. The model SOYCROS

Specific soya bean models have been published, including SOYGRO (Jones et al., 1988) and one by Sinclair (1986). The models do not consider soils with impeded drainage and capillary contribution of a water table, typical for rice-based cropping systems, and can therefore not be used for our objectives. Three modules (L1D, L2C and L2SS) from the MACROS series (Penning de Vries et al., 1989) were combined into SOYCROS, a model to simulate soya bean growth on soils with impeded drainage. SOYCROS is written in the simulation language CSMP (IBM III, 1975) and runs on PC's; it is listed in Appendix I. A copy is available on request.

Model structure. SOYCROS is a summary model on crop physiology, agrometeorology and soil physics, with additions pertaining to water stress and functioning of roots. In the model, daily rates of crop photosynthesis, respiration, carbohydrate partitioning, phenological development, transpiration, and of infiltration, drainage and movement of water in the soil are calculated in relation to the status of the crop, the soil water and current weather conditions. Nitrogen balance processes are not explictly simulated. Rates are integrated at the end of each day to update the weight of the crop organs and the water contents of the soil layers. The cycle is repeated until the end of the growing season is reached. Figure 1 shows an outline of SOYCROS.

The following features were added to the original modules:

1. There is a choice of four crop management situations: rainfed and irrigated upland and lowland fields. Uplands are characterized by light soil and a deep water table depth. Lowlands have a heavier soil type, and a variable shallow water table depth but irrigated crops are continuously flooded (Appendix I, lines 60-62, Appendix II explains names of variables); the latter case is also referred to as saturated soil culture (SSC, Summerfield and Lawn , 1987; Troedson et al., 1985; Lawn and Byth, 1985). In upland situations, irrigation corresponds with 80 % of the Class A pan evaporation in the preceding irrigation interval minus rainfall, and for SSC with the total of evapotranspiration minus rainfall, augmented by 25 % to account for conveyance losses (Lines 431-434). The irrigation interval on uplands is 14 d (cf. PCARRD, 1987). Bunds are absent. The soil surface is supposed to be moderately flat (surface storage capacity 0.02 m), except for SSC (flat surface); surface storage is an important feature in flooding and hence for germination and survival.

2. Simulation starts at the beginning of a turn around period between crops and before sowing (lines 132-151). This permits the soil water balance to be adjusted to the weather of the weeks preceding germination. The duration of the period can be modified, but was 15 d for this study (line 503).

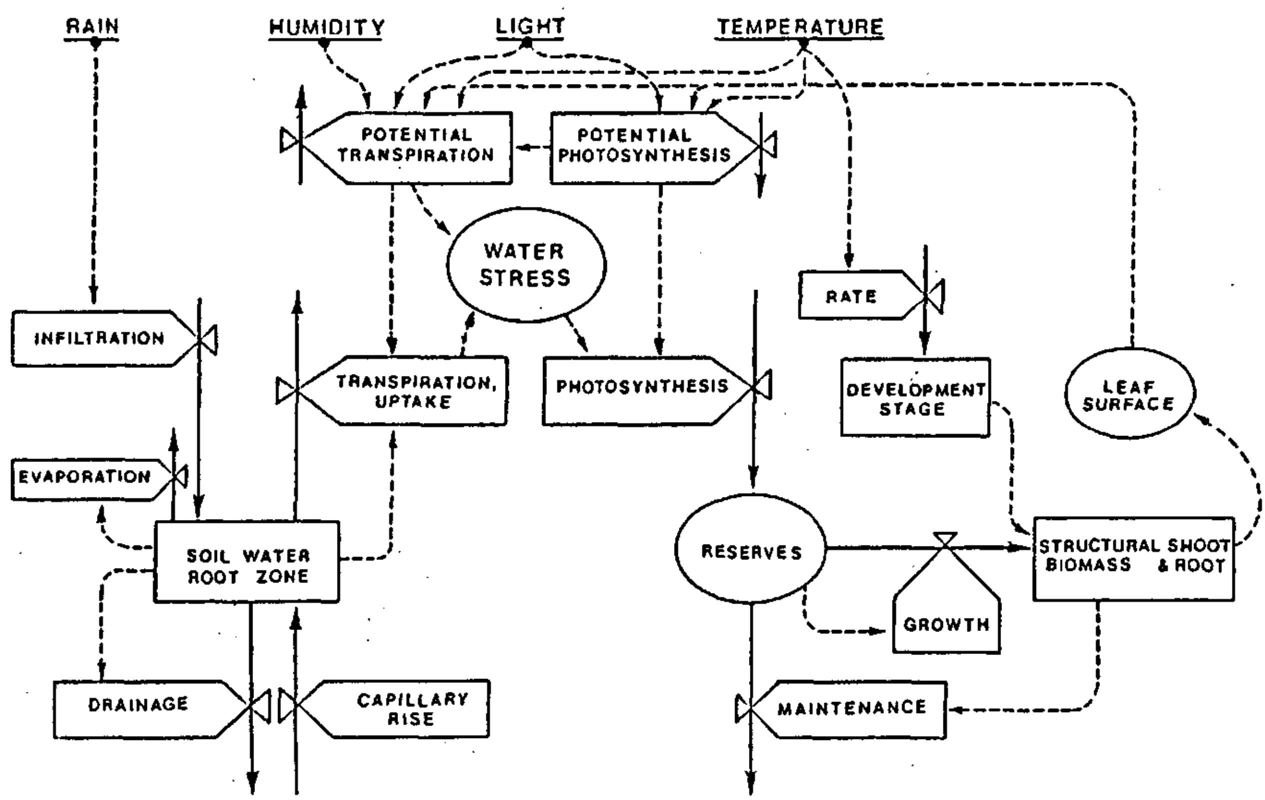


Figure 1. A relational diagram of the SOYCROS model with a crop (right) and a water balance part (From: Penning de Vries et al., 1989).

3. Germination. The seeds are 'sown' on a specified date (DATEB+TAP, line 135). The germination process starts immediately if the soil is not too wet (more than 97 % of the saturated soil water content) or too dry (less than 80 % of field capacity). In favourable conditions, soya bean seeds emerge in 4 d. The crop emerges when the germination status reaches the value of 1.0 (dimensionless) (Line 146). If the soil becomes too wet or too dry, the germination process reverses. If the crop does not germinate within 30 d, it fails and simulation is halted (line 149: FAILG). This simulation of germination is derived from Timsina et al. (1992a) and Diputado and del Rosario (1985). At emergence, the roots are 0.05 m deep. When the top layer is dry, young plants may die. But if its water content permits roots to grow a few days, deeper layers are reached that generally contain more water and the plant survives. Leaves and stems have an initial weight corresponding with the seed rate applied.

4. Effect of N-redistribution. Redistribution of nitrogen (N) from leaves to grains in the reproductive period is pronounced in soya bean. It leads to lowering of the maximum rate of leaf photosynthesis and to loss of leaf area (Sinclair and de Wit, 1976; Sinclair, 1986). We assume this maximum to decrease progressively during the final four weeks from zero to 0.1 d^{-1} at physiological maturity (line 557). Loss of leaf area increases from 0.02 to 0.1 d^{-1} during the final two weeks for the same reason (lines 587-590). Both loss processes are mimicked in this way, and simulated dynamically but not mechanistically.

5. After-effects of water stress. Water stress is defined as the ratio of actual crop transpiration and the transpiration of the crop with ample water, and may run from 0.0 to 1.0 (no stress). This ratio is not affected by nutrient stress (Tanner and Sinclair, 1982; Van Keulen and Seligman, 1987). In addition to the instantaneous effect of water stress through stomatal closure, there is a cumulative effect: the longer stress lasts, the more severe is the effect (Van Keulen et al., 1982). During drought, soya beans are more stressed by lack of N than by lack of assimilates (Sinclair, 1986; CSIRO, 1987). This leads to a reduced leaf N-content and, consequently, to a lower maximum rate of leaf photosynthesis and accelerated leaf senescence. This cumulative effect is approximated by treating the maximum rate of leaf photosynthesis as a state variable (line 215), the value of which decreases by 0.05-0.15 d^{-1} once the average stress level is below 0.7 (line 221). Its value increases when drought is relieved at a stress level above 0.8 by 0.1 d^{-1} when leaves are still growing (lines 217). The rate of leaf senescence is assumed to increase by 0.05-0.1 d^{-1} when the average stress level drops below 0.5 (line 185). There is only circumstantial evidence for these values. Average stress is a running average of the current stress, calculated with a time coefficient of three days (line 297). The effect of water stress on leaf area is added to the rate of loss of leaf weight due to stress (line 182).

6. Roots in anaerobic soil. Soya bean seeds germinate in an aerobic environment. Roots extend downwards till about one week after flowering (after which pods are a strong sink for carbohydrates). When the soil imposes no limitation to penetration, the rooted depth increases by 0.03 m d^{-1} to a maximum of 1.2 m or more. When soil water content increases, the continuity of its air channels is interrupted, the soil turns anaerobic quickly (Meek and Stolzy, 1978) and most roots die. In such conditions, the effective depth of rooting decreases rapidly, and is assumed to be halved each day (Taylor, 1980). This would kill the crop in a few days if not an alternative rooting system develops concurrently to adopt the task of water absorption. Under a shallow water table (0.05 - 0.25 m), thick roots develop just above the fully saturated zone. Diffusion

through the remaining air channels provides them with sufficient O_2 to grow and function (Armstrong, 1980; Jackson and Drew, 1984; de Willigen and Van Noordwijk, 1987; Lawn, pers. comm.), and to sustain high rates of nodulation and nodule activity (Troedson et al., 1986). We assume that growth of acclimated roots is induced when the air volume in the top soil layer is between 1-5 $cm^3 cm^{-3}$, provided that the crop is still young enough to grow roots (line 334). These roots grow slowly and do not grow deep. When the air content drops below 1%, the flow of O_2 is too low and these adapted roots also die. The acclimation process implies that soya bean performs well on soils with a high but stable water table, and that damage by brief flooding in an early stage can be overcome; waterlogging in a late stage is always disastrous. The relation between the rate of water uptake by roots (relative to the potential transpiration) and the soil water content is expressed in Figure 2. The effect of low water contents reflects the consequence of drought. The response to high water contents, between field capacity and saturation, is due to lack of O_2: the uptake of water by the upland rooting system is strongly reduced under anaerobic conditions. The alternative rooting system is close to the surface and does not suffer from anaerobiosis. When both root types are present, the weighted mean of both depths determines the water uptake reduction factor (line 351). The computation of the depth of the normal and acclimated root system are contained in Appendix I, lines 324-349.

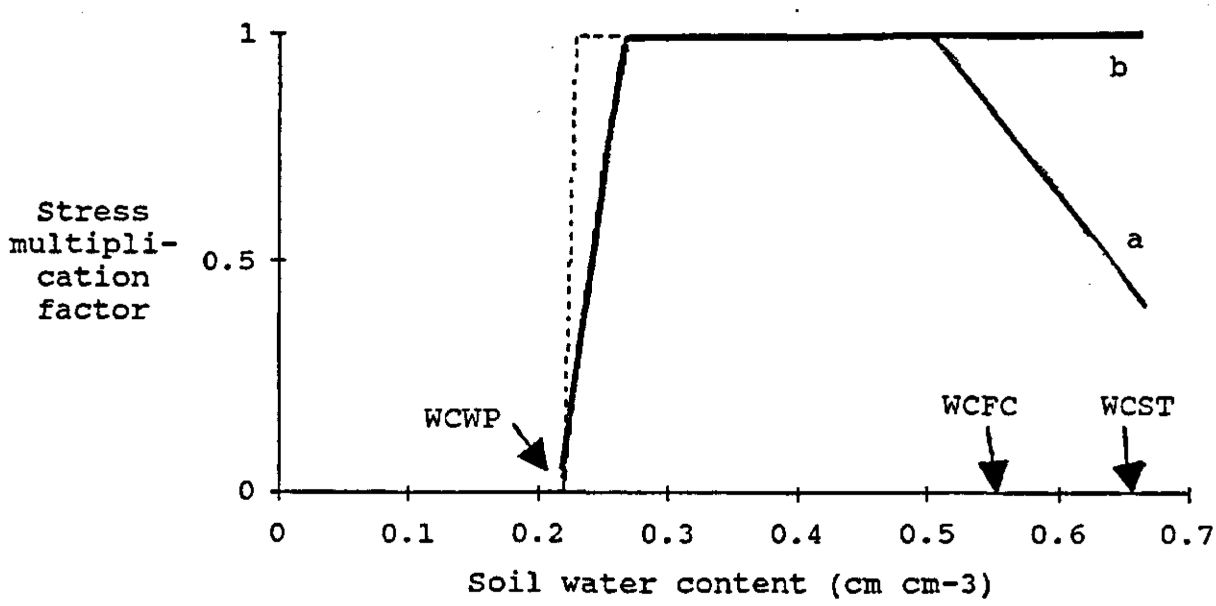


Figure 2. Water uptake reduction factor as a function of the soil water content for upland (a) and lowland (b) root systems. The dotted line shows the response under high evaporation conditions. Water contents at saturation(WCST), field capacity (WCFP) and permanent wilting (WCWP) are marked.

7. Maximum rate of water absorption. Our model uses Van Keulen's (1975) concept of a similar rate of water extraction at all depths (when conditions are the same throughout). At an optimal soil water content, this rate (TRRM) is obtained by dividing the potential canopy transpiration rate by the rooted depth. When rooted depth decreases in response to waterlogging, TRRM increases. We chose to maximize this rate to 100 mm d^{-1} m^{-1}, or 10 mm d^{-1} for a root system only 0.1 m deep (lines 315-317) to avoid unrealistically high values. Yet, high transpiration demand may lead to water stress when live roots are very shallow, such as after sudden flooding.
8. At initialization, model-leaves have the full capacity for photosynthesis. This is not quite correct, because the first trifoliate leaves have a low N-content as nodulation is not yet effective. On the other hand, dicotyledons provide reserves for seedling growth (Whigham, 1983; Woodward, 1976). We assume that both aspects compensate each other.

Model data. The types of crop, soil and weather data plus those related to crop management are shown in Table 1. All data are as reported previously (Penning de Vries et al., 1989), except for those presented in the next paragraphs.

Table 1. Crop, soil, weather and management data that should be chosen or selected carefully.

Crop:
Crop duration
Development rate towards emergence, flowering, maturity
Partitioning of biomass under optimal conditions
Sensitivity to water stress and flooding
Soil:
Saturated hydraulic conductivity
Water table depth
Soil types in the profile
Maximum rooted depth
Weather:
Daily precipitation
Radiation
Temperature
Management:
Duration of turn around time
Thickness of top layer
Irrigation schedule
Initial conditions:
Leaf, stem and root weight of seedlings
Moisture content of soil profile per layer

The soya bean cultivar SJ.2 was selected. It is a determinate, medium duration variety (33 d from emergence to begin of flowering, plus 60 d to maturity) and is grown commercially in the Philippines. It is a recommended cultivar by PCARRD (1987) and is insensitive to daylength. It is assumed that roots can grow down to 1.2 m at a rate of 2.8 cm d^{-1}.

Lowland soil is represented by 0.2 m of silty clay loam overlaying light clay, and the upland soil by 0.2 m of sandy loam on top of silty clay loam (Escano et al., 1985; Rebancos, 1985). The conductivity of the silty clay loam (not measured in situ) was increased from the standard 1.5 to 10 cm d^{-1} to improve drainage and allow the top layer of the upland soil to reach field capacity after a large rain in one day, as is common in field conditions (Garrity, IRRI, personal communication). The increase reflects cracks or animal activity in the soil. Water that does not infiltrate in this period fills the surface storage capacity, and runs off when its limit is exceeded. The soil is specified to be 1.2 m deep and is divided into 7 layers (2x0.1, 5x0.2m).

In SOYCROS, water for evaporation is withdrawn from the upper layer. Capillary rise can replenish it, unless the potential evaporation rate is very high, as on bright days in the tropics. In situations where it is known that ploughing leads to drying of a thicker layer, the thickness of the top layer in SOYCROS should be increased. For non-tilled soils, its value should be lower. The success of germination is related to the thickness of the top layer. Upland soils have a constant, deep water table (10 m), which does not supply water to the crop. In lowland conditions, a shallow water table permits substantial capillary rise. From a study on water balance dynamics on the IRRI farm (Herrera-Reyes, 1988), the following lowland water table pattern was adopted: 0.35 m depth during the rainy season, 1.2 m in the dry season, and receding at 0.04 and 0.02 m d^{-1} in the dry season and wet season, respectively, for every day without rain, to a maximum depth of 1.5 m, and returning to the first level after rain (Figure 3). Values for hydraulic conductivity or water table dynamics in

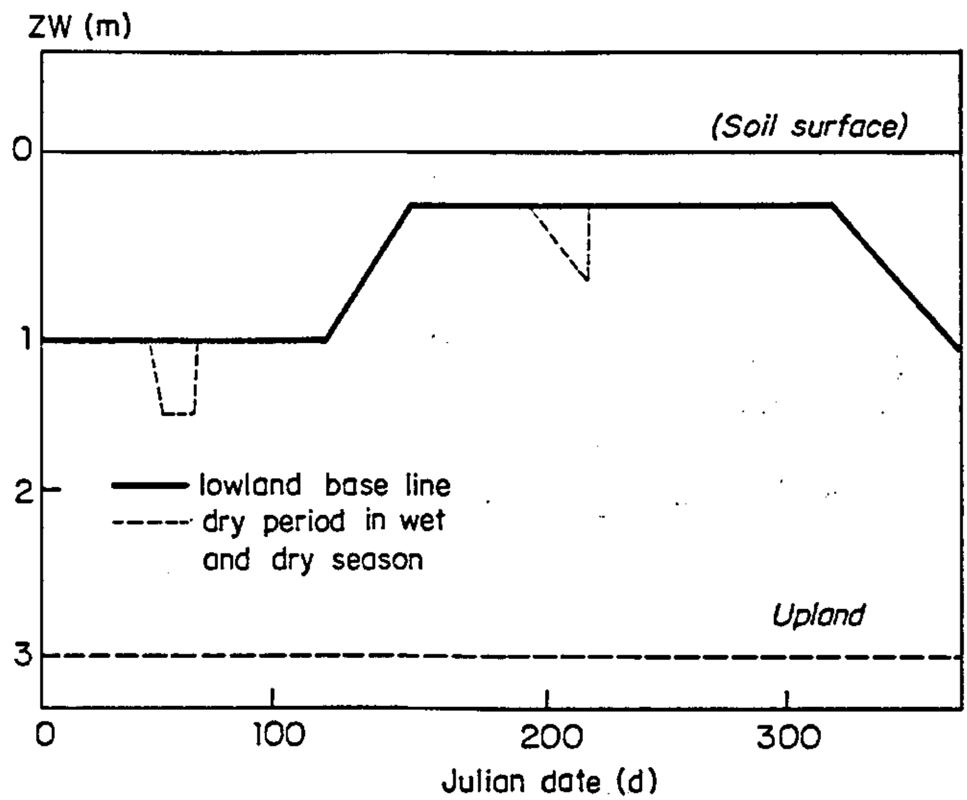


Figure 3. Water table depth in lowland and upland conditions in Los Baños; dotted lines refer to the lowering of the water table in dry periods (From: Herrera-Reyes, 1988).

the Philippines are unavailable to us, so that we cannot claim generality of the rainfed lowland results. No single water table pattern may be truly representative for rainfed lowlands because the topography of the area is important for water table dynamics. We suggest that such observations be made in all future rainfed lowland experiments. For the saturated soil culture simulations, the level of the free water table is 0.1 m and the saturated conductivity of the deepest layers is set to a non-limiting value to mimic lateral inflow from furrows.

In the Philippines, temperatures are rather constant, so that climatic zones are distinguished based on rainfall (Lansigan et al, 1987). The wettest part has 2 dry months (below 100 mm) and 9 wet months (above 200 mm), the driest part has 6 dry months and 3 wet months. We chose as representative sites the cities of Aparri, Tuguegarao, Baguio, Los Baños, Iloilo, Dumaguete, Davao, and Tupi (Figure 4). Some important characteristics of the sites are given in Table 2. Weather data for Los Baños were obtained from IRRI's station; all other data were obtained from the Philippine weather bureau, PAGASA. For all sites other than Los Baños, only 5-8 years of recorded weather data were available. This is insufficient for stability analysis, so that daily weather data were generated to complete sets of 20 years, using the program by Supit (1986), based on Richardson and Wright (1984). This program generates weather data in patterns that cannot be distinguished from recorded data, though rainfall and wind in typhoon conditions are not reproduced (Lansigan et al., 1989).

Table 2. Characteristics of the sites for which soya bean yields are simulated. Figure 3 shows their locations. Observed weather parameters are averages for the number of years specified.

LOCATION	LAT.	ELEV. (m)	NO. OF YEARS	ANNUAL RAINFALL (mm)	TEMPERATURE MAX (°C)	TEMPERATURE MIN (°C)	SOLAR RADIATION (MJ $m^{-2}d^{-1}$)
APARRI	18.2	3	5	1956	27.0	20.4	12.3
BAGUIO	16.3	1500	8	3404	24.2	15.1	17.8
DAVAO	7.0	125	4	2079	31.9	23.3	16.3
DUMAGUETE	9.2	6	6	1142	30.8	24.4	17.8
ILOILO	10.4	8	7	2241	31.9	24.0	17.3
LOS BAÑOS	14.2	21	20	2026	31.4	22.6	16.8
TUGUEGARAO	17.4	24	8	1586	32.8	22.0	18.4
TUPI	6.2	0	18	2580			

Another limitation to simulation was posed by the fact that crop models use daily total global radiation (MJ m^{-2} d^{-1}) as input, and while IRRI measures radiation in these direct units, PAGASA reports cloudiness (octas). We plotted the recorded daily total global radiation against the radiation level derived from cloudiness with an equation by Oldeman and Frere (1982) for Los Baños (Figure 5). While the average radiation level agrees fairly well, radiation from overcast skies is overestimated significantly. Variability in radiation was therefore underestimated, and, consequently, variability in potential production was underestimated for all sites, except Los Baños. Variability in potential yield using radiation data from a solarimeter is 12 % less than variability simulated with converted cloudiness recordings in Los Baños. Since it would take many years to obtain proper measurements, we preferred to make a correction of 12 % in predicted yield stability for all stations (except Los Baños). For rainfed situations, variability results mainly from variation in rainfall, so that yield variability for rainfed crops is properly estimated. The large number of weather data used in this study were read in their original format from external files, unlike the normal procedure in CSMP (lines 116-125, 405-414).

Evaluation. Essential parts of the model have been evaluated for crop production studies in the humid tropics: canopy photosynthesis and potential production of rice (Herrera-Reyes & Penning de Vries, 1989), soil water balance and crop growth (de San Agustin et al., 1990). Other tests are described in Penning de Vries et al. (1989). This section deals with evaluation of SOYCROS for soya bean production in the tropics, particularly in lowland areas. Carefully executed experiments (Tedia, 1988), conducted during the 1987 dry season at IRRI's farm (14.11 oN, 121.15 oW) were either used for calibration or for evaluation. The cultivars SJ.2 and ELGIN were sown in mid-January; SJ.2 is a medium duration cultivar and ELGIN is an early type (Senthong, IRRI, personal communication). Five irrigation treatments (I1-I5) with four replicates were placed along a gradient starting 4 m from a line source sprinkler: I1 received the highest irrigation and I5 none. The amount of water applied was 80 % of the Class A pan evaporation, recorded in the preceding irrigation interval. Irrigation was applied at 11, 31, 38, 44, 52, and 72 days after emergence (DAE) of SJ.2. Only treatments I1 and I5 were used in the evaluation; the former is closest to 'potential production' and the latter to 'rainfed production'. Weather data were recorded at 100 m from the site. Rainfall during the experiment was only 12 mm, while potential evapo-transpiration averaged 5 mm d^{-1}.
The types of input data derived from the experimental results are shown in Table 1. Development rate constants were derived from the duration of the vegetative and reproductive stages; actual development rates are assumed not to be affected by daylength. Water table depth was not recorded: its value was estimated from circumstantial evidence as being 1.0 m at the beginning of the experiment and 1.5 m at the end. The measured relationships of moisture content and matric suction (Figure 6) were used to derive two constants (WCST and MSWCA, Appendix B). Saturated hydraulic conductivity of the top layer (0.1 m) was increased so that the soil is at field capacity after irrigation, as was observed. The upper 0.4 m soil layer was silty clay loam and the underlying layers consist of a light clay (0.4-0.6 m) and loam (0.6-1.0 m). The soil was divided into 10 layers. The initial moisture content of the soil profile was extrapolated to reach the observed moisture content at 14 d after sowing (DAS). Soil evaporation constants were calibrated for rainfed uplands with a water balance module for soils with deep water table (SAHEL, Penning de Vries et al., 1989)
Crop simulation started three days after emergence. Initial weights of leaves, stems, and roots were not recorded and were obtained by calibration. Initial leaf weight was set at 32 and 16 kg ha^{-1}, and initial stem weight at 19 and 9.5 kg ha^{-1} for SJ.2 and ELGIN, respectively. Initial root weight was assumed to be equal to that of leaves. Based on observed root length densities, the maximum rooted depth (depth where root length density exceeds 0.1 cm^3 cm^{-3}) for SJ.2 and ELGIN was set at 0.6 and 0.5 m, respectively.
Observed and simulated crop variables are presented in Table 3. The duration of the vegetative and reproductive stage were well reproduced. The model and the experiment showed better performance of SJ.2 than of ELGIN in pod yield and total dry matter production for both treatments. Final leaf, stem, and pod weight for SJ.2 were simulated well for irrigated conditions; they were a little high for rainfed condition but the variation between replicates was large (Figures 7a-c). Simulated leaf area did not correspond well with observed values; rainfed conditions did not have significant leaf area loss compared with observations. Leaf area development under irrigated conditions was better.

Table 3. Simulated and observed final weights of SJ.2 and ELGIN under irrigated and rainfed conditions. Dates are expressed in Julian dates.

	IRRIGATED		RAINFED	
	OBSERVED	SIMULATED	OBSERVED	SIMULATED
SJ.2:				
BIOMASS (t ha^{-1})				
TOTAL	4.82	4.88	3.01	3.81
PLANT ORGANS				
leaf	0.78	0.78	0.39	0.64
stem	0.78	0.85	0.62	0.69
pod+grain	3.11	3.25	2.00	2.48
grain	2.85	2.18		
Leaf area (m^2 m^{-2}):				
48 d	1.41	2.8	1.39	2.2
56 d	4.10	3.7	1.89	3.0
62 d	3.95	3.9	2.06	3.2
69 d	5.51	3.9	2.61	3.2
75 d	4.38	3.8	1.65	3.1
82 d	4.08	3.4	1.23	2.8
90 d	3.2	2.3	0.99	1.9
ELGIN:				
BIOMASS (t ha^{-1})				
TOTAL	3.62	2.75	2.24	1.74
PLANT ORGANS				
leaf	0.47	0.23	0.52	0.17
stem	0.47	0.43	0.37	0.31
pod+grain	2.68	2.08	1.34	1.26
grain	1.87	1.13		
Leaf area (m^2 m^{-2}):				
48 d	0.73	0.33	0.47	0.29
56 d	1.85	0.72	0.86	0.64
62 d	2.26	1.12	0.97	0.93
69 d	2.3	1.54	1.11	1.18
75 d	2.2	1.57	0.89	1.17
82 d	1.99	1.49	0.73	1.11
90 d	1.36	1.32	0.42	0.98

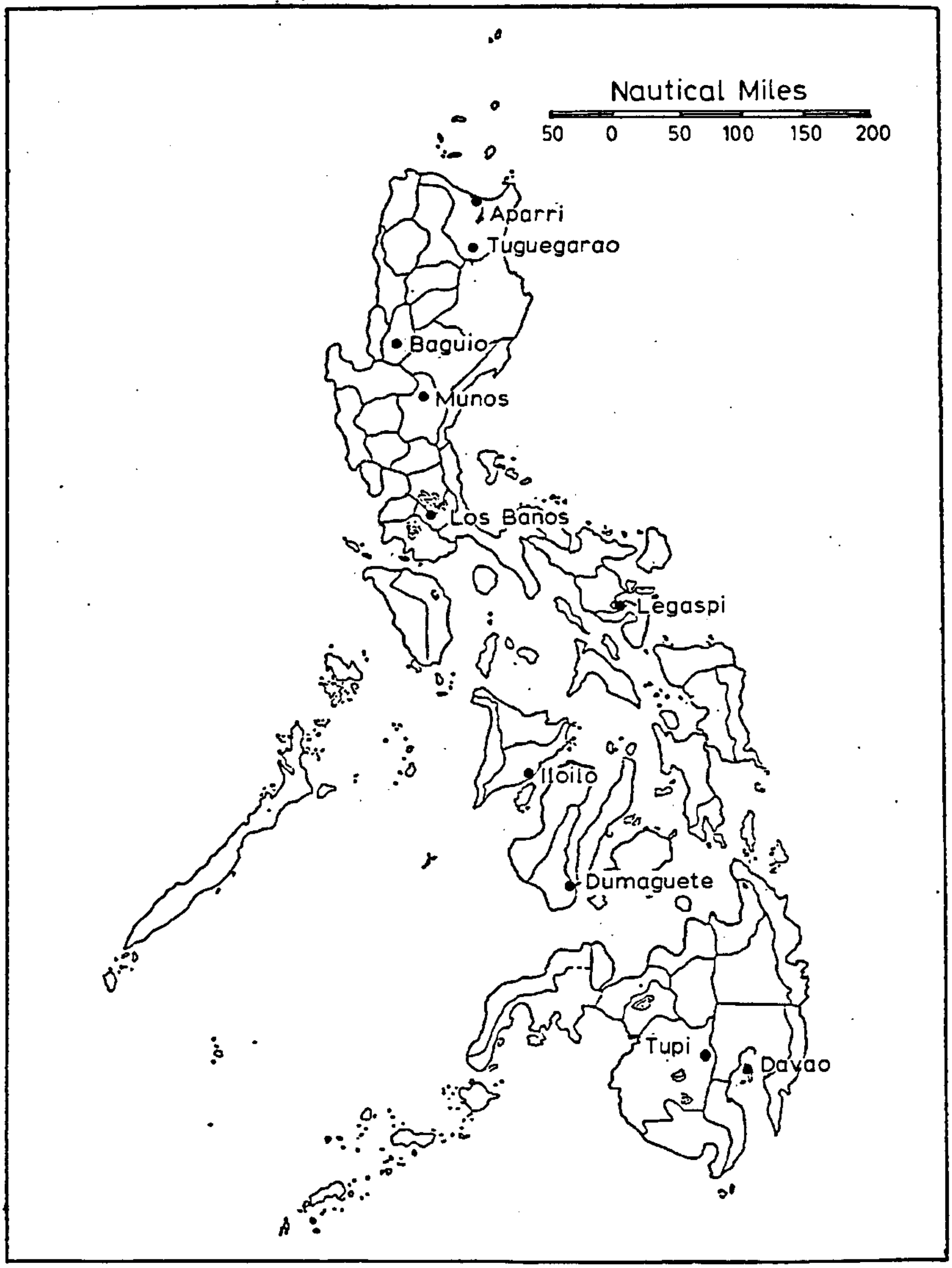


Figure 4. Location of the sites for which simulations were performed in the Philippines (From Lansigan et al., 1987).

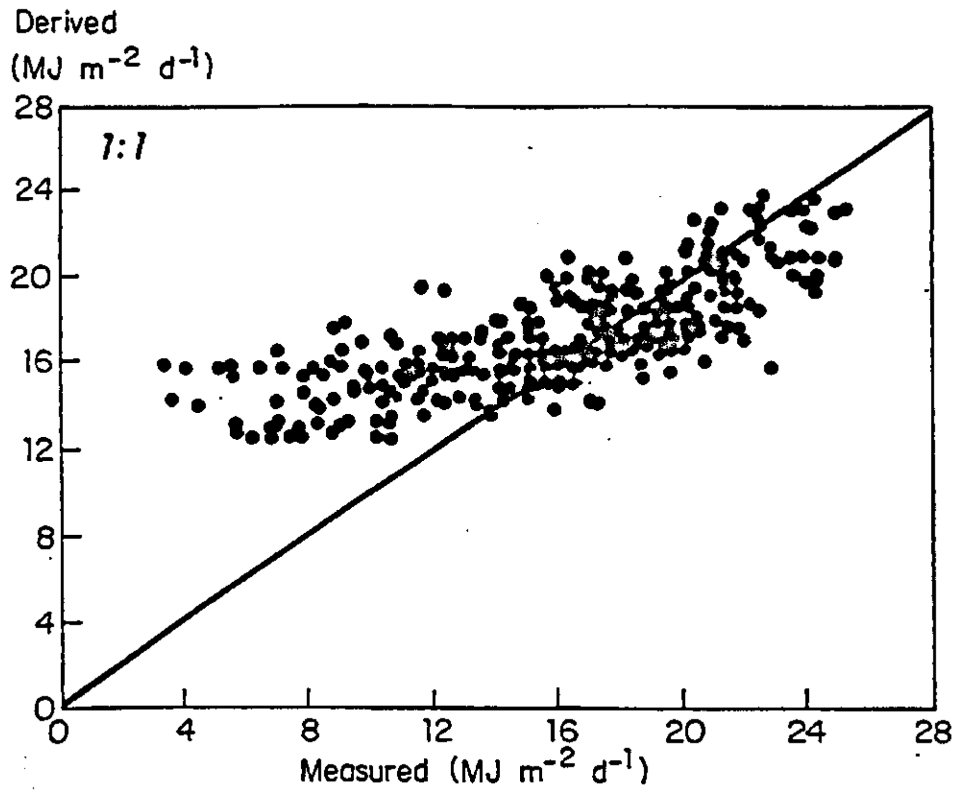


Figure 5. Relation of directly measured daily total global radiation at IRRI and global radiation derived from cloudiness observations. The data are for 1989, January 1 to November 30.

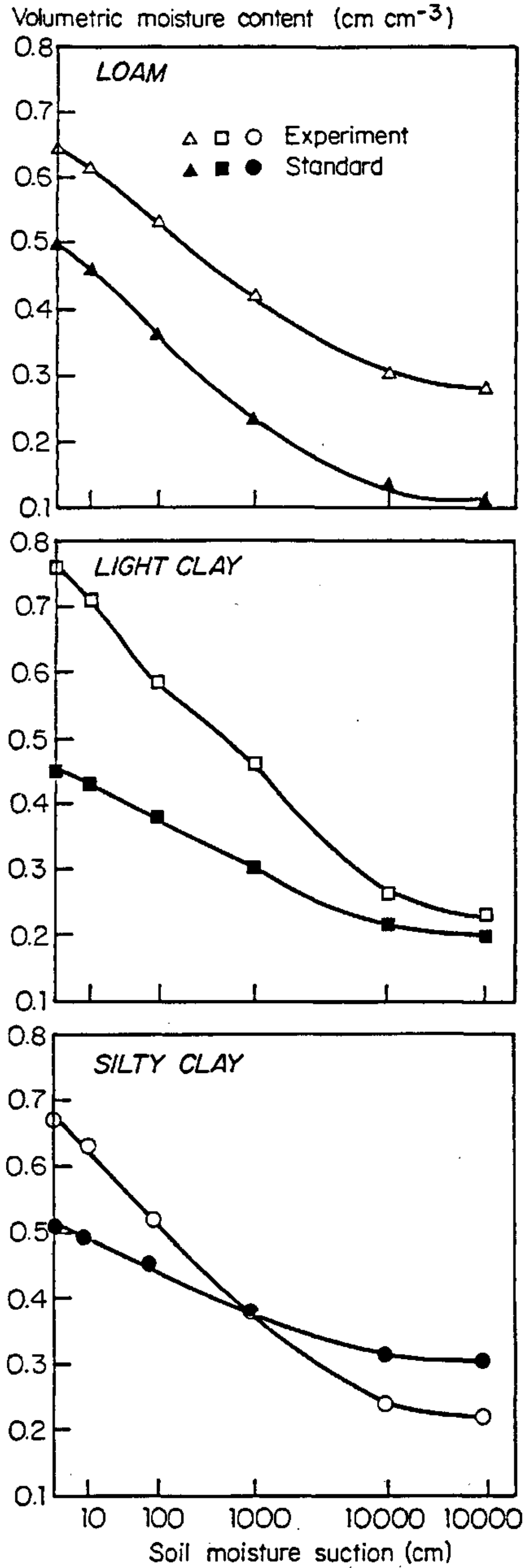
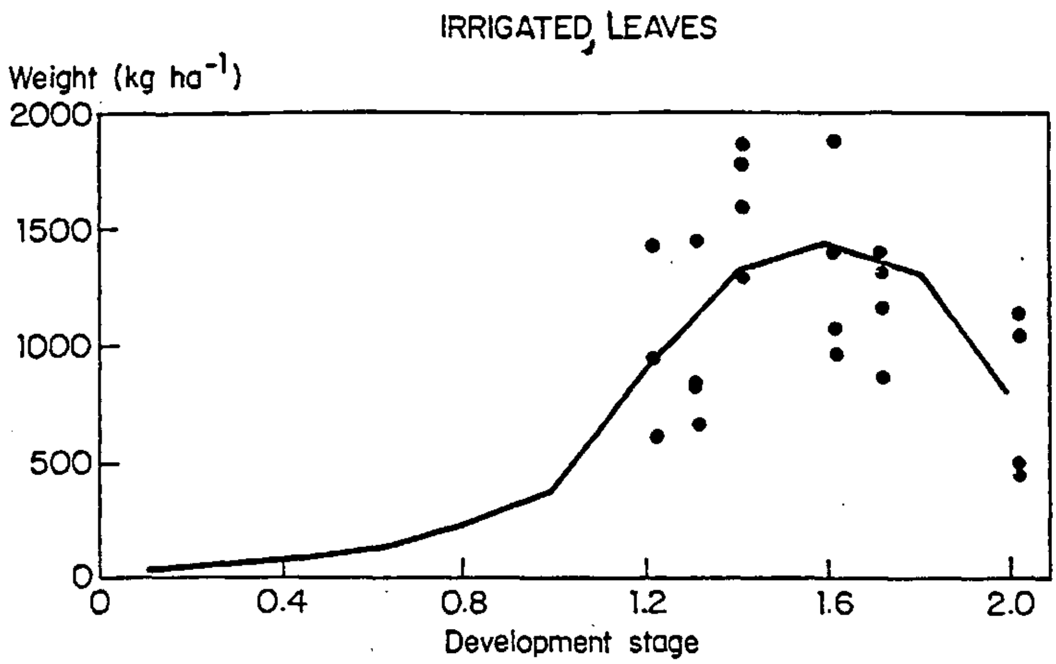


Figure 6. pF-curves of standard silty clay, light clay, and loam and of the soil types used by Tedia (1988) and selected for model evaluation.



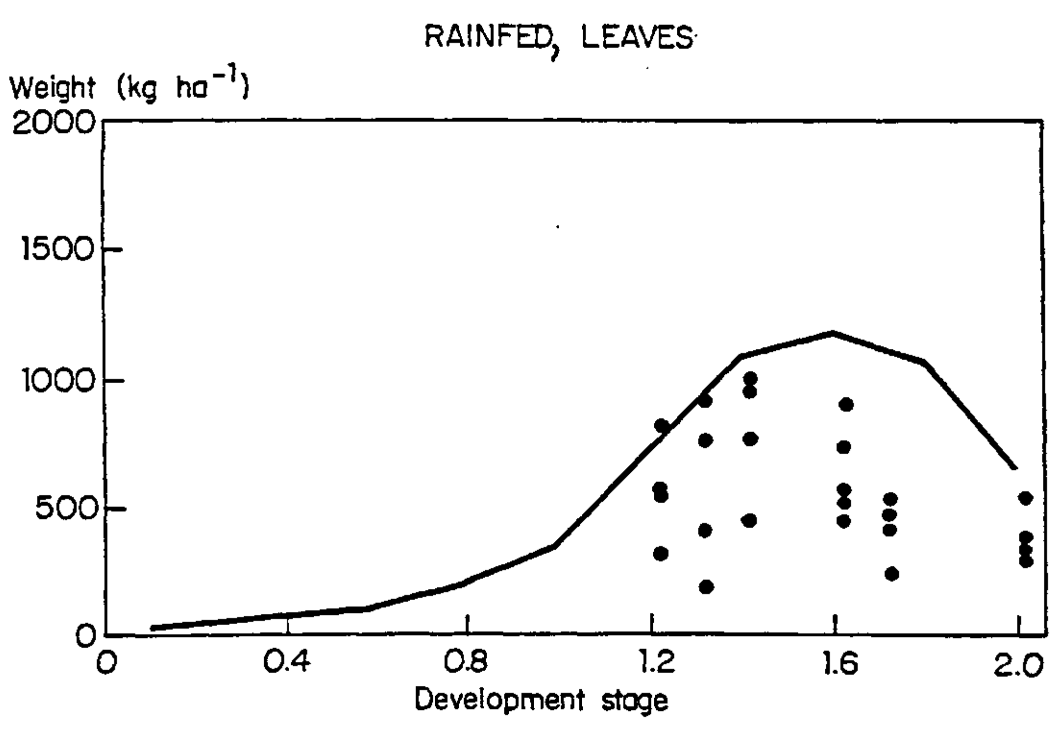
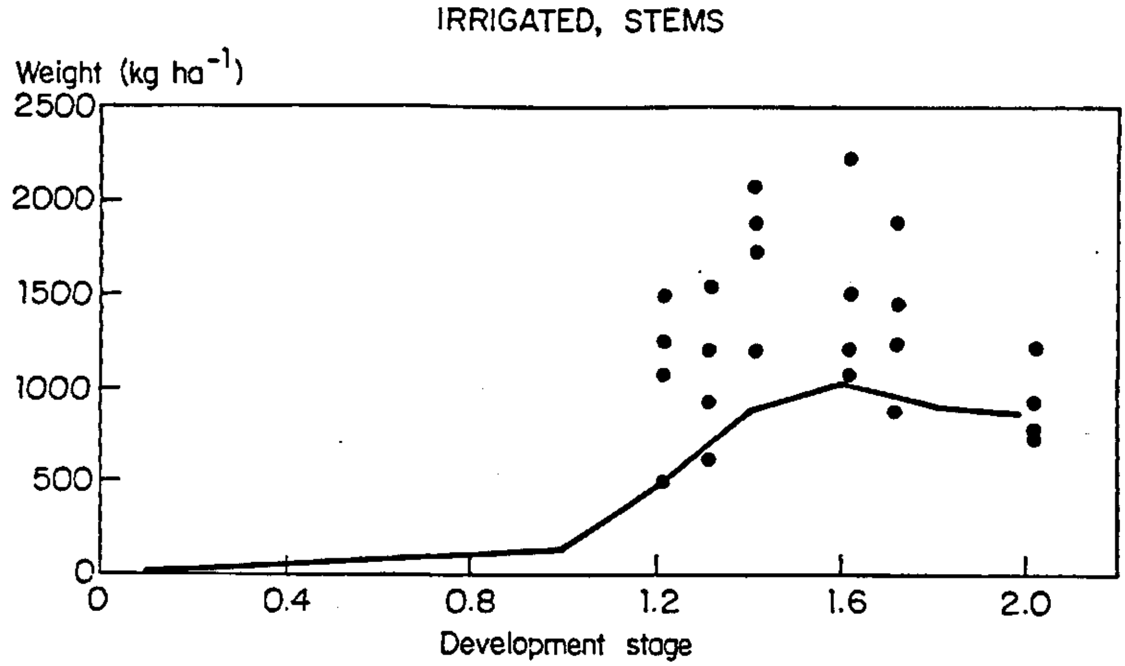


Figure 7a. Observed (dots) and simulated (lines) weights of leaves of SJ.2 for irrigated and rainfed conditions. Symbols represent individual replicates. Flowering corresponds with crop development stage (DS) 1.0 and maturity with 2.0. No observations were made before DS 1.



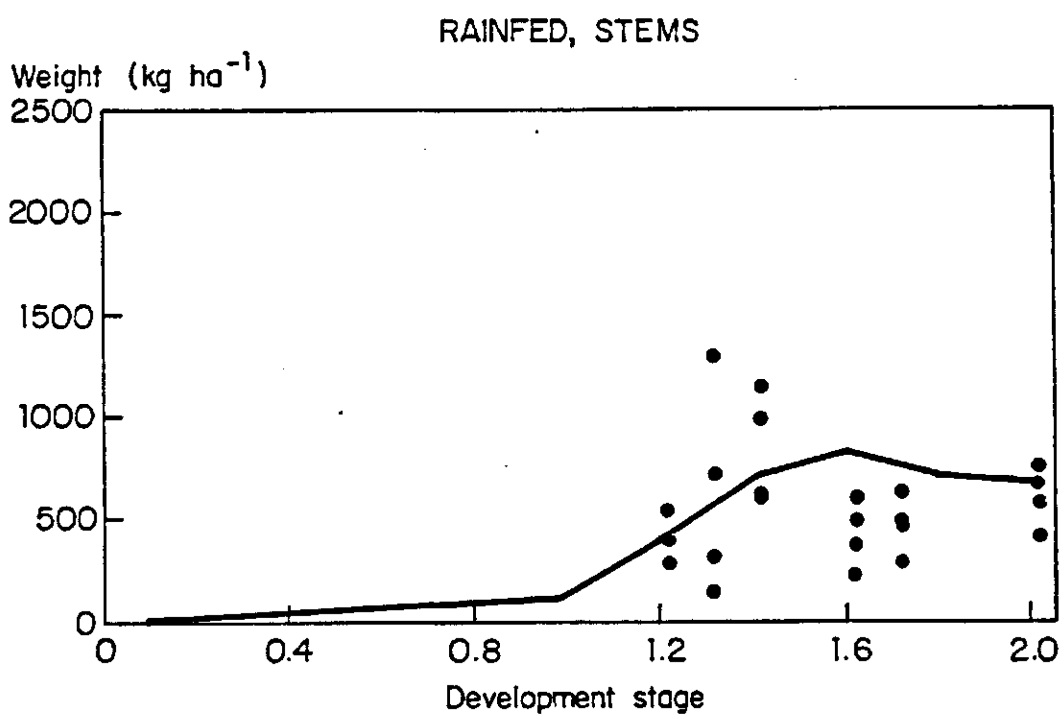


Figure 7b. Observed (dots) and simulated (lines) weights of stems (plus reserves) of SJ.2 for irrigated and rainfed conditions. Symbols represent individual replicates. Flowering corresponds with crop development stage (DS) 1.0 and maturity with 2.0. No observations were made before DS 1.

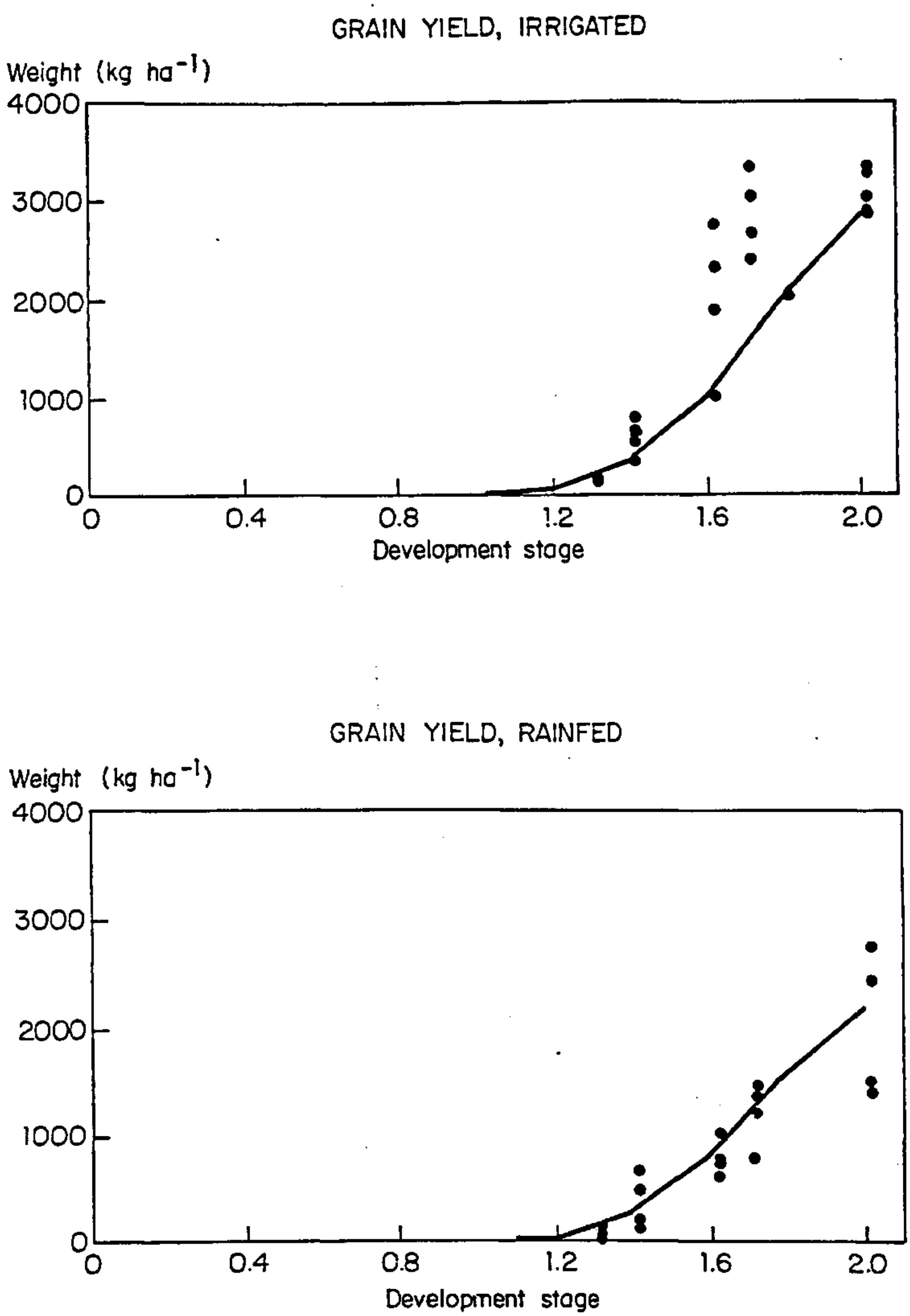


Figure 7c. Observed (dots) and simulated (lines) grain yield (12% moisture content) of SJ.2 for irrigated and rainfed conditions. Symbols represent individual replicates. Flowering corresponds with crop development stage (DS) 1.0 and maturity with 2.0.

SOYCROS simulates soil water contents at various depths. Observed and simulated volumetric moisture content are comparable (Table 4). Figure 8 shows simulated and observed water contents for SJ.2. The simulated change in moisture content in the upper 0.3 m is a little more than was measured, while the reverse is true in lower layers. We attribute the difference in soil moisture pattern between observed and simulated to the value of the saturated hydraulic conductivity (KST): our standard value was probably too low, but field values were unavailable. The upper 0.4 m supplied most of the water to the crop. The reduction in the total soil water content during the experiment (180 mm) for SJ.2 and ELGIN corresponds well with the simulated value (200 mm).

Tedia (1988) calculated crop water use as the sum of precipitation, irrigation and change in soil moisture content between successive samplings for the period sowing to maturity, similar to Turk et al. (1980) and Bohm (1979). In this widely used method, it is assumed that runoff, deep percolation and capillary rise are negligible. In SOYCROS, those processes are simulated. Observed and predicted water use of SJ.2 are presented in Table 4. Of 236 mm water used by SJ.2 in rainfed conditions, capillary rise was computed to be 72 mm. It exceeded the 12 mm of rainfall by an order of magnitude.
The simulated water use coefficient of irrigated soybean is about 920 kg water (transpiration + evaporation) kg^{-1} dry matter (Table 4) or 100 kg water kg^{-1} grain or 92 kg water (transpiration) kg^{-1} CO_2 assimilated. Data by Doorenbos and Kassam (1979) for the water use efficiency of soya bean are similar, confirming indirectly that capillary rise in Tedia's trials must have been significant. In conditions similar to Tedia's, Senthong and Pandey (1989) found a yield increase of 3.5-5.6 kg seed mm^{-1} water applied in the reproductive period; our simulations gave slightly lower values (3.0-3.6) for irrigation water provided in both the vegetative and reproductive period (Tables 3, 4).
From these comparisons, we conclude that SOYCROS simulated growth of soya bean under irrigated and rainfed conditions satisfactorily for our purpose.

Table 4. Water balance variables observed (Tedia, 1988) and as on simulations for the irrigated and rainfed treatments.

	VOLUMETRIC MOISTURE CONTENT					
	SATURATION		FIELD CAPACITY		WILTING POINT	
SOIL DEPTH (cm)	OBS	SIM	OBS	SIM	OBS	SIM
0 - 20	*/	0.67	0.52	0.52	0.22	0.22
20 - 40	*/	0.67	0.54	0.52	0.24	0.22
40 - 60	*/	0.76	0.58	0.58	0.23	0.23
60 - 80	*/	0.64	0.54	0.53	0.29	0.28
80 - 100	*/	0.64	0.51	0.53	0.27	0.28

	IRRIGATED		RAINFED	
	OBSERVED	SIMULATED	OBSERVED	SIMULATED
SJ.2				
FLUXES OUT:				
Transpiration (mm)	*/	216.2	*/	172
Evaporation (mm)	*/	185.7	*/	65
Evapotranspiration (mm)	408.5	401.9	167.7	236.
FLUXES IN:				
Precipitation (mm)	12	11.7	12	11.7
Capillary rise (mm)	*/	32	*/	72
WATER USE EFFICIENCY				
(kg H_20 kg^{-1} DM)	847	919.2	555	619.6
ELGIN:				
FLUXES OUT:				
Transpiration (mm)	*/	119.16	*/	79.42
Evaporation (mm)	*/	247.54	*/	53.83
Evapotranspiration (mm)	378.3	366.7	181.5	123.2
FLUXES IN:				
Precipation (mm)	12.	11.7	12.	11.7
Capillary rise (mm)	*/	12	*/	4.
WATER USE EFFICIENCY				
(kg H_20 kg^{-1} DM)	1041	1332	813	708

*/ no observation

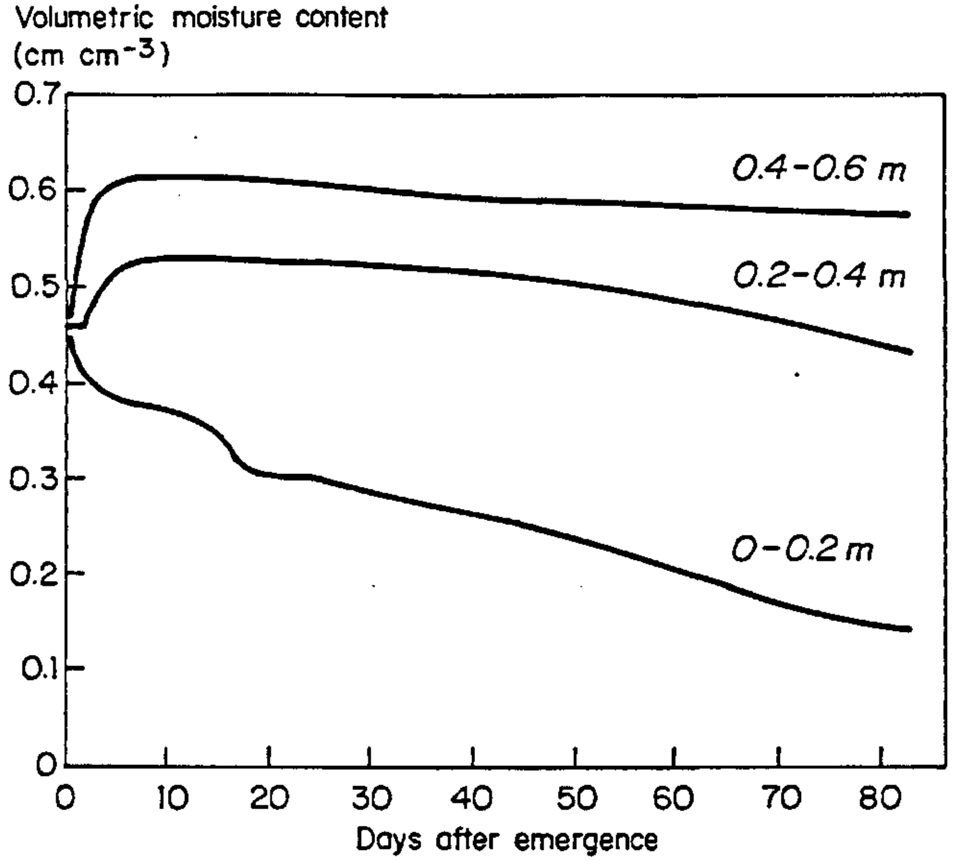


Figure 8a. Simulated course of the water content in three layers of the upper 0.6 m of the soil.

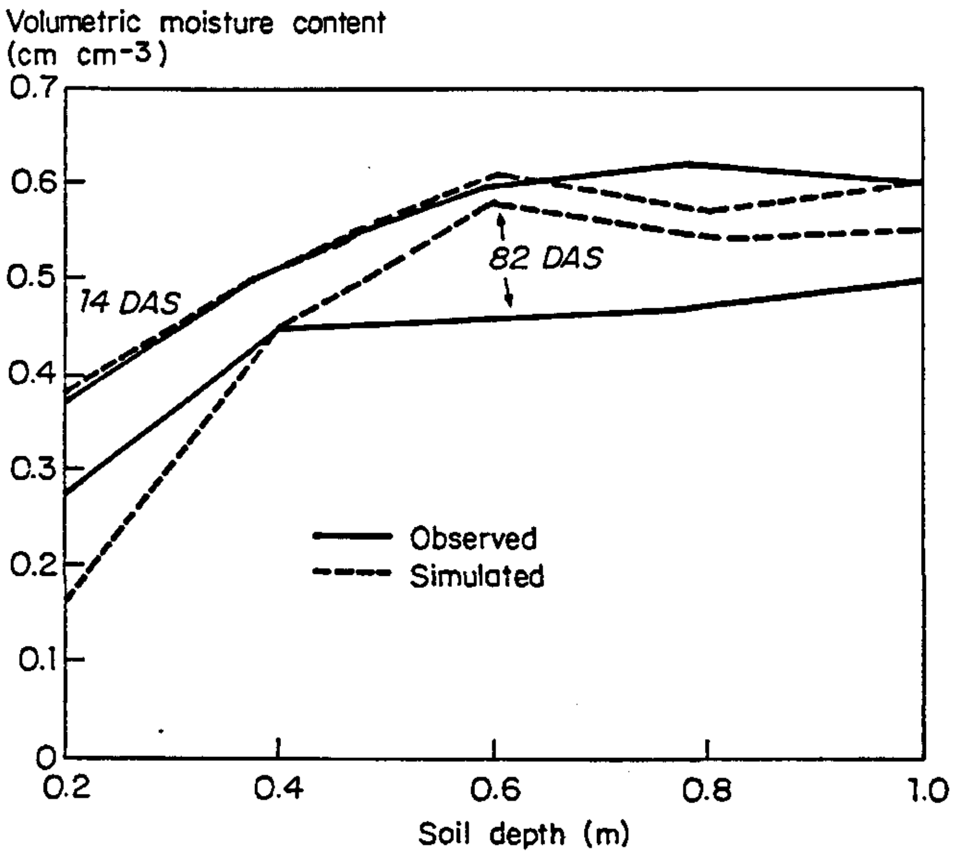


Figure 8b. Simulated and observed soil moisture profiles at 14 and 82 DAS. Observed values from Tedia (1988).

3. Soya bean production potential: applications of SOYCROS

We simulated potential soya bean production and concommittant water use on lowland rice soils and in upland conditions, with or without irrigation (Table 5) for 20 years and monthly sowings. A procedure was set up in which results of all individual simulations were read into a spreadsheet, sorted, and a probability analysis was performed. Graphs were made of yields levels that have a 75 %, 50 % and 25 % probability of being exceeded; the difference between the 75 % and 25 % levels is an expression of yield variability. The procedure was written in MS-EXCEL (Microsoft, 1989), and can be performed with a few keystrokes; it is presented in Appendix C1 (but it could have been programmed in the terminal section of the CSMP program instead).

For Los Baños, we determined that variability in potential yield using radiation data from a solarimeter is 12 % less than using converted cloudiness recordings. This ratio was then used to correct the simulated variability around the simulated mean for all stations (except Los Baños). Rainfed variabilities were retained.

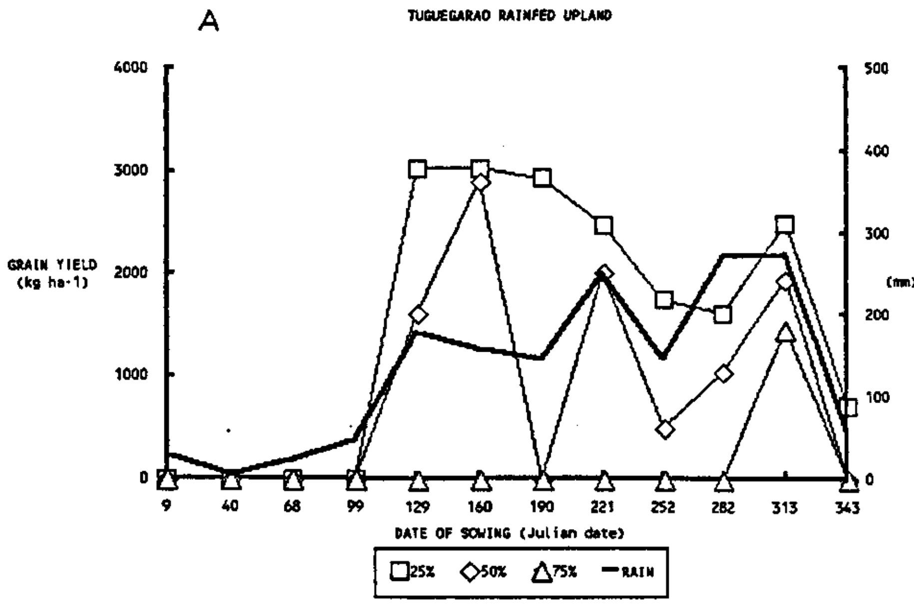
The results of the station Aparri and Tuguegarao appeared to resemble each other very much, and so do results of Los Baños, Iloilo and Dumaguete, and those of Davao and Tupi. The reason of the similarity in results may be due to the similarity in weather patterns. To reduce the number of figures, the results of only Tuguegarao, Baguio, Los Baños and Tupi are shown.

3.1 Potential production

1. Maximum crop growth rates.
   The growth rate of soya bean under optimal conditions in the Philippines is around 100 kg $ha^{-1}d^{-1}$ in the vegetative phase and about 50 in the reproductive phase. The high energy content of the beans (22.7 MJ kg^{-1}, about double that of cereals) leads to lower growth rates, when expressed in weight units, than that of cereal crops (Penning de Vries et al., 1983). In energy terms, both growth rates correspond with a gain of 0.12 MJ $m^{-2}d^{-1}$, or about 2 % of absorbed solar radiation (PAR). Such a value is moderate to low for field crops (Loomis, 1983) because temperatures are high and under high levels of solar radiation energy is used less efficiently. In addition, high temperatures shorten the growing season. As a consequence, world record soya bean growth rates and productions cannot be achieved in the Philippines.
2. Production potential.
   The potential soya bean yield (the SSC-yield) varies during the year from 2.3-4.2 t ha^{-1} over locations . Yield variability over the year is much higher in Los Baños than in other stations (Figures 9-12). The yields in Aparri, Dumaguete, and Iloilo show some seasonality due to temperature and radiation changes. SSC-yields in Tupi and Davao are very stable at 3.0 t ha^{-1} due to a stable radiation and climate. Potential yields in Baguio are 0.5-1.0 t ha^{-1} higher because lower temperatures cause longer growing seasons and the lower respiration losses more than compensate for the lower radiation.

Table 5. Simulated water supply situations.

	RAINFED	IRRIGATED
Lowland	rainfed, following rice (RFLL)	saturated soil moisture culture (SSC)
Upland	intensive management without irrigation (RFULP)	intensive management conventional irrigation (IRUPL)



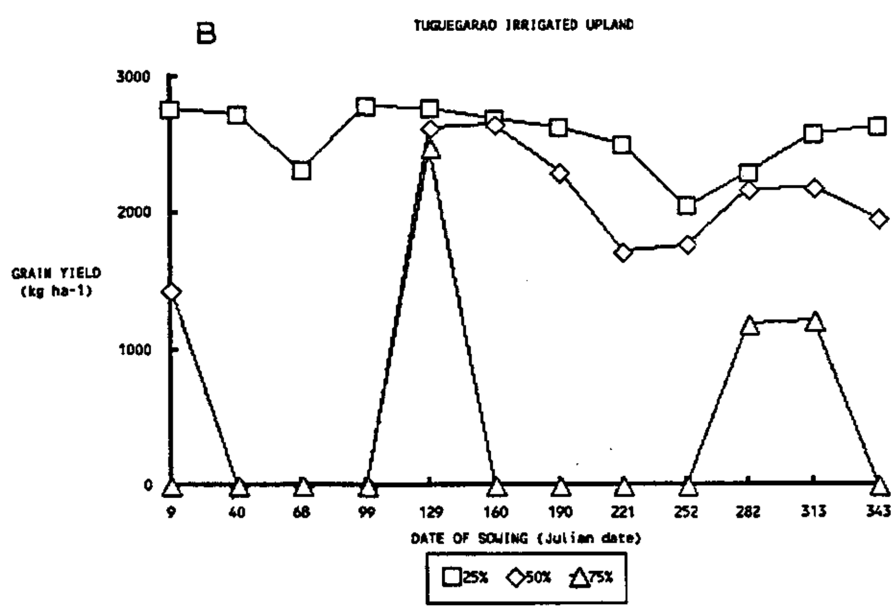


Figure 9. Mean grain yield of soya bean at 25, 50 and 75 % probability of being exceeded in Tuguegarao as a function of sowing date in different growing environments: A. Rainfed upland; B. Irrigated upland.

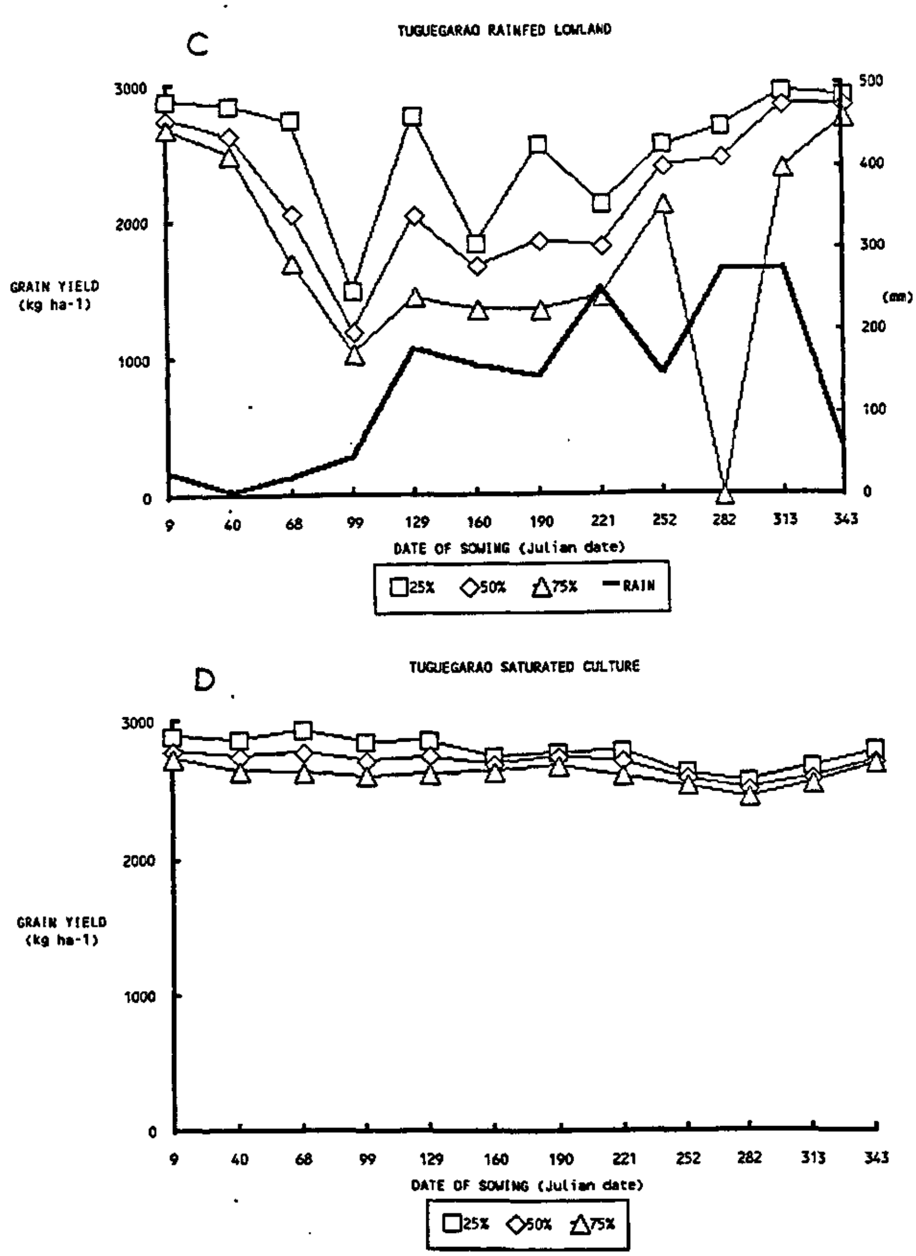


Figure 9. Mean grain yield of soya bean at 25, 50 and 75 % probability of being exceeded in Tuguegarao as a function of sowing date in different growing environments: C. Rainfed lowland; D. Saturated soil culture. The respective sowing dates in the different months are: 9., 40., 68., 99., 129., 160., 221., 252., 282., 313., 343.

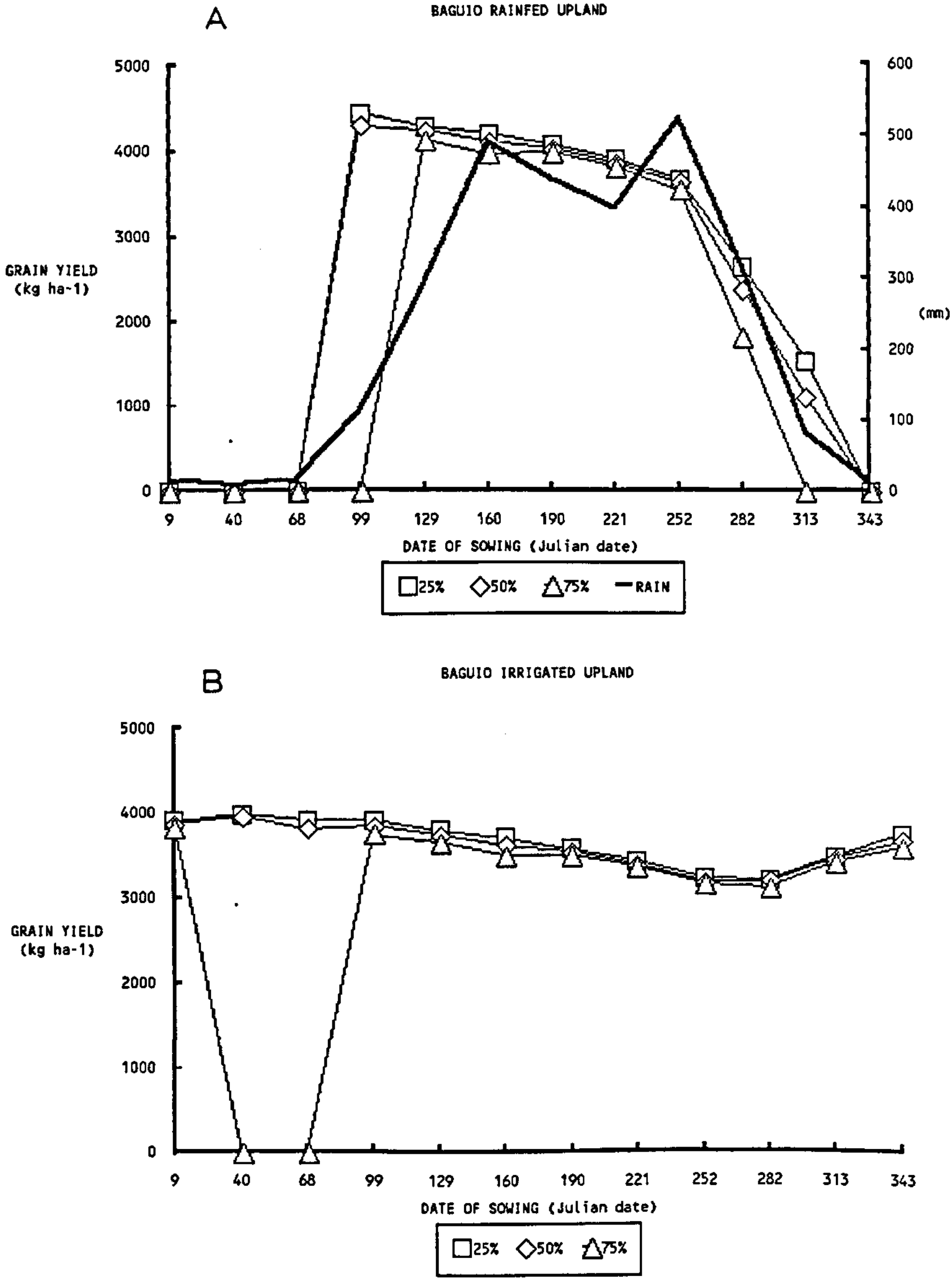
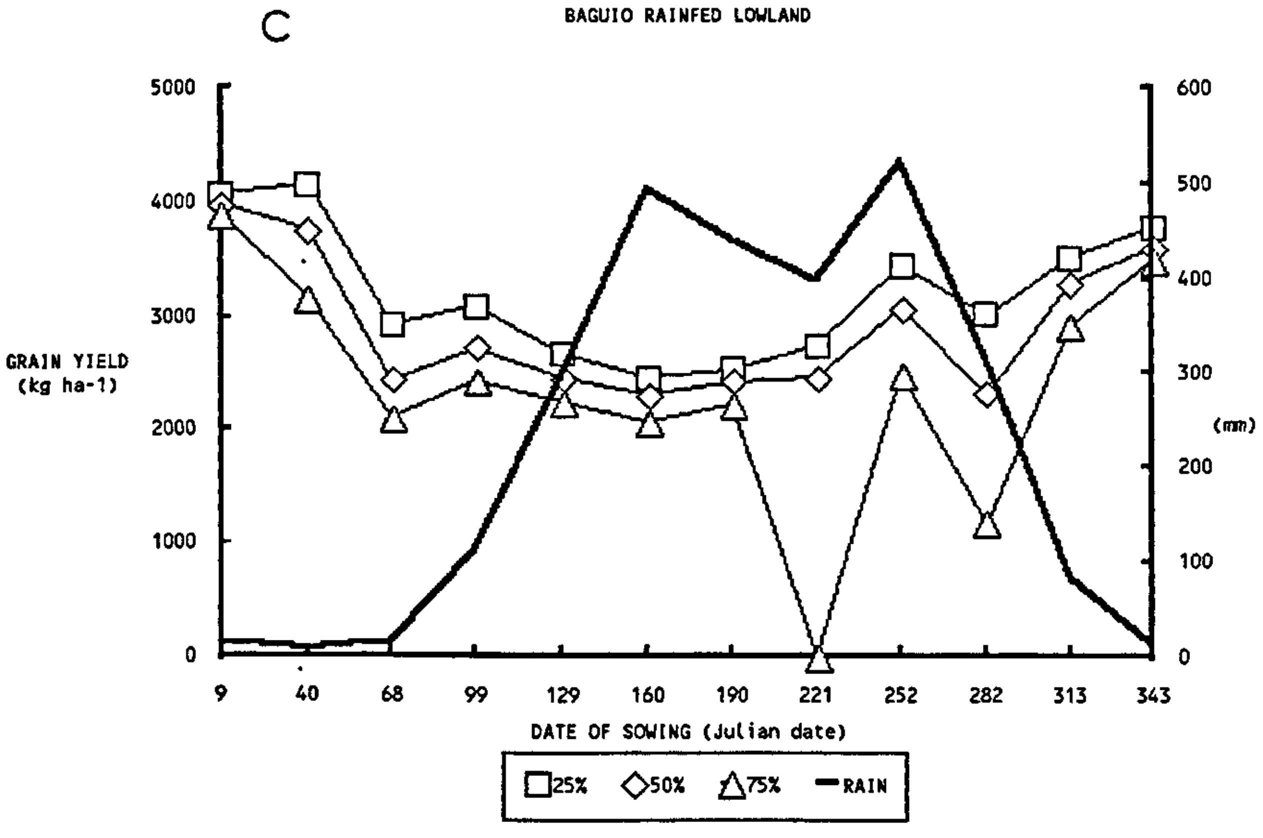


Figure 10. Mean grain yield of soya bean at 25, 50 and 75 % probability of being exceeded in Baguio as a function of sowing date in different growing environments: A. Rainfed upland; B. Irrigated upland.



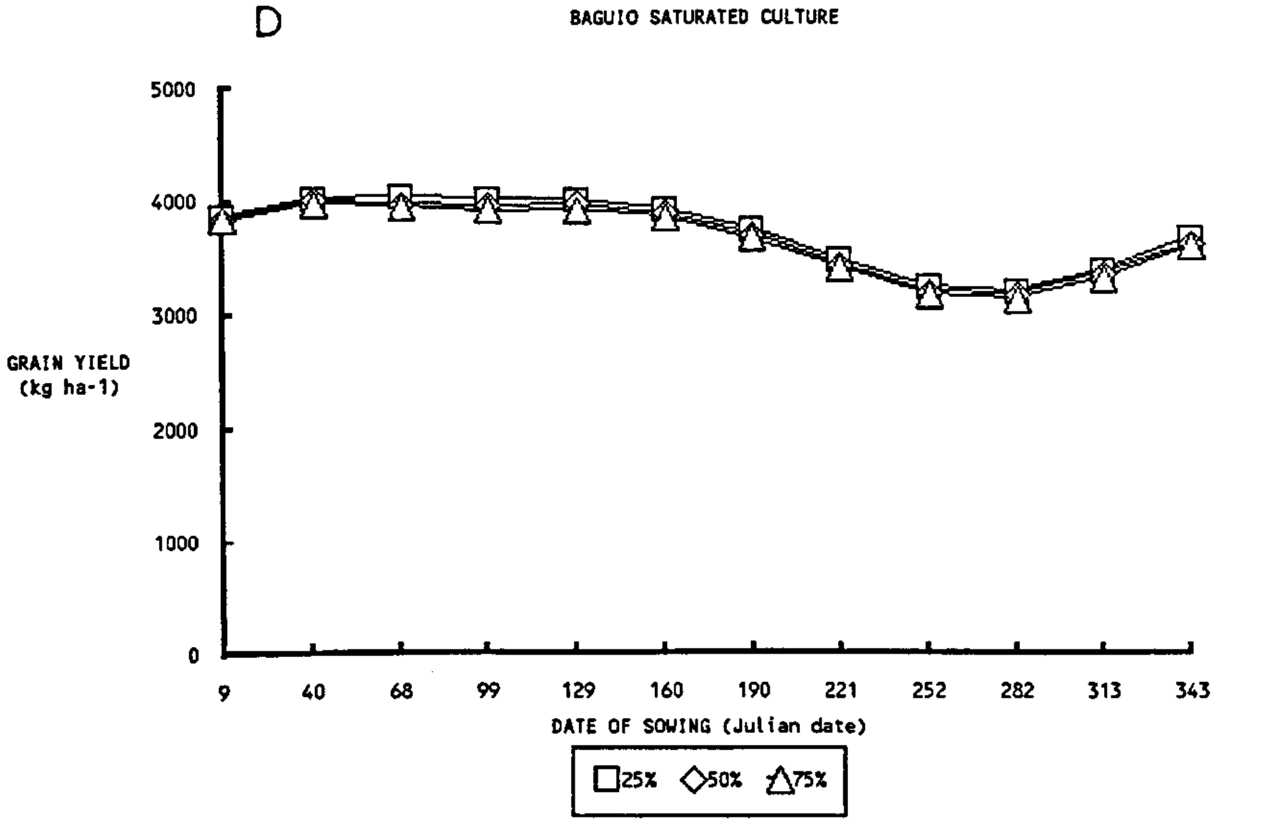


Figure 10. Mean grain yield of soya bean at 25, 50 and 75 % probability of being exceeded in Baguio as a function of sowing date in different growing environments:
C. Rainfed lowland; D. Saturated soil culture.

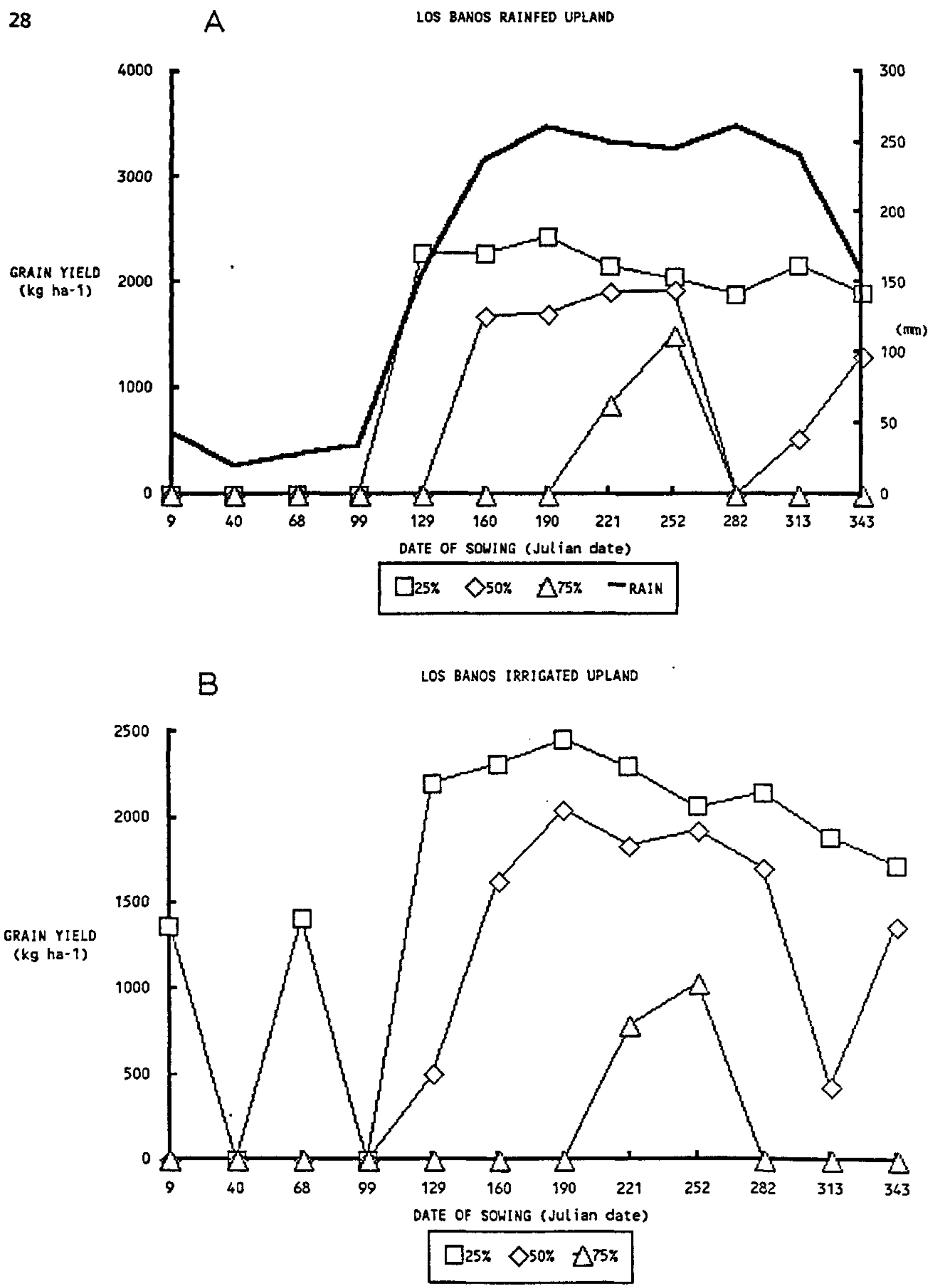
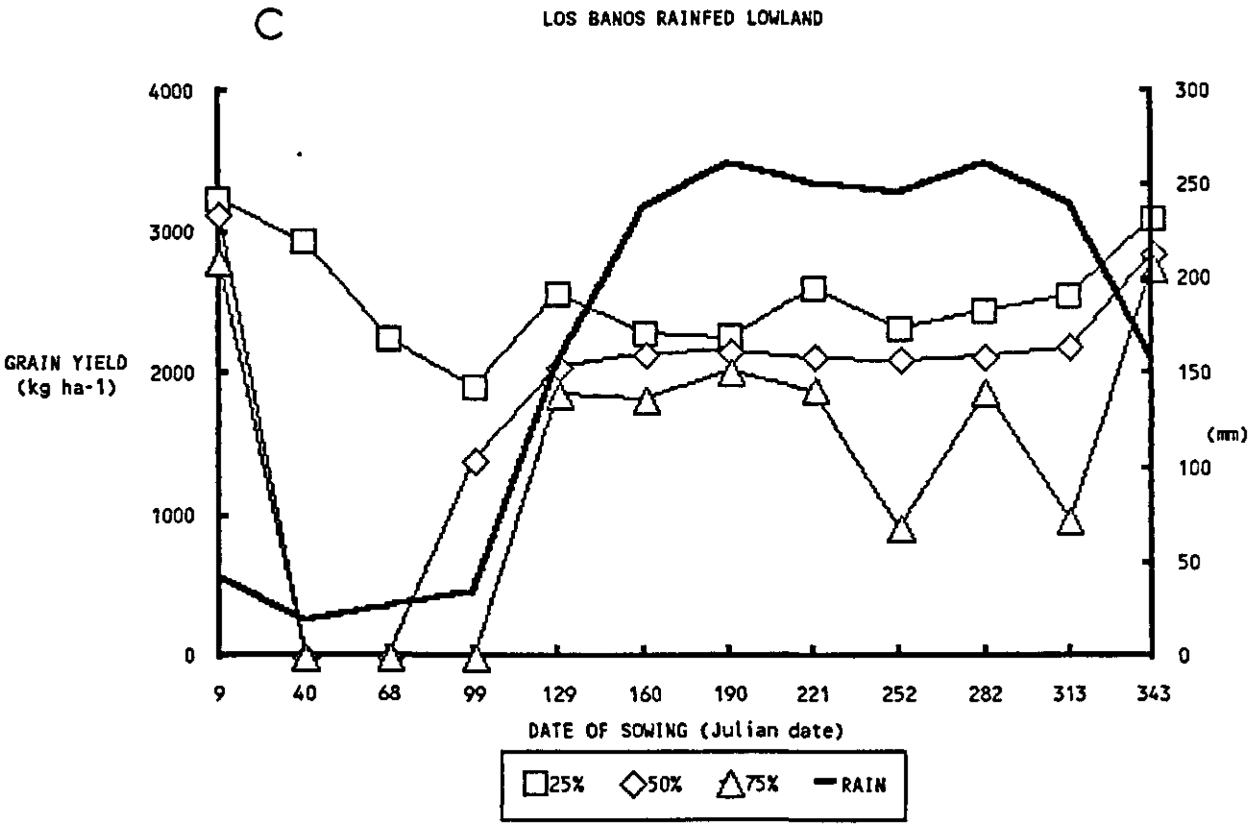


Figure 11. Mean grain yield of soya bean at 25, 50 and 75% probability of being exceeded in Los Baños as a function of sowing date in different growing environments: A. Rainfed upland; B. Irrigated upland.



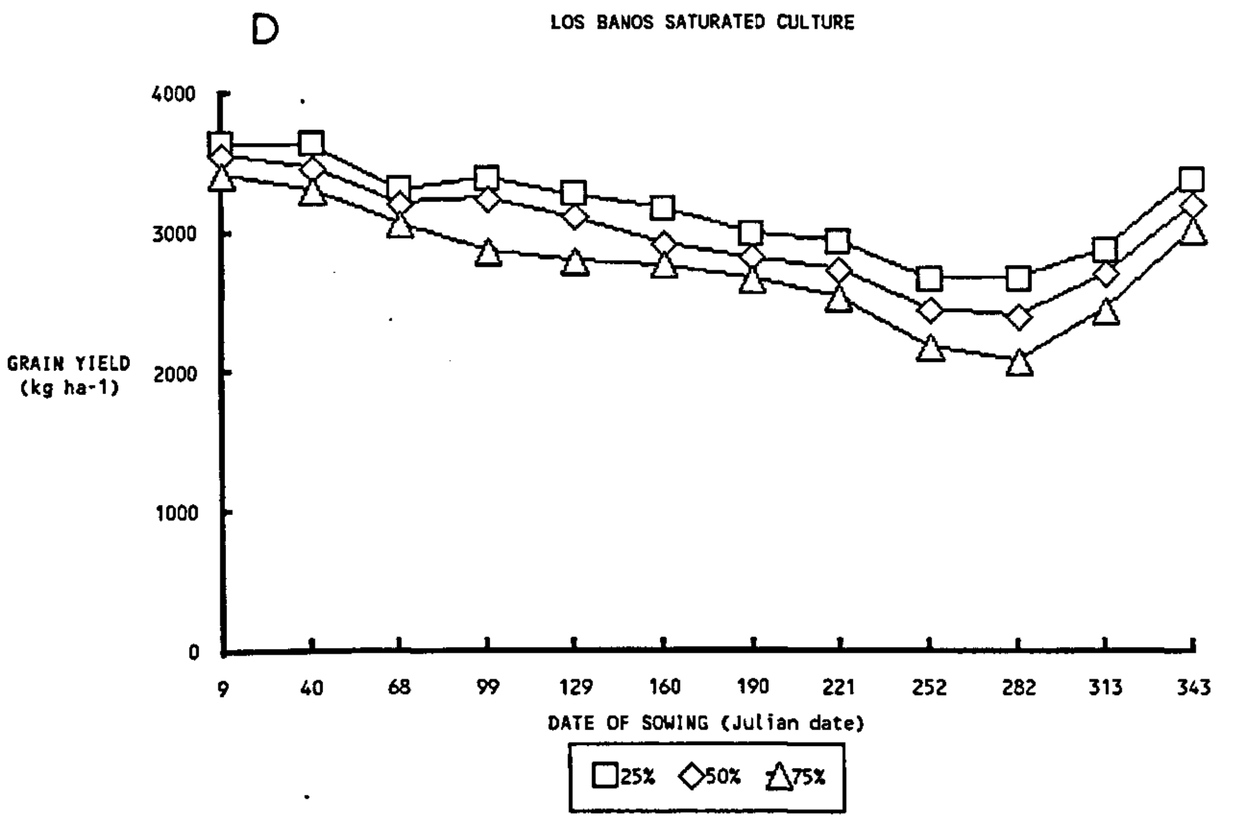
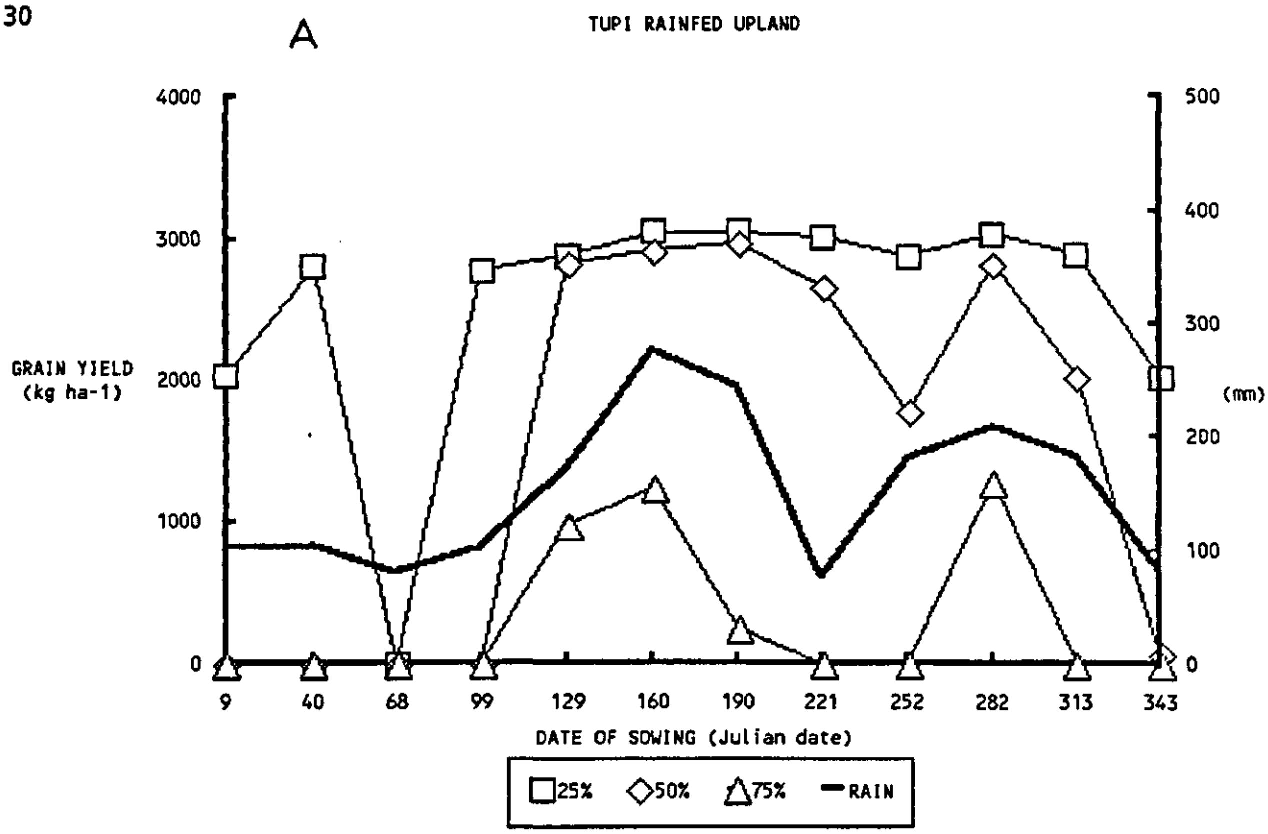


Figure 11. Mean grain yield of soya bean at 25, 50 and 75% probability of being exceeded in Los Baños as a function of sowing date in different growing environments: C. Rainfed lowland; D. Saturated soil culture.



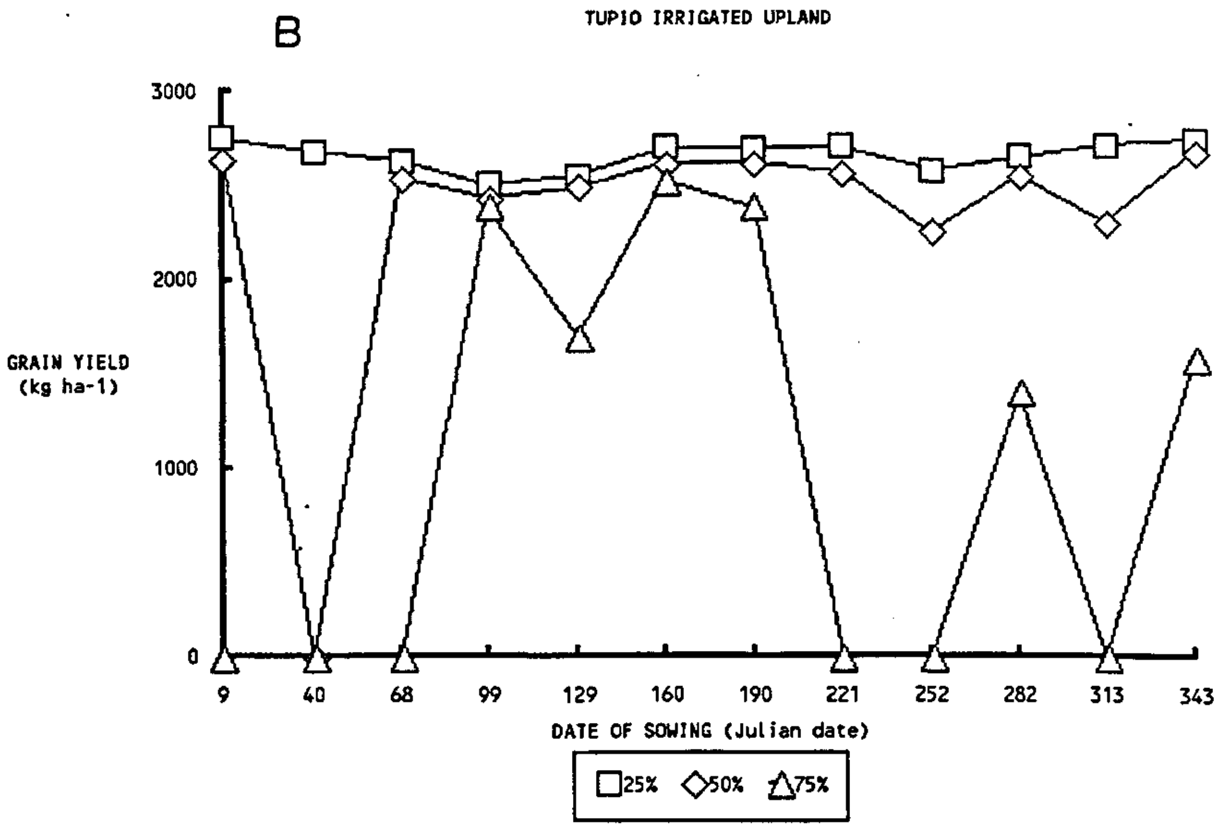
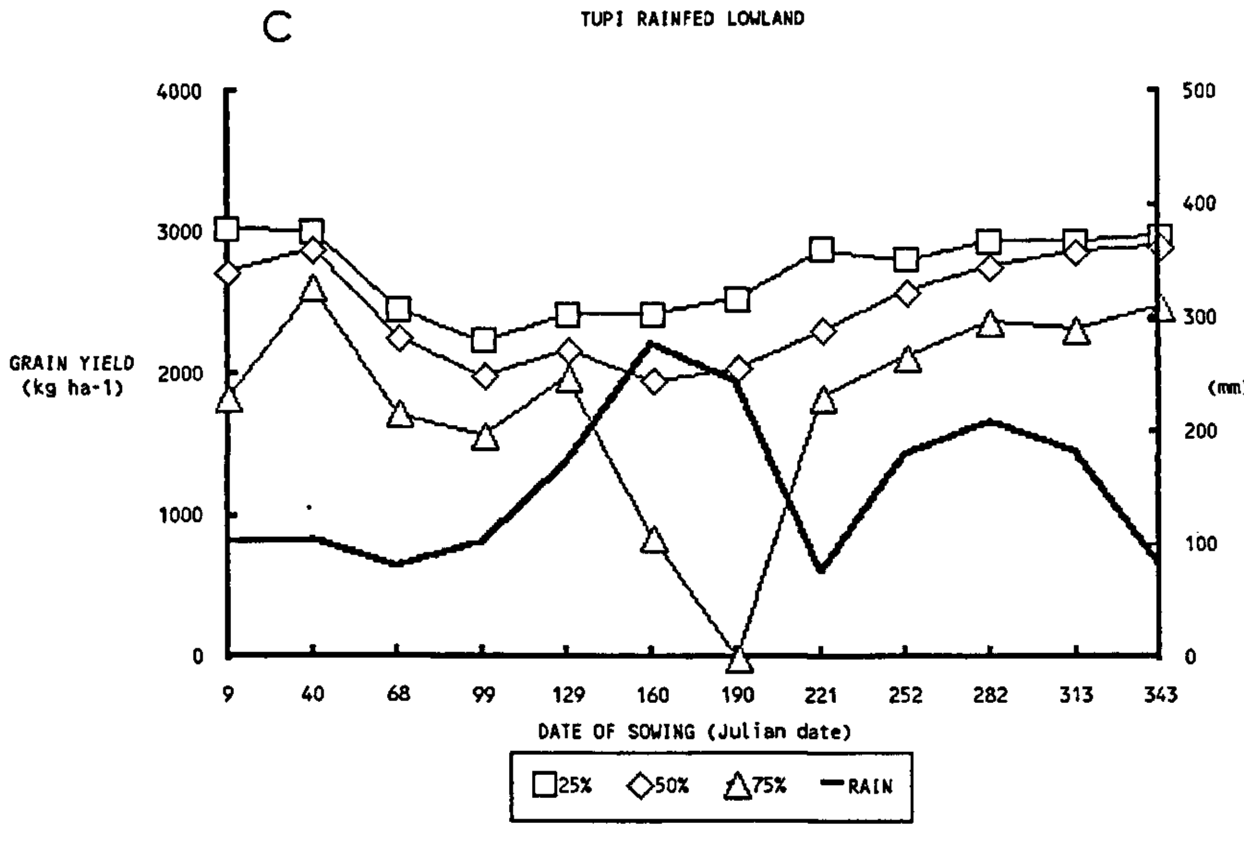


Figure 12. Mean grain yield of soya bean at 25, 50 and 75 % probability of being exceeded in Tupi South Cotabato as a function of sowing date in different growing environments: A. Rainfed upland; B. Irrigated upland.



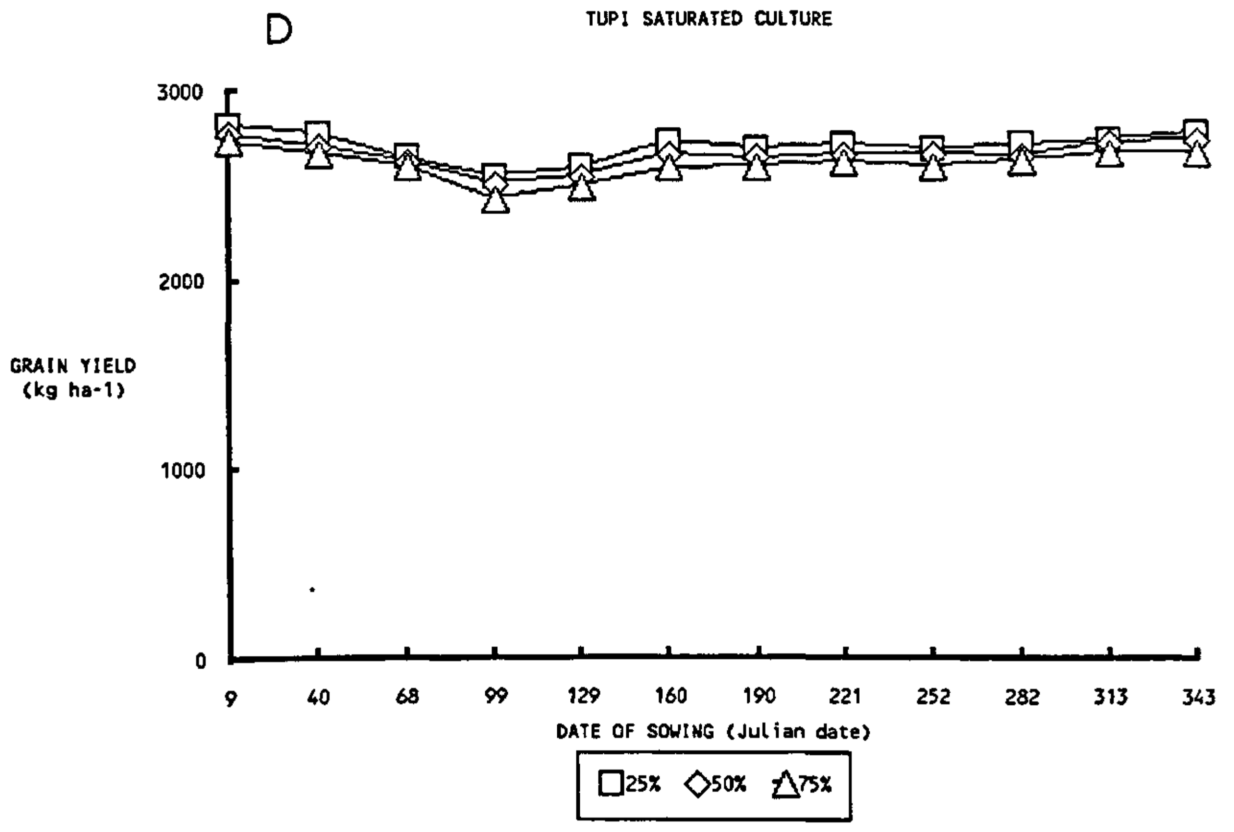


Figure 12. Mean grain yield of soya bean at 25, 50 and 75 % probability of being exceeded in Tupi South Cotabato as a function of sowing date in different growing environments: C. Rainfed lowland; D. Saturated soil culture.

The variability is relatively small in most stations, and suspiciously small in others, in spite of its amplification (see model data). The southern stations have least seasonality. Irrigated upland yields are almost similar to SSC-yields for all stations (but not for Los Baños), provided that the germination phase succeeded. This implies that the irrigation scheme was optimal for crop growth on the deep soil. The SSC yields in Los Baños are much higher than that of irrigated uplands. The high frequency of zero yields at the 75 % probability level indicates that many seeds did not germinate in low rainfall years because of lack of water in the period just before and after sowing.

3. Highest possible rainfed yields.
Soybean is a successful upland crop for the southern locations where rainfall is stable. Baguio, with a cool climate, promises a yield potential of 4.0 t ha^{-1} in rainfed upland conditions when sown from June to October with adequate rain. Iloilo yields 2.8 t ha^{-1} only in September to November and Tupi yields 3.0 t ha^{-1} in July and August. At northern locations (except Baguio), soybean yields can reach 3 t ha^{-1} in good rainfall years, but the crop fails in other cases (unless better irrigation would be provided).

Yields in rainfed lowlands are less variable than in uplands. There is a significant benefit from capillary rise when the water table rises: at 1.5 m, yields range from 0.5 in to 2 t ha^{-1} while yields are stable at about 3 t ha^{-1} with a 0.35 m deep water table. Crop failures occur only when flooding persists for several days. Mean yield and stability in Dumaguete are slightly higher than in Iloilo because of lower rainfall and less drainage problems.

Because the location of the water table is significant for the results obtained and an approximate pattern is used here, such simulations should be repeated when local data on water table patterns are available.

3.2 Sensitivity analyses

1. Capillary rise. Capillary rise can be a significant source of water for crops. Capillary rise is defined here as the amount of water that passes upward through the bottom of the deepest rootable layer in response to soil moisture gradient. Its value depends on rainfall in the first place, but soil hydraulic characteristics and water table depth, rooting depth and crop water uptake also play a role.
In rainfed lowland in Los Baños, we simulated that a dry season soya bean crop obtains 70 % of the difference between 300 mm and rainfall, up to 140 mm, from below the soil profile (Figure 13). By 'withholding' capillary rise (by setting KST of the deepest layer to a very low value), we simulated that yield did not exceed 1 t ha^{-1} and that the crop died before maturity. This reconfirms that ground water was a major source of water.

Our model showed that such results are quite sensitive to the adopted value of the saturated hydraulic conductivity (KST). With the standard KST-value (3.5 cm d^{-1}, for clay in the deepest layer), capillary rise provides about half of the total demand for water in a very dry season; when KST is higher (all other conditions similar) the crop would be almost free from water stress, while when KST is smaller, the crop would die from drought before reaching maturity (Figure 14). To improve quantification of

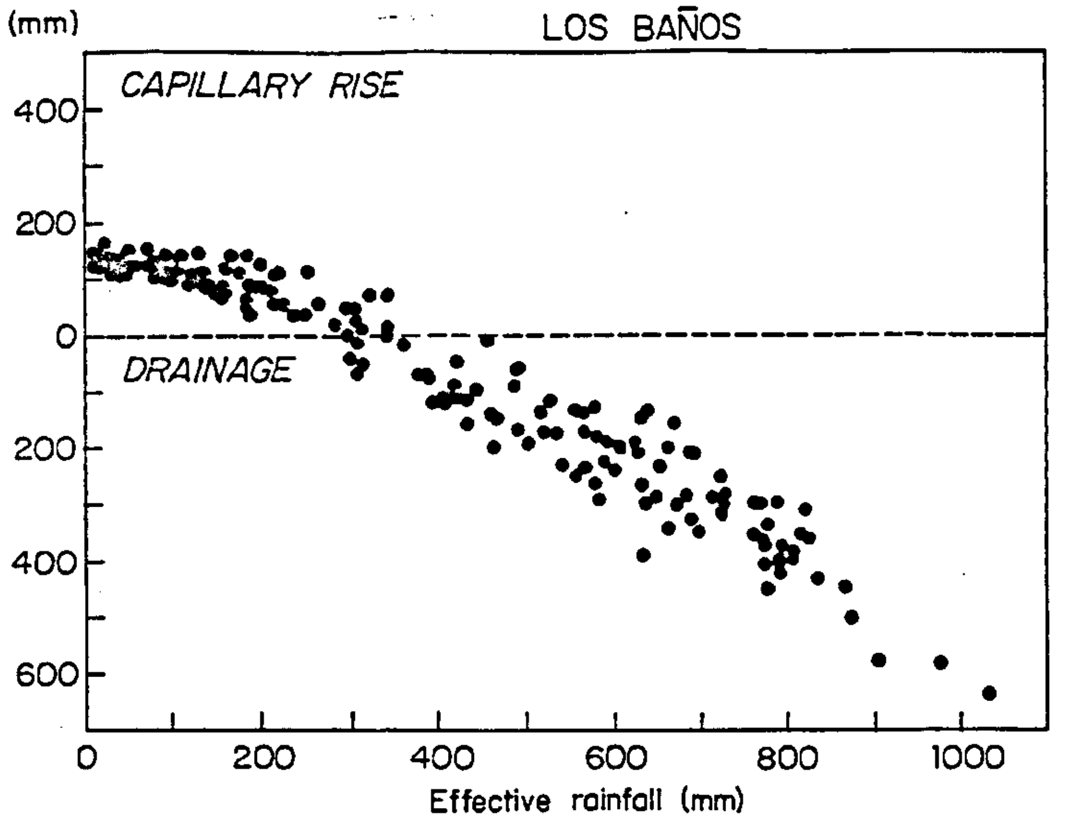


Figure 13. Simulated cumulative capillary rise (positive) a drainage in a soya bean growing season on lowland soil in Los Baños, plotted against effective rainfall (rain-runoff) in the same season. Data points refer to monthly sowing in 23 historic years.

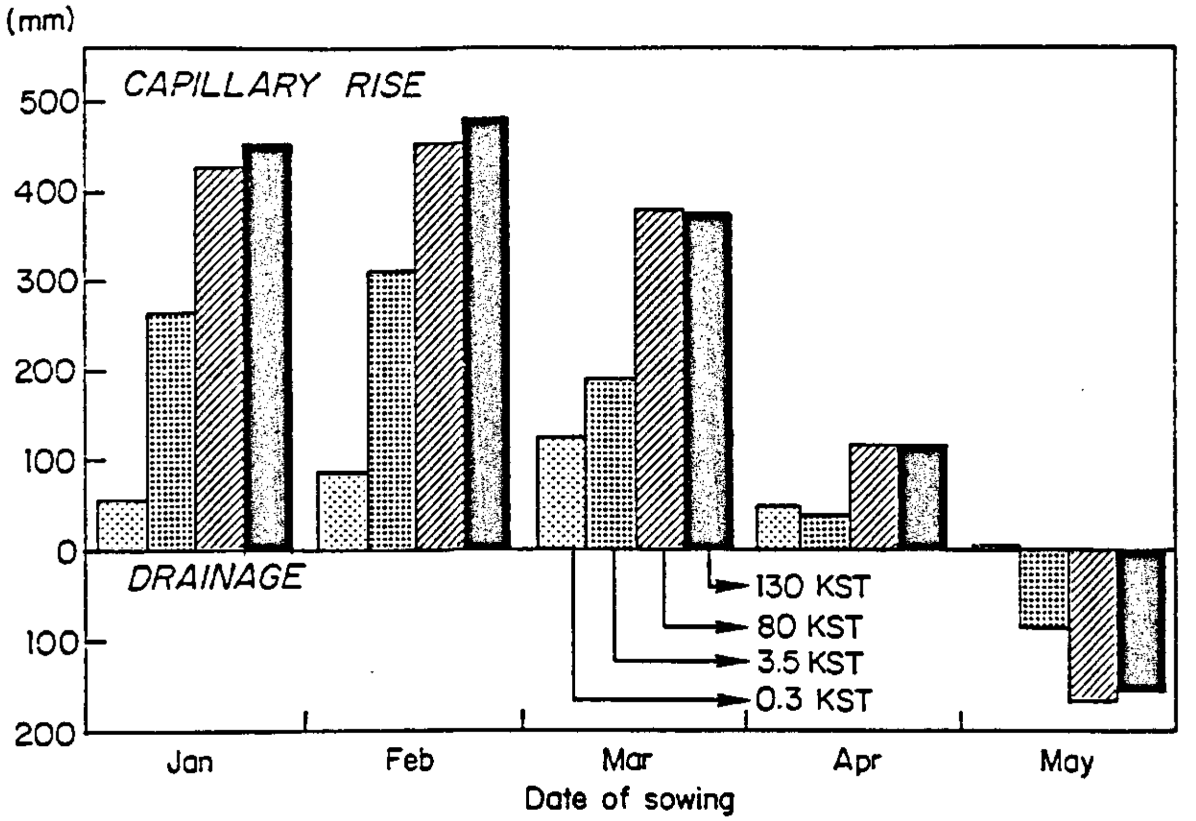


Figure 14. The average contribution of a fluctuating water table to capillary rise and total drainage during a growing season as a function of the saturated hydraulic conductivity (KST) in Los Baños when soybean is sown at the start of each month (dry season: Nov-Apr).

productivity of crops after rice, and particularly of the contribution of capillary rise, more data should become available on KST and on soil water table dynamics.
We recommend that hydraulic conductivity be determined in the soil layers in every major rainfed lowland experiments, and that water table depth be recorded during trials.

2. Soil depth and yield stability. Yield level as a function of maximum rooting depth was studied for locations in the north and south of the Philippines where expansion of soya bean production is being considered: Tuguegarao and Tupi (Quebral, 1984). The rainfall patterns at these locations differ: rainfall is fairly evenly distributed in Tupi (near Davao), while there is a distinct dry and a wet season in Tuguegarao. Tupi soils are light sandy loams with a compacted layer at 0.5 m; soils near Tuguegarao are deep clay soils without restrictions to root growth. The top layer contains usually sufficient moisture to sustain growth. Further increase in rooting depth is ineffective since rainfall can lead to excess moisture in deeper layers. Soya bean is responsive to increasing its rooting depth up to 0.9 m in Tuguegarao, and waterlogging occurs here rarely at any depth. Deep rooted cultivars are most appropriate in these conditions. In Tupi, there is little response to soil depth (Figure 15).

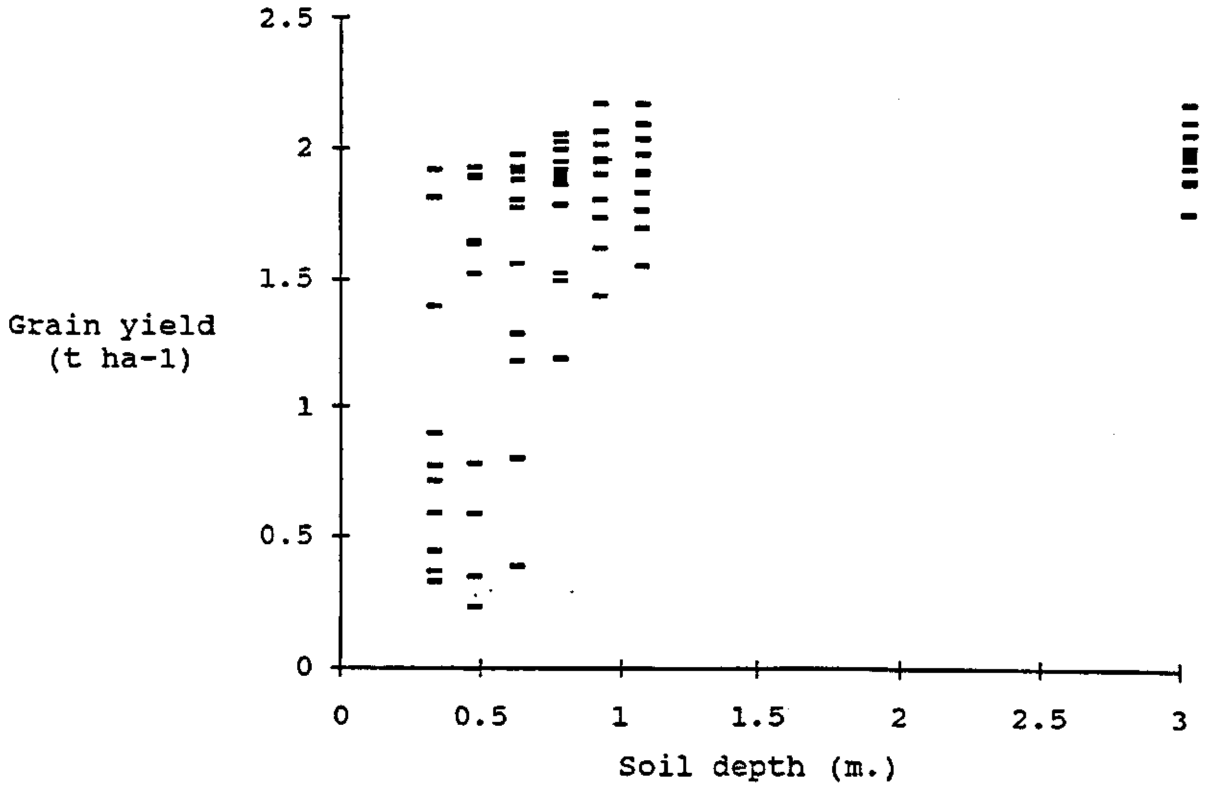


Figure 15. Soybean yields in different years and growing seasons, as affected by the soil depth in Tupi, South Cotabato.

3. Sensitivity to water shortage. The actual shape of the response curve of water uptake and root growth to water stress (Figure 2) is not based on much experimental evidence. We varied the level of sensitivity to drought stress between extremes reported for agricultural crops as reported elsewhere (WSSC=0.5, 0.9; Penning de Vries et al., 1989) for Los Baños, upland rainfed, all years and planting dates. The result of these changes was negligible in the best and in the worst (driest) years, but added about 400 kg ha^{-1} in average years.

4. Climate change. Our climate is changing slowly. It is predicted for 2020 that the CO_2 concentration will be around 410 ppm and the temperature 1.2 °C higher (Jansen, 1990). Precipitation in the Philippines is expected to remain roughly similar (Malik, 1988). Higher CO_2 levels increase the maximum rate of leaf photosynthesis and reduce the transpiration ratio; higher temperatures shorten the crop duration and increase the transpiration ratio. In SOYCROS, such changes lead to a decrease in potential yields by 0.2-0.4 t ha^{-1} for all stations in the Philippines. We expect, therefore, that consequences of climate change in the near future for soya bean productivity will be small.

5. Plant density. Increasing plant density was shown to increase yield up to a maximum, since higher density is associated with greater radiation interception and photosynthesis, resulting in higher yields (Clapp, 1971). With SOYCROS, we simulate that for a short duration variety, a density of around 40 plants m^{-2} is optimal, on average; doubling this density is counter productive and decreases yields by about 12 %. Barlaan (IRRI, personal communication) found no significant differences between two row spacings (40 and 80 plants m^{-2}) for soya bean grown after rice in the Philippines. Optimum density may depend on rainfall and soil type. We did not explore this topic any further.

3.3 Conclusions

Soya beans can produce good yields in the Philippines in conditions of a stable, adequate water supply. This applies to irrigated upland, and particularly to nearly saturated soils. Soya bean production is of particular interest in heavy soils and wet conditions of rice based cropping systems. Control of irrigation and drainage are the keys to high yields.

The coolest location, Baguio, is expected to provide the highest potential yields in the Philippines (around 4.0 t ha^{-1}). Yet, the crop is still almost absent in Philippines highlands. Introduction of soya bean in such cool areas appears promising.
Potential soya bean yields are 2.3-4.1 t ha^{-1} for stations at low elevations. Yields of irrigated crops are rather constant. Rainfed crops show strong seasonality, which is particularly due to failure of crops to emerge or establish due to drought and sometimes due to flooding. When planning crop production, water supply from the ground water table should be taken into account. Short duration waterlogging in rainfed lowlands is a significant cause of yield loss. Deep soils permit much higher dry season yields than medium deep soils.

There is scope for increasing yields of irrigated crops generally by 50-100 %: the best Philippine farmers yields on irrigated fields are 1.5-2.0 t ha^{-1}, but potential yields are 50 to 100 % higher. For the saturated soil culture and for irrigated crops, there are no problems for timing of soya bean before or after rice because weather is always suitable for good yields.

For rainfed crops, if sown at the end of the rainy season after rice potential yield is around 2 t ha^{-1}, and quite variable. The scope for improvement should be considered per site. Supposing that rice remains the first crop in the rainy season, soya bean has to wait about 100-130 d for this crop to mature, and another two weeks for field preparation. This gives the farmer a window of only a few weeks at the norther stations on deep soils, and certainly less for shallower ones. Southers stations have a longer suitable planting period. Crops preceding rice need irrigation for establishment; provided that water is available, there are no restrictions on sowing date.

SOYCROS has many features that also apply to other leguminous crops. With cowpea crop data, it was used to investigate the suitability of cowpea in rice based cropping systems of the Philippines (Timsina et al., 1992a, b) and cowpea, soya bean and peanut in Indonesia (Padjung, 1990).

It should be realized that variability in production at a national level is different from what is presented here. Variability of soya bean production at the national level is a function of both yield per unit area, which is related to weather and of fluctuations in the area harvested. Area variability is outside the scope of this study. Weather patterns in different parts of the country in any particular year may be unrelated.

There are also several research topics that were identified in this study. Soya bean may suffer from spells of waterlogging. Deterioration of root functions under anaerobic conditions and growth of the acclimated root system need further study, particularly with respect to rates of deterioration and acclimation.
Research is needed to more accurately quantify the relation of water shortage to water uptake (Figure 2). During seedling establishment in the dry season, there is often a race between the progressing drought zone and the rooting depth. More in-depth studies are needed. Few data are yet available on cultivar differences.

The critical moisture content for germination (set at 80 % of field capacity) must be evaluated for different soil types and weather conditions.

To develop recommendations for crops at specific locations, capillary rise should be accounted for. If the water table is less than 1.5 m deep, its level should be monitored during the cropping season, and the soil hydraulic conductivity should be measured.

4. The economic potential production

It is wasteful attempting to reach the agronomic potential of soya bean when this cannot be economically viable. Economic viability depends on the quantities of inputs and outputs and on their prices. We have evaluated the economics for farmers of growing soya bean in an efficient, intensive and probably sustainable cropping system. Crops convert material inputs (nutrients, water, CO_2 and solar energy) into biomass, of which a large fraction has economic value. Radiation and CO_2 are provided free-of-charge, and so is all or most of the water. In an equilibrium situation with respect to nutrients , all of the major minerals (P, K) and some N are provided by the farmer, while most of the N is provided through symbiotic fixation. Sowing, harvesting and threshing are essential activities. Additional labor is required for efficient conversion of inputs into grains: preparing land and suppressing growth reducing factors (pests, diseases, weeds). Crop management requires labour and/or material inputs. Finally, the opportunity value of the cropped land is to be substracted. The net profit is that what may be expected of a single soya bean crop above the profit that other common crops would have brought.

The data that we use on quantities involved and on costs per unit input, hectare or labor are based on economic surveys by PCARRD (1987) and Rosegrant et al. (1987). Prices refer to 1987 levels in the Philippines and are in US$ (20 Peso = 1 US$). Spatial and temporal variability in prices and labour are not considered.

Biological constraints and post harvest operations cause losses that can be avoided or reduced. However, it is uneconomical to eliminate them completely. The economic potential yield is therefore assumed to be 80 % of the agronomic potential yield. This fraction is exceeded in experimentation (Tedia, 1988), but not always reached in commercial production (as comparison of potential yields and data of PCARRD (1987) shows). No studies could be located to support our 80 %-assumption, so that a sensitivity analysis is made.

We could not collect a set of data to derive the comparative advantage of soya bean produced in the Philippines over that in the international market.

4.1 Method of analysis

Financial benefits and costs are computed for each case for which crop production was simulated. In a preprogrammed procedure, all simulation results were read into a spreadsheet; an economic balance sheet was made, and net profit established (Appendix III). In this way, the entire analysis is performed with a few keystrokes in MS-EXCEL (Microsoft, 1989); but it could also have been implemented in the terminal section of the CSMP-program. A sample output in tabular form is shown in Appendix IV. Probability levels of net profits and corresponding graphs were prepared similarly to those for agronomic yields. Quantities of inputs needed for production, their cost, and quantities and value of outputs are discussed first (Tables 6, 7).

Table 6. Cost of inputs and outputs in the Philippines, 1987, expressed in US $ (20 P = 1 US$).

ITEM	COST	
Outputs		
soya bean, pods, cleaned	0.35	kg^{-1}
urea in soil	0.01	kg^{-1} grain
Inputs		
seed	0.75	kg^{-1}
chemicals	7.00	kg^{-1}
fertilizer	0.07	kg^{-1}
water	6.5	$(1000\ m^3)^{-1}$
depreciation	5 % of cost inputs	
land rent=opportunity cost	150	$crop^{-1}$
man-day	1.75	d^{-1}
man-animal-day	3.0	d^{-1}

Table 7. Material inputs (in kg) and labour (in MD) required for potential production of one hectare of soya bean in Los Baños, early dry season. Q stands for quantity involved, and L for labour requirements. 1 MD (man-days) corresponds with 0.5 MAD (man-animal-days).

	RFULP		IRUPL		RFLL		SSC	
	Q	L	Q	L	Q	L	Q	L
Dry season								
Benefits								
yield*0.8	500	-	3300	-	2700	-	2500	-
Urea equivalents	20	-	132	-	108	-	100	-
Cost								
land preparation	-	18	-	18	-	0	-	2
seeding	50	8	50	8	70	8	70	8
crop protection	3.5	39	3.5	39	3.5	39	3.5	39
fertilizer	300	2	300	2	300	2	300	2
water	-	-	2*	4.5	-	-	2*	4.5
(post)harvest	-	24	-	24	-	24	-	24
fixed cost	150	-	150	-	150	-	150	-
capital	+5%	-	+5%	-	+5%	-	+5%	-
Wet season								
Benefits								
yield*0.8	1400	-	1200	-	2100	-	2300	-
Urea equivalents	56	-	48	-	84	-	92	-
Cost								
land preparation	-	18	-	18	-	0	-	2
seeding	50	8	50	8	70	8	70	8
crop protection	3.5	39	3.5	39	3.5	9	3.5	39
fertilizer	300	2	300	2	300	2	300	2
water	-	-	-	-	-	-	-	-
(post) harvest	-	19	-	19	-	19	-	19
fixed cost	150	-	150	-	150	-	150	-
capital	+5%	-	+5%	-	+5%	-	+5%	-

* no. of irrigations, quantity of water supplied varies.

Benefits

Grain yield. The farmers main benefit is derived from selling the soya bean grains at 7 P kg^{-1}.

Soil N. A crop following soya bean extracts more N from the soil than one that follows a cereal or tuber crop, because legumes leave N in root nodules that decompose. De Datta & Morris (1983) report a benefit of about 20 kg N ha^{-1} in the following rice crop after a dry season soya crop. This corresponds with 0.01 kg N per kg soya grain, and is roughly equivalent to 0.04 kg purchased urea per kg of soya grain harvested (assuming 50 % recovery by the rice crop of applied N). Thus it reduces the fertilizer N requirement of a following rice crop, and this indirect benefit is added to the balance sheet.

Straw. We are ignoring the benefits accrued from soybean straw in our analysis. However it must be recognized that the indirect benefits such as the amount of N released and residues used as soil cover or mulch, can be obtained from the soya bean straw.

Costs

Land preparation. Tillage on upland soils improves crop establishment and suppresses weeds. Clearing, plowing, harrowing and mulching requires 18 man-animal-days (MAD) ha^{-1}. On lowland, where weed problems are smaller, zero tillage is assumed to be practiced; this shortens the turn-around time between crops. Furrowing, needed in the SSC system, requires 2 MAD ha^{-1}. Tillage operations for crops following soya bean are not affected by soya bean tillage, so that there are no indirect costs or benefits. Machines or chemicals can replace labour. We assume that the total costs of land preparation and harvesting do not increase due to mechanization.

Seed. 50 kg ha^{-1} of a good quality seed is needed for upland and 70 kg ha^{-1} for lowland soils (PCARRD, 1987). Sowing requires 8 man-days (MD) ha^{-1}.

Crop protection. The amount of chemicals currently used per crop is around 3.0 l ha^{-1} insecticide plus 0.5 l ha^{-1} fungicide, independent of yield. Spraying 3-4 times requires 6 MD ha^{-1}. Weeding without chemicals and cultivation requires 10 MD and 4 MAD ha^{-1}, respectively. Insect pressure is highest at the end of the wet season, so that the quantity may then be higher. Since the total costs for crop protection is relatively low, we assume this to be independent of the level of technology. For crop care (suppression of weeds, insects, diseases), we assume that the total cost of activities plus materials do not increase when farmers shift from manual operations to using chemicals or integrated pest management (IPM) measures. However, we do not encourage farmers for the high use of chemicals or pesticides, as they may cause the pollution and envoronmental damage. Depending upon the labor availability and the different activities of a particular household, the farmer may continue manual weeding or shift to using chemicals or IPM measures. Use of chemicals could be reduced when an effective IPM program is designed and more pest resistant varieties are bred.

Fertilizer. A fixed amount per crop of 40 kg ha^{-1} of N, P and K is assumed to be used, or 300 kg ha^{-1} of 'complete' fertilizer (14-14-14). The fertilizer N stimulates early growth, and an effective Rhizobium strain normally permits the crop to fix the remainder of the 150-200 kg N ha^{-1} that accompanies maximum productivity. In general, for higher crop production more fertilizer is needed. But since the soil provides a buffer and since we are considering only high yield levels, the fertilization rate is kept constant at twice the average removal rate of P (20 kg ha^{-1} crop^{-1}). Applying fertilizer to the field requires 2 MD ha^{-1}. The eventual cost of

Rhizobium and micronutrients are assumed to be negligible. Cost of initial liming at a rate of 3-5 t ha^{-1} on acid upland soils to increase pH is not considered, although such practice may be adopted by the upland farmers of the Philippines.

Irrigation water. The quantity of water required for conventional irrigation (upland) and for the SSC system depends mainly on weather. To compensate for loss of water during irrigation, these amounts are increased by 25 % (Bhuiyan, IRRI, personal communication). We suppose that all irrigation is provided from privately owned pumps using deep wells, which enables the farmer to control the water supply and to be independent of the rising cost of water for rural areas. Irrigation water through privately owned pumps may not be sufficient, especially if farmers become interested to grow soy beans in relatively larger areas, and especially when ground water reservoirs dry up during the dry season. The irrigation water costs about 0.15 US \$ m^{-3} (3.0 P m^{-3}). Irrigation requires 4.5 MD ha^{-1} $crop^{-1}$ of field work.

Harvesting and Post harvest operations. Harvesting requires 15 MD ha^{-1}. Grain drying requires 5 MD ha^{-1} in the wet season but none in the dry season. Threshing costs 7 % of the gross yield and grading 0.25 P kg^{-1}. Packaging and hauling is estimated at 4 MD ha^{-1} for the crop; 0.1 P kg^{-1} of packaging materials are used.

Opportunity cost. Actual land rent is around 25 US\$ ha^{-1} $crop^{-1}$. However, cost for shifting to soya bean production can better be expressed as the financial gain that could be obtained with the best alternative crop (the opportunity cost). Rosegrant et al. (1987, Table A13) compute that rice is the most profitable crop for irrigated conditions, and cotton or peanut for upland conditions. Both fetch net profits of about 150 US\$ $crop^{-1}$ ha^{-1}. The financial yield of a soya bean crop expresses the net profit on top of that of an alternative crop.

Interest. An interest of 5 % $crop^{-1}$ on the capital involved in previous steps is included in the analysis.

Off-farm storage and transport. Cost of long-term off-farm storage and transport hardly affect the profitability for farmers, and are not considered. Moreover the practices and the cost involved in the off-farm storage and transport is expected to be not much different from other crops.

4.2 Results

The fixed part of production costs is relatively large, so that net benefits of soya bean production are almost proportional to yield above 1400 kg ha^{-1}. The pattern of the financial yields are similar to those of the agronomic potential yields (Figures 16-19). Mean values for irrigated crops at low elevations are 8000 to 12000 P ha-1 (400 - 600 US\$), and values can be higher in favorable seasons. Also in Baguio, higher profits can be expected. The net returns for irrigated upland situations range from -10,000 to 8,000 P (Los Baños) to about 20,000 P (Baguio). For irrigated lowlands (SSC) situations, net returns range from 8,000 to 10,000 P (Tupi) to about 11,000 to 18,000 P (Baguio). Net returns for SSC situations are more stable than irrigated uplands in all locations. In Baguio, even for irrigated uplands, the net returns are relatively stable.

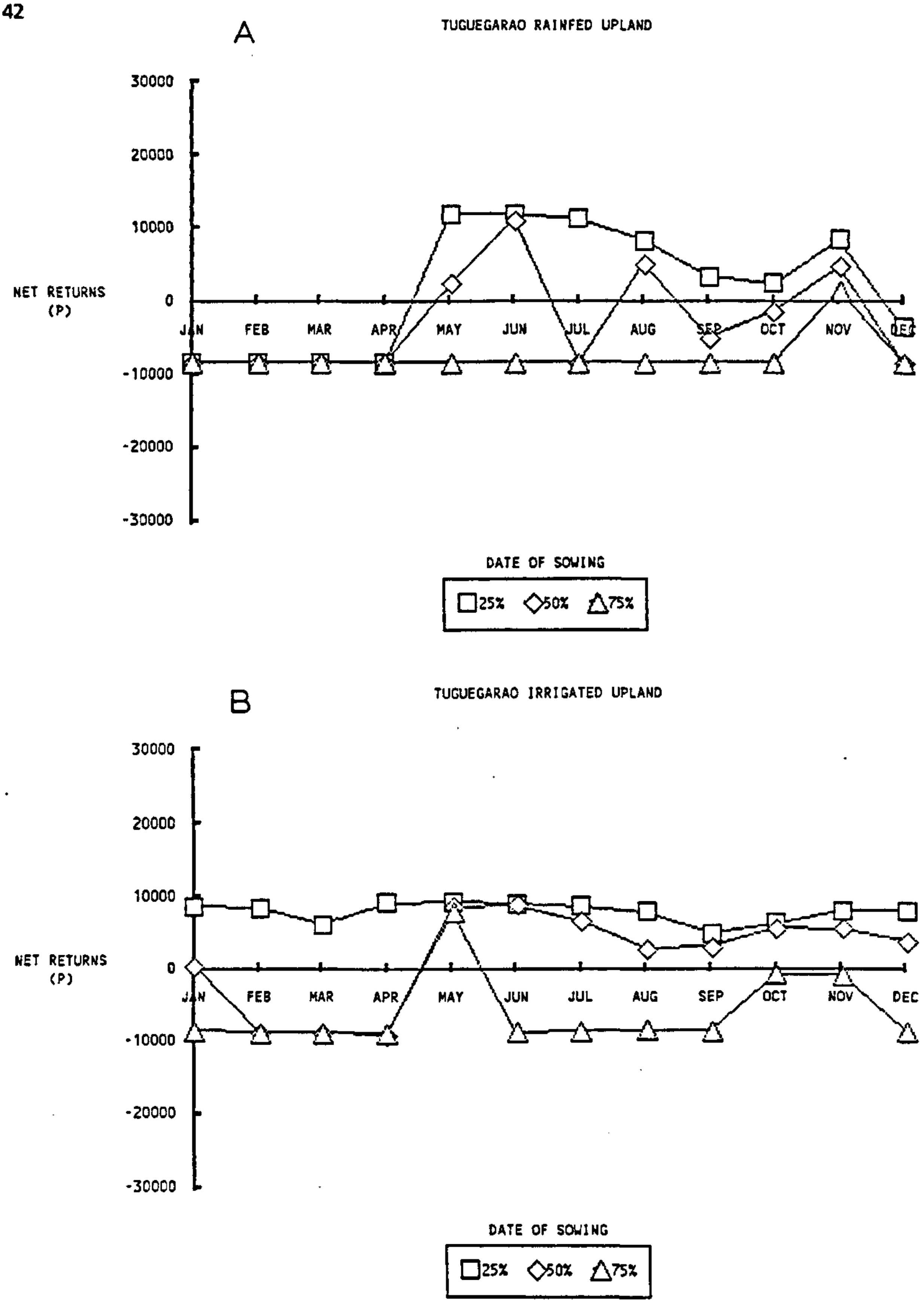
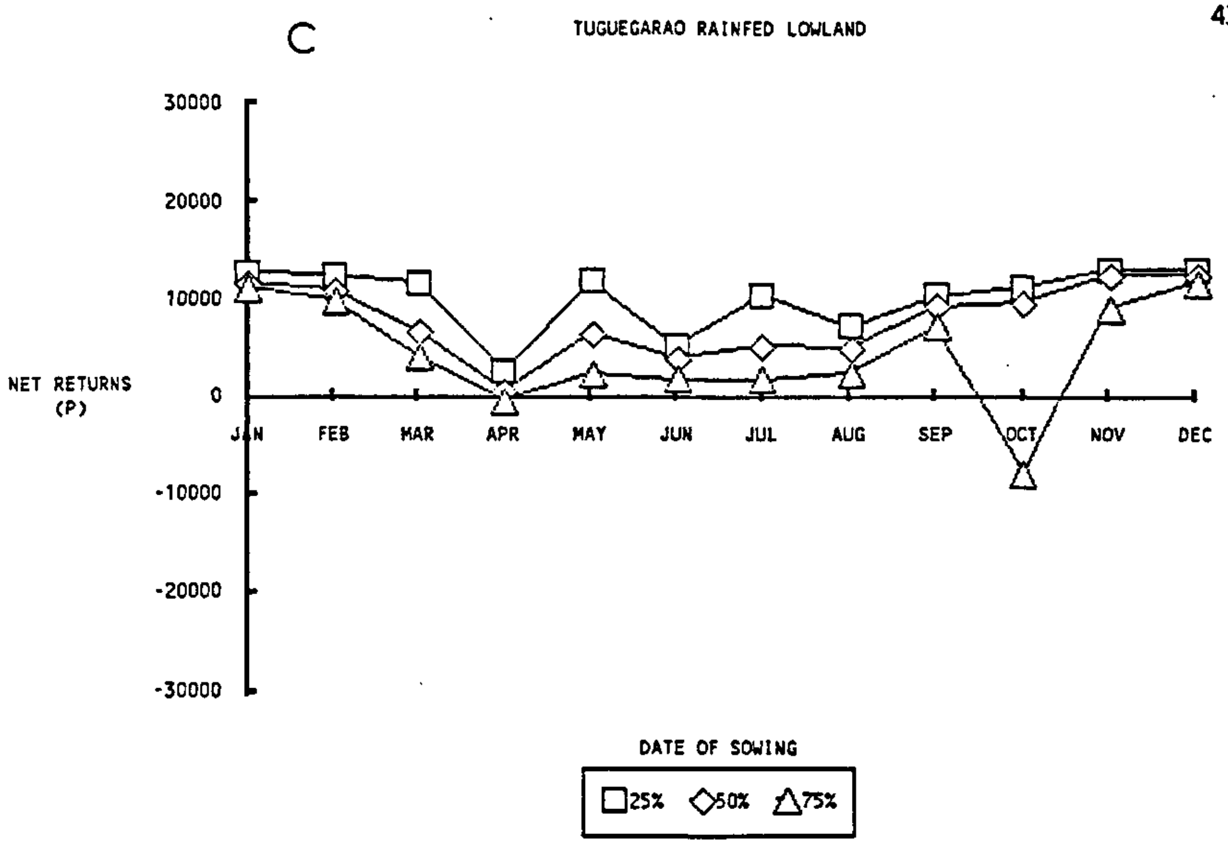


Figure 16. The economic profit of soya bean at probabilities 25, 50 and 75 % of being exceeded in Tuguegarao as a function of sowing date in different growing environments: A. rainfed upland; B. Irrigated upland.



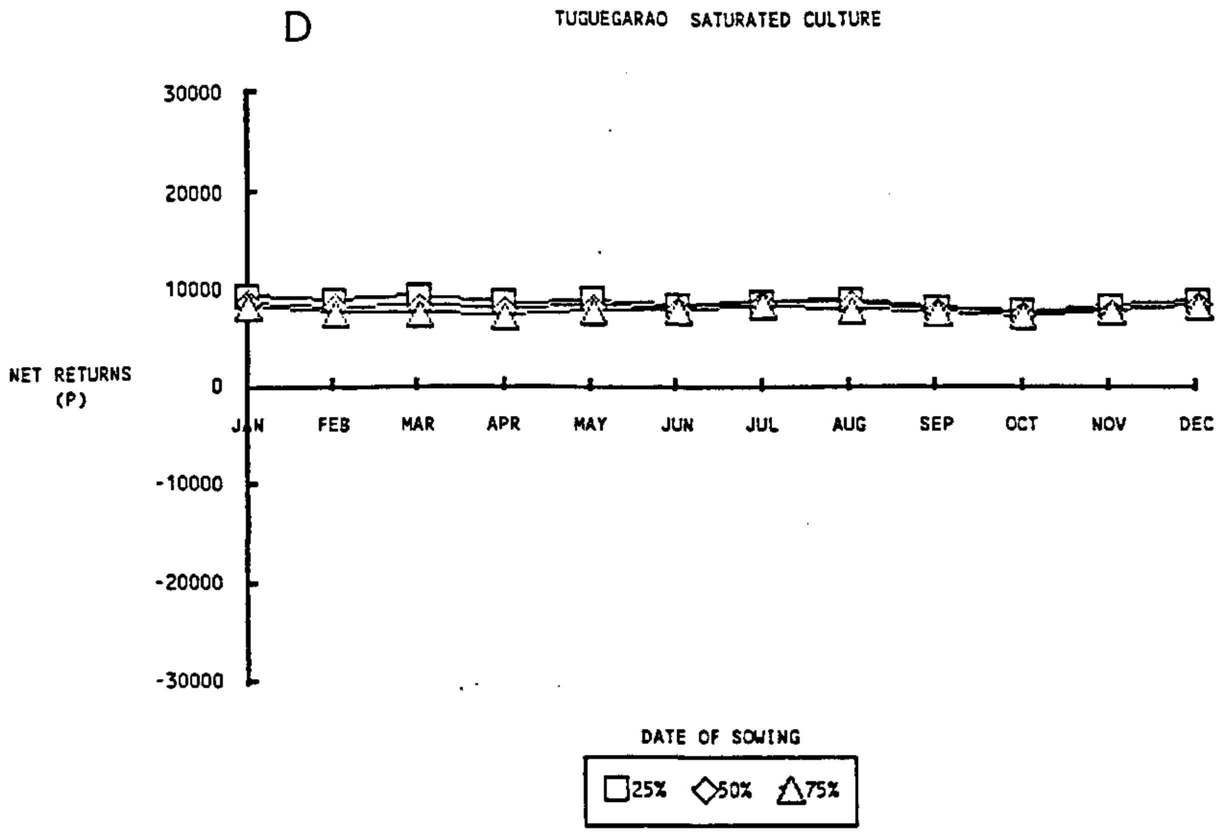


Figure 16. The economic profit of soya bean at probabilities 25, 50 and 75 % of being exceeded in Tuguegarao as a function of sowing date in different growing environments: C. Rainfed lowland; D. Saturated soil culture. The respective sowing dates in the different months are : 9., 40., 68., 99., 129., 160., 190., 221., 252., 282., 313., 343.

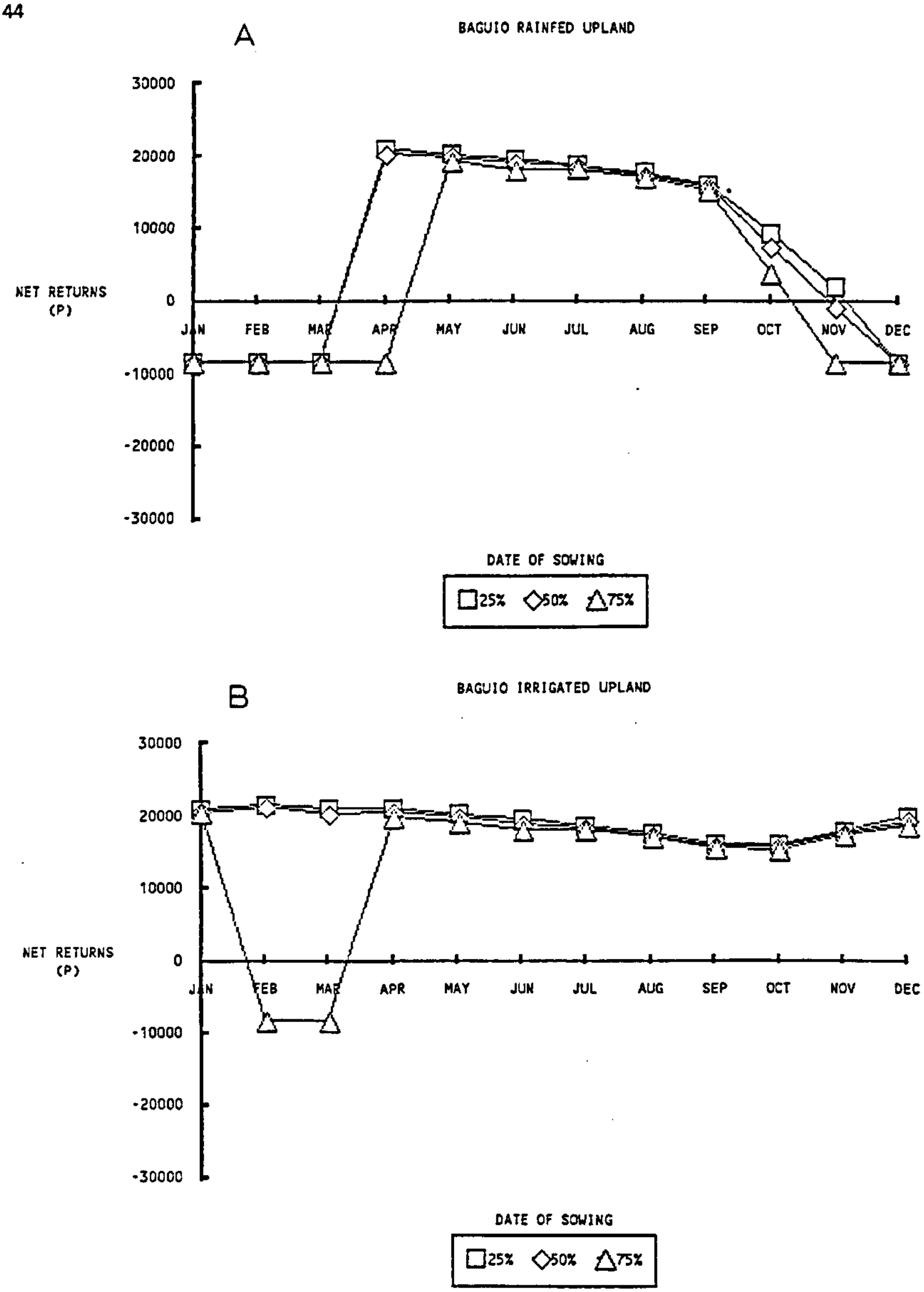
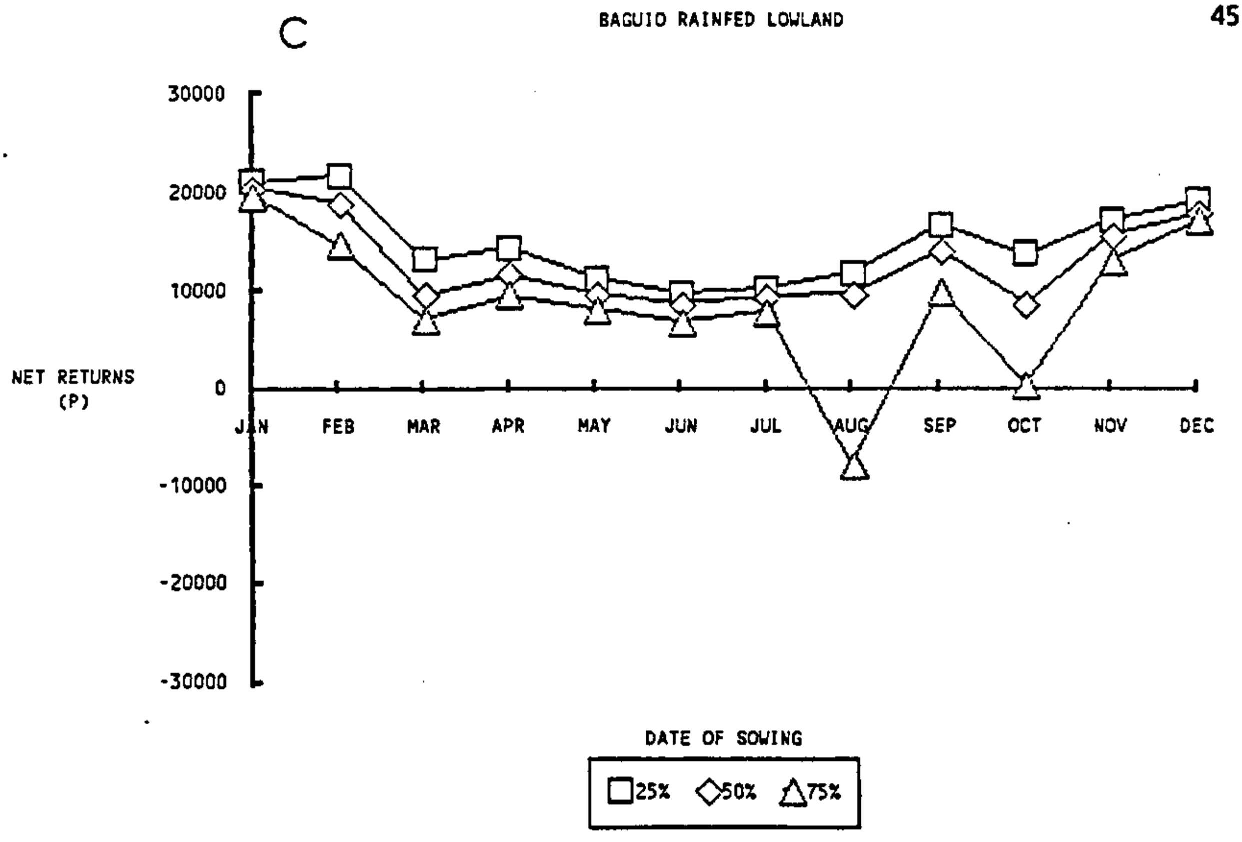


Figure 17. The economic profit of soya bean at probabilities of 25, 50 and 75 % of being exceeded in Baguio as a function of sowing date in different growing environments: A. Rainfed upland; B. Irrigated upland.



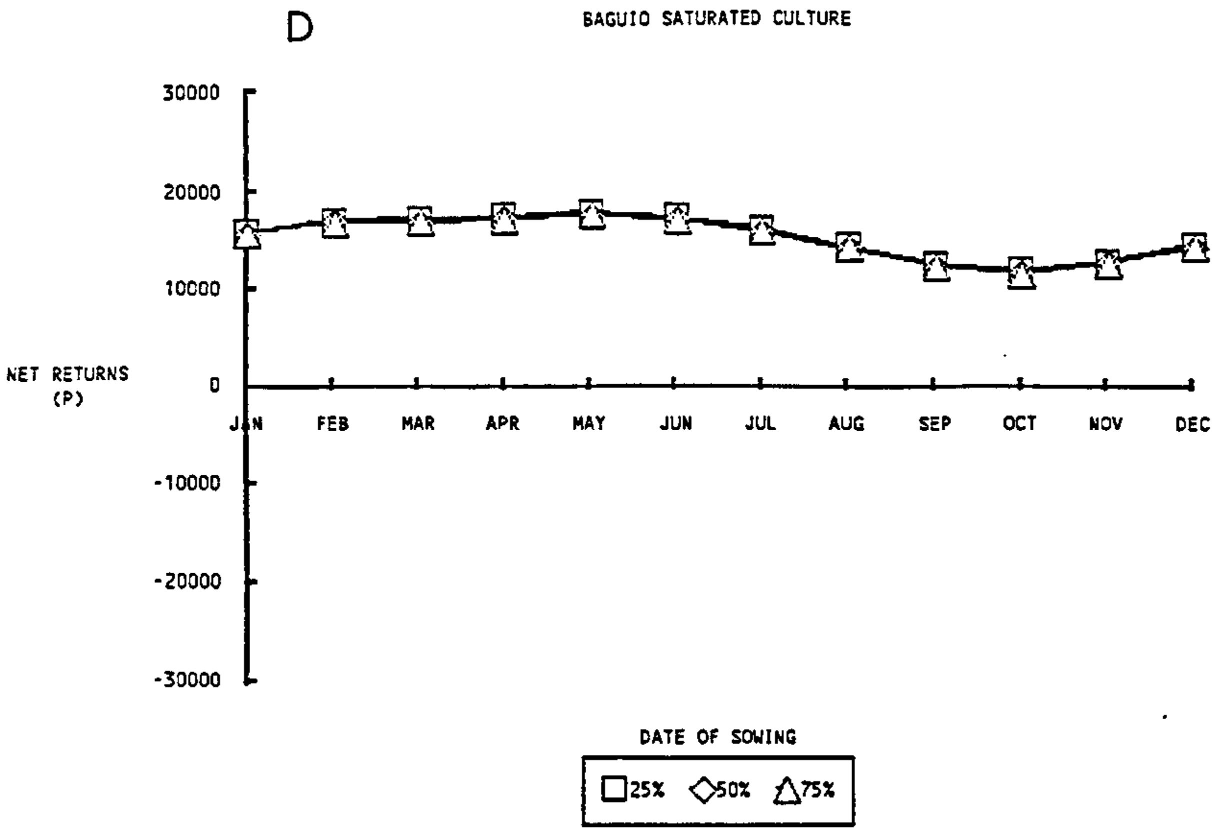
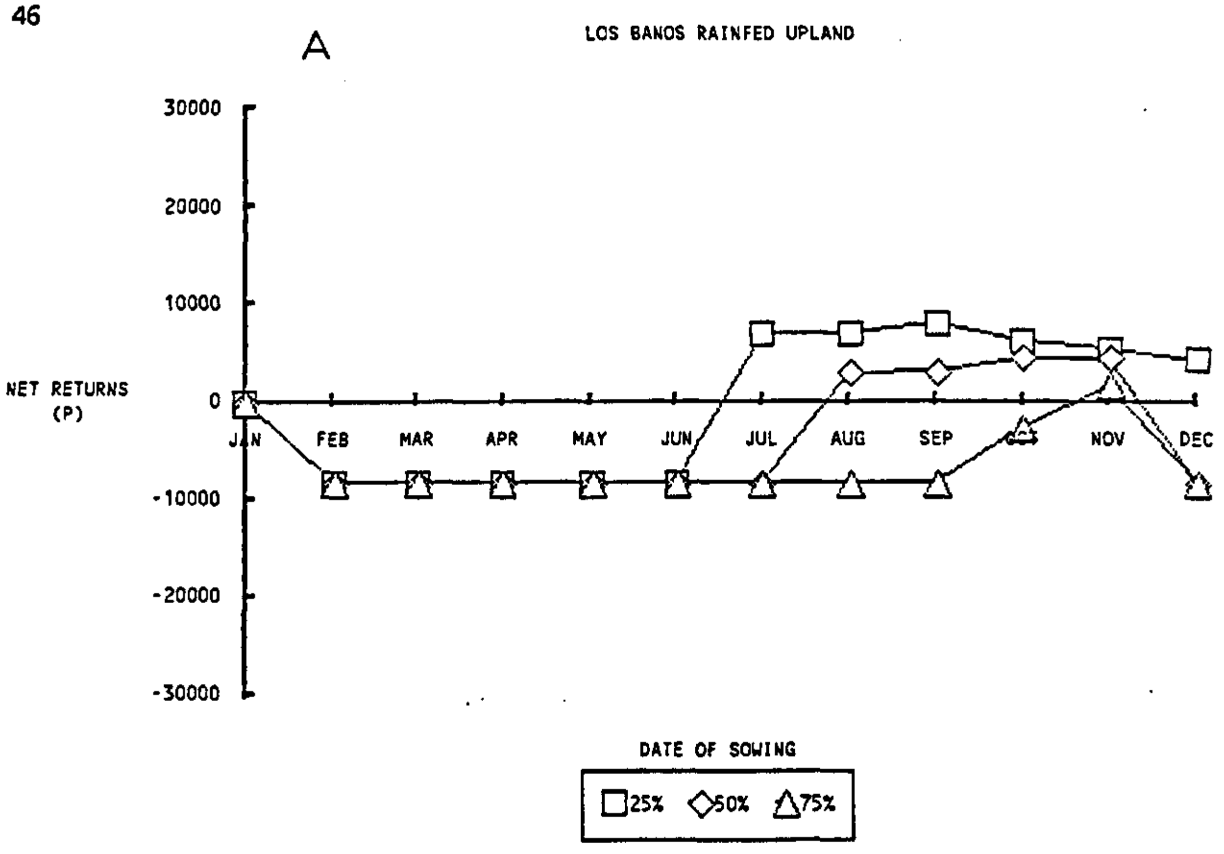


Figure 17. The economic profit of soya bean at probabilities of 25, 50 and 75 % of being exceeded in Baguio as a function of sowing date in different growing environments: C. Rainfed lowland; D. Saturated soil culture.



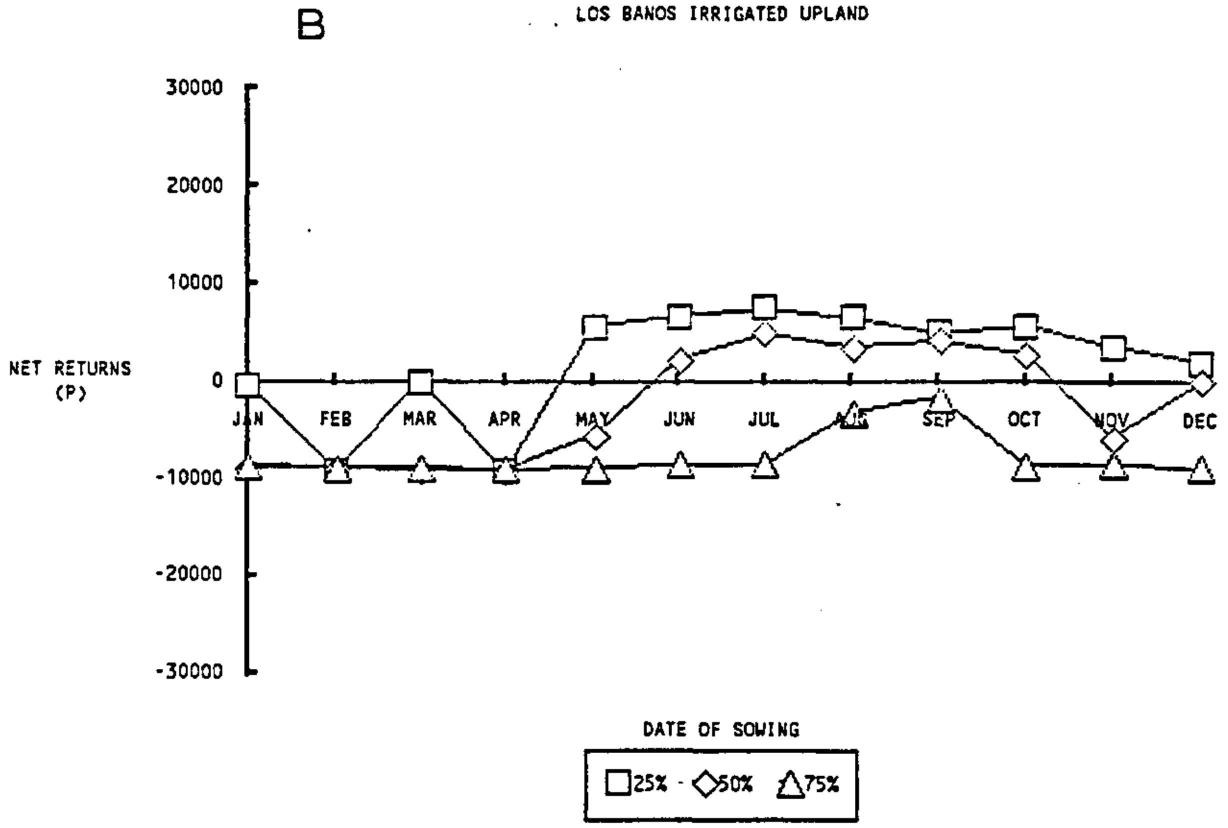
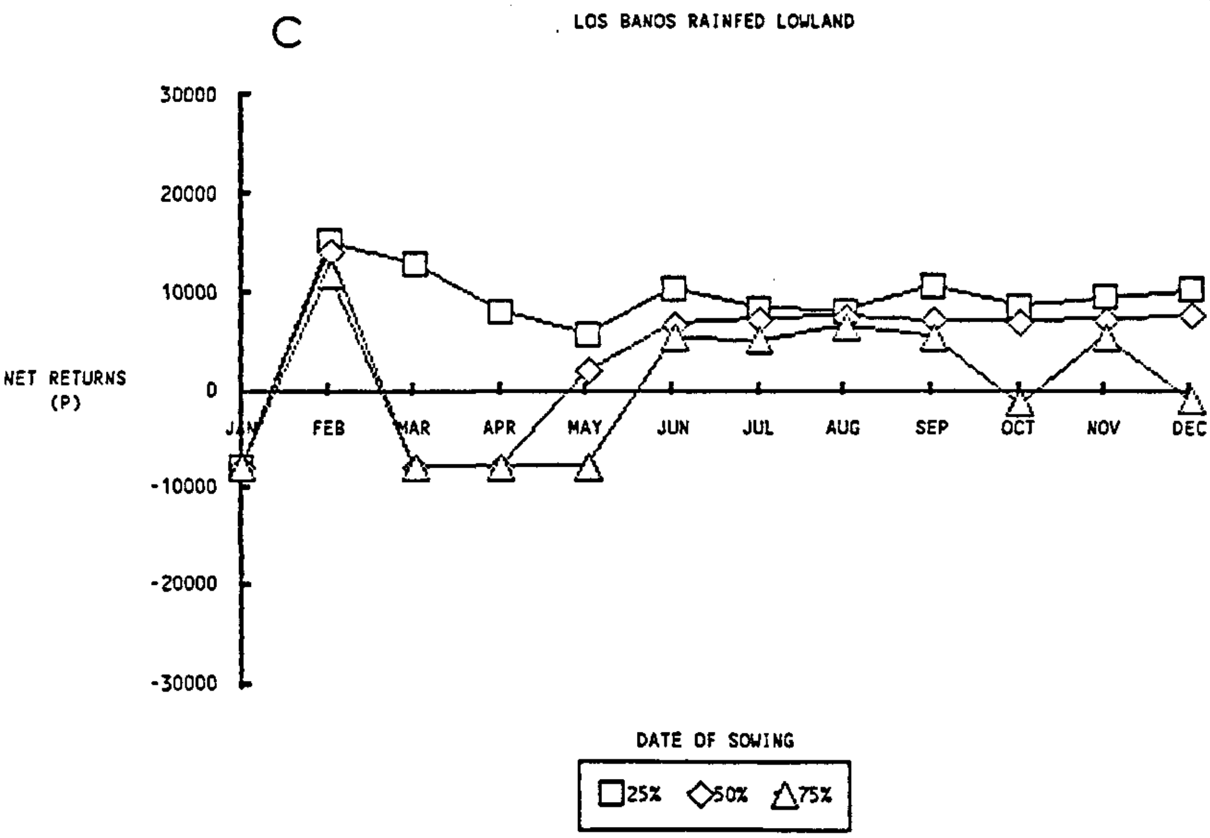


Figure 18. The economic profit of soya bean at probabilities of 25, 50 and 75 % of being exceeded in Los Baños as a function of sowing date in different growing environments: A. Rainfed upland; B. Irrigated upland.



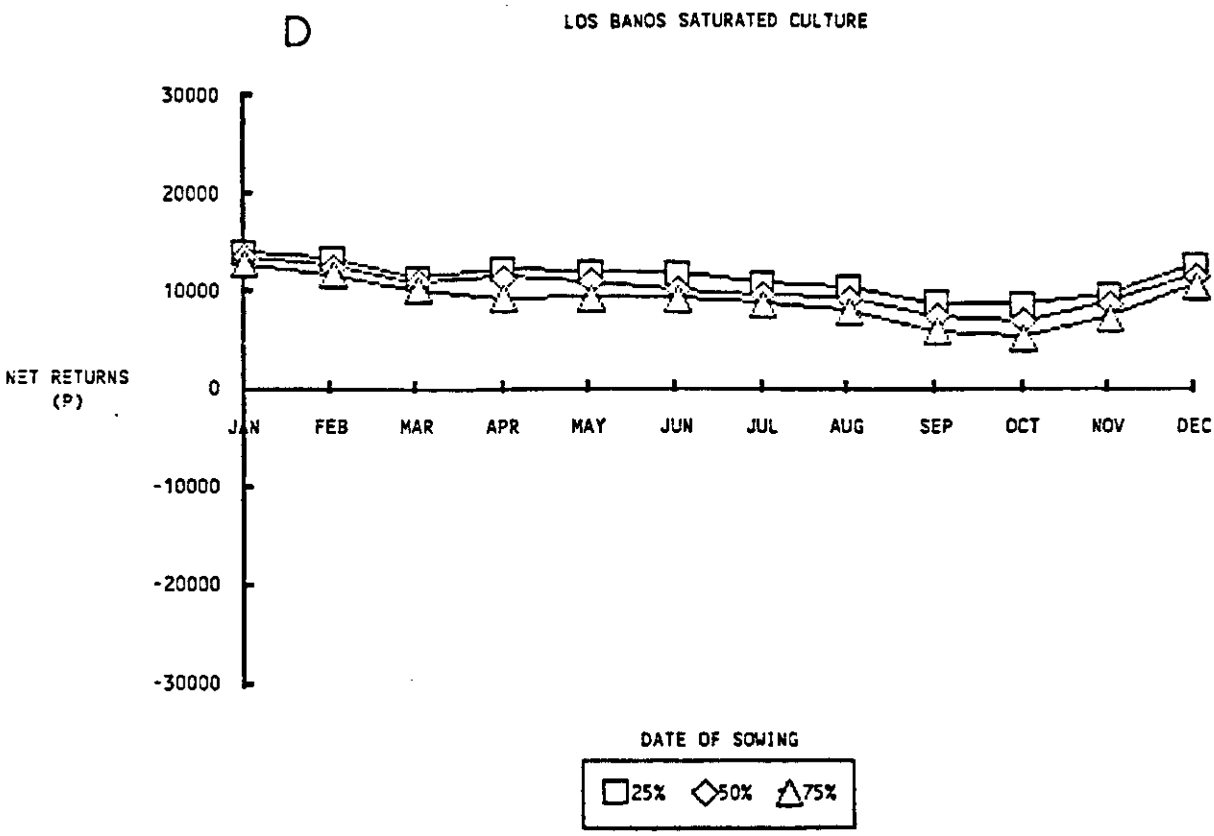
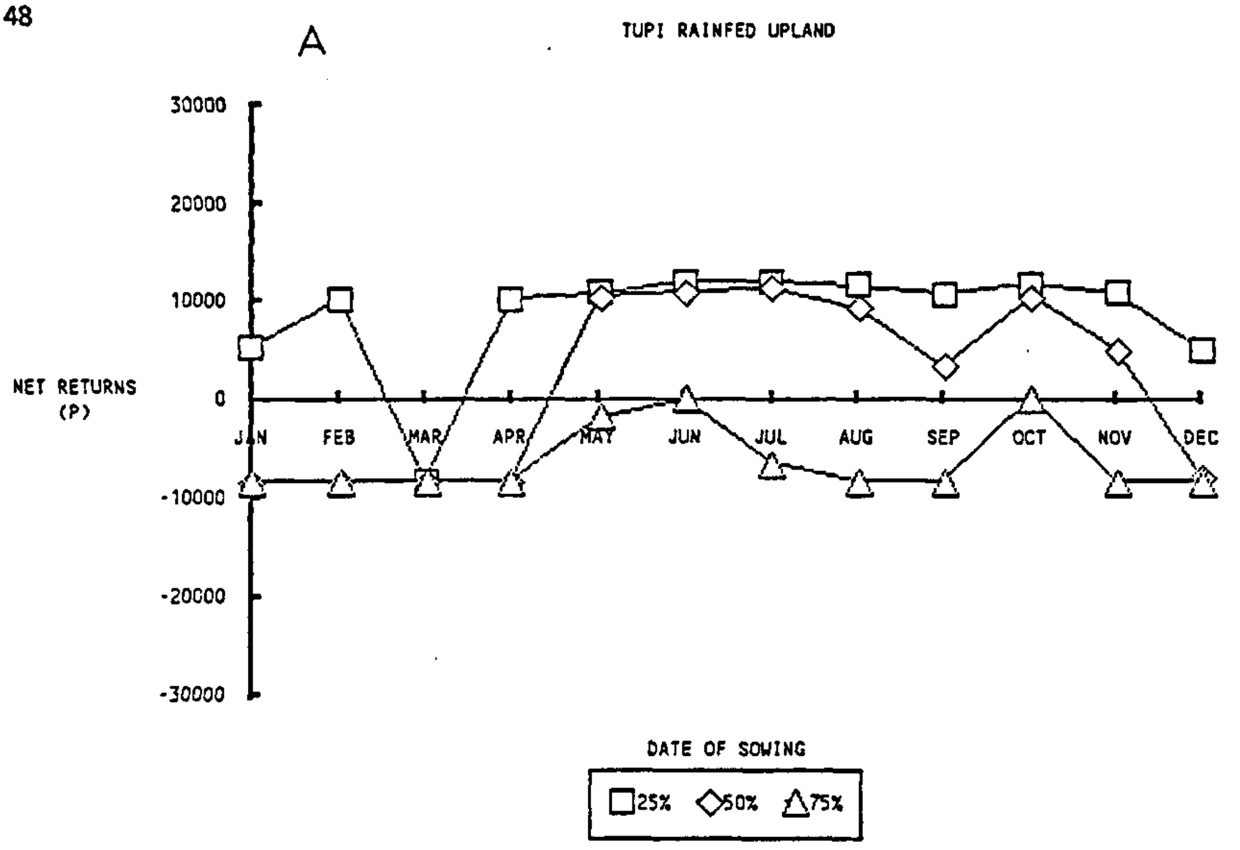


Figure 18. The economic profit of soya bean at probabilities of 25, 50 and 75 % of being exceeded in Los Baños as a function of sowing date in different growing environments: C. Rainfed lowland; D. Saturated soil culture.



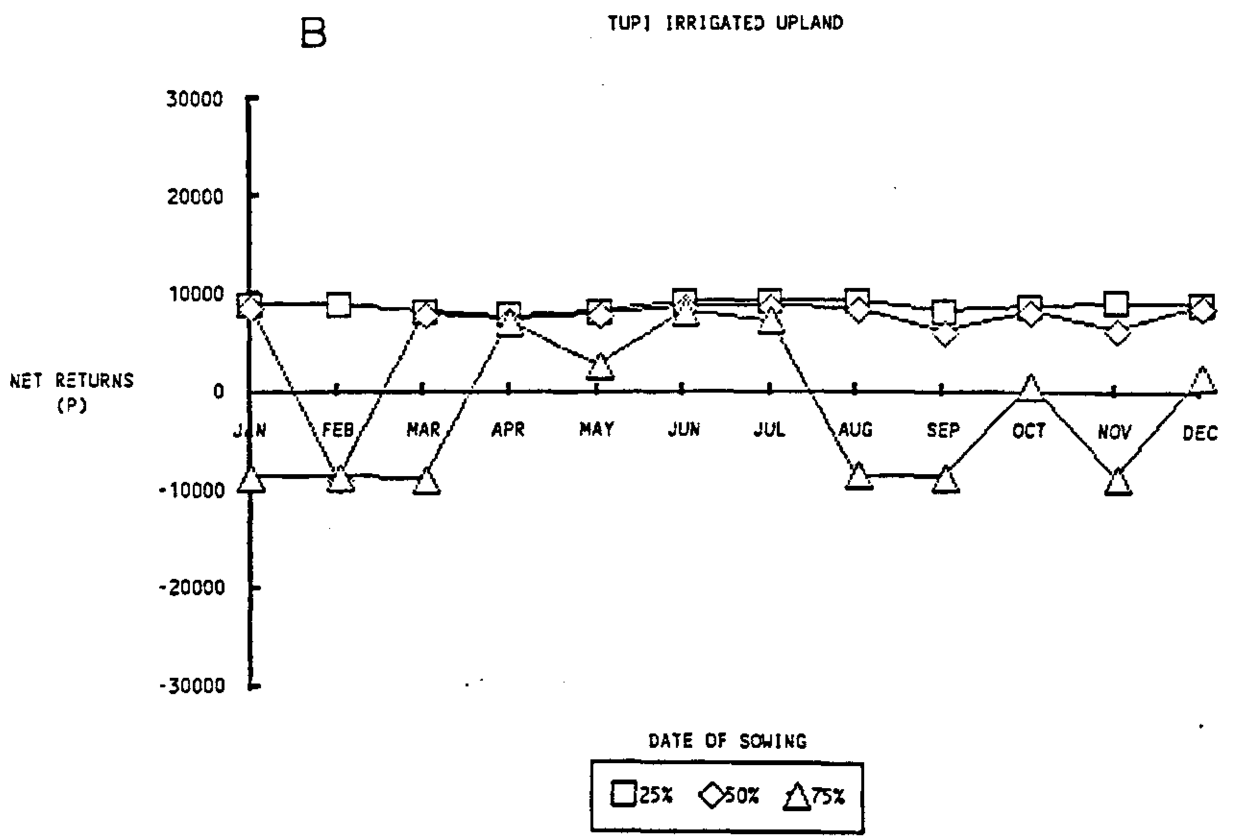


Figure 19. The economic profit of soya bean at probability of 25, 50 and 75 % of being exceeded in Tupi, South Cotabato as a function of sowing date in different growing environments: A. Rainfed upland; B. Irrigated upland.

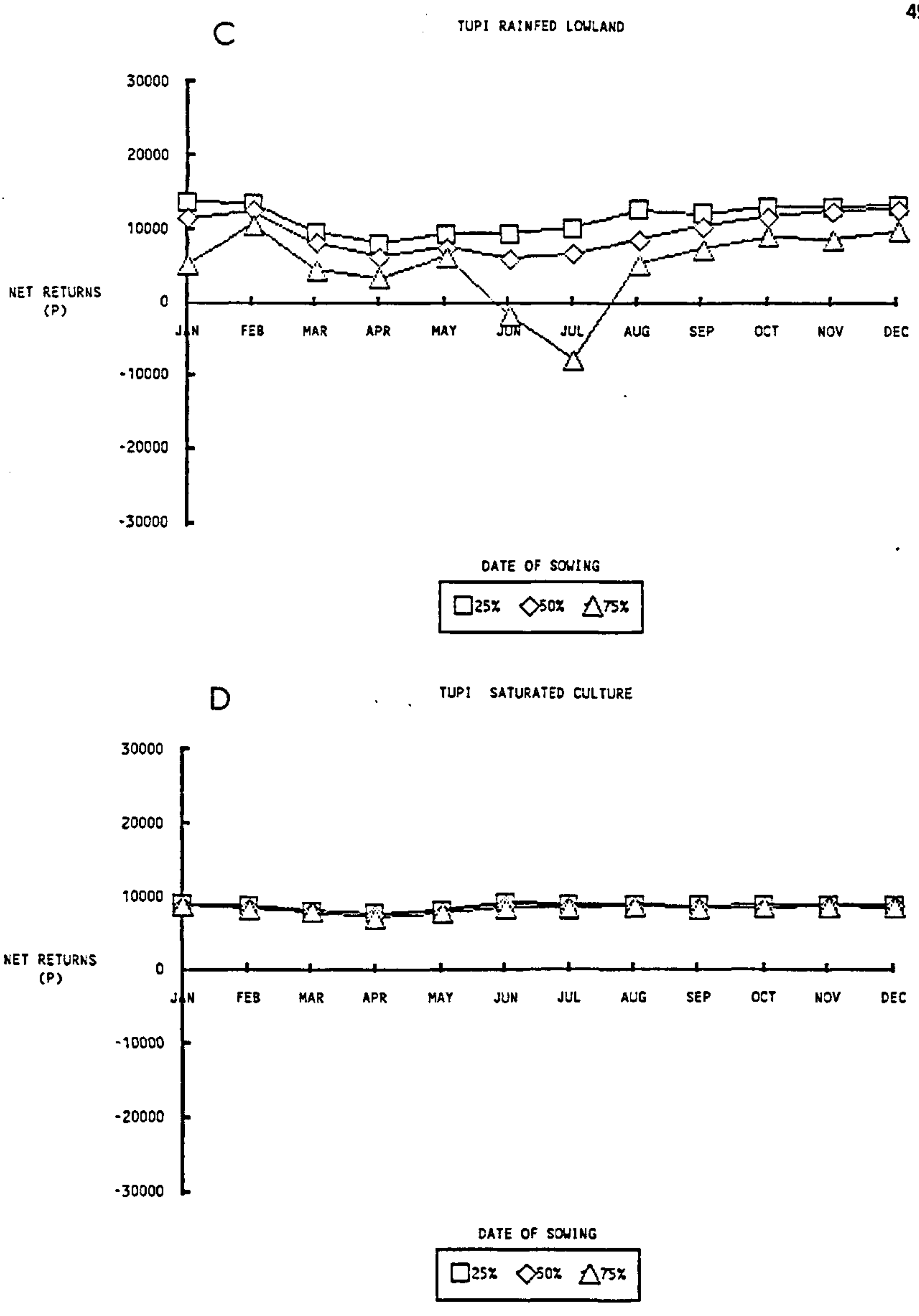


Figure 19. The economic profit of soya bean at probability of 25, 50 and 75 % of being exceeded in Tupi, South Cotabato as a function of sowing date in different growing environments: C. Rainfed lowland; D. Saturated soil culture.

For rainfed lowland situations, the profit ranges from -10,000 to 15,000 P (Los Baños) to 5,000 to 20,000 P (Baguio). The net returns under such situations are moderately stable over the year.

For rainfed upland, net profits range from 8000 P ha^{-1} in most years in Davao to a 2000-8000 P ha^{-1} in Los Baños, with large year to year variations. Yields are low on medium deep soils, and mean net profits are negative for sowings during a large part of the year. Even irrigated fields produce negative results (relative to rice) in many cases.

The net profits for SSC are never negative indicating that the crop can be profitably grown in all months in all the locations. In the rainfed lowlands also, net returns are greater than zero for most of the months. In the uplands, where soils are medium deep, yields in most locations (except Baguio) are low and mean net profits are negative for part of the year.

Sensitivity analysis showed that net profits are proportional to the ratio between potential and achievable yield. We assumed as our standard ratio 0.8. A value of 0.6 would reduce profits (relative to rice) to zero in many cases. This case seems to correspond with the yield level at which many soya bean farmers currently produce. With a low marginal profit, there would be little stimulus for expansion of the hectarage (Rosegrant et al., 1987). Farmers need to expect an increase in profit of at least 30 % before adopting new techniques (Flinn, IRRI, personal communication), so that additional profits from improved soya bean production should be 50 $ ha^{-1} or more. This implies that research is needed to reduce yield losses or stimulate production by at least 150 kg ha^{-1}. Gonzales (1989) concludes that soya bean production in the Philippines and Indonesia cannot compete internationally unless research improves productivity by 30 %. For rainfed uplands, this may be difficult. For rainfed lowlands and irrigated conditions, this can be achieved.

5. Discussion and Conclusions

5.1 Discussion

The simulation results on grain yields and the corresponding net returns computed for rainfed upland, rainfed lowland, irrigated upland, and irrigated lowland clearly indicate that there is a high prospect of growing soya beans in the Philippines. The Philippines is a tropical country, solar radiation and temperatures are not much variable, only the rainfall is erratic. The crop must be grown in rice-based cropping systems as a post-rice crop so as to utilize residual soil moisture and the capillary rise in the lowland systems. Excess moisture during the germination and seedling establishment is a constraint, but can be avoided by the proper choice of planting dates and suitable cultivars, and with a field drainage. In the uplands, the crop should be growing as an intercrop either with upland rice or with maize. Timsina et al. (1992b) have analyzed the simulated yields of cowpea cultivars for different growing situations for the rice-based cropping systems of the Philippines, and concluded that there are niche-specific cultivars for rice-based systems. Since soya beans and cowpeas are grown under similar situations in rice-based cropping systems, we can expect such specificity in soy beans also. Further runs are required to observe such specificity or differences.

The results show that the grain yields and net profits are higher and more stable for saturated soil culture (SSC) than for other situations. Recent research work in Australia, Thailand, and Philippines also demonstrates that soya bean cultivars grow very well in a saturated soil culture with a high water table. A continuous supply of water should be assured for the SSC crop. It means there should be reliable source of irrigation. Likewise there should be proper drainage facilities, so that excess water can be drained especially after heavy rains. If the crop is grown in small-scale, farmers may irrigate from their hand pumps, but for a crop grown in large scale, a village or a community level irrigation systems is necessary. National irrigation systems administered by National Irrigation Authority (NIA) distributes water to the farmers in the Philippines, but small-scale communal irrigation systems administered by farmers are also popular. The cost of pumped irrigation water, used in our analysis, is higher than that for wate that can now be obtained from the NIA, which charges a flat rate per season.

Risks in production are moderate to small in irrigated and saturated soil conditions, provided that the field permits drainage of excess water after heavy rains. The SSC technique of growing soya bean is relatively new and has promised well in Australia and Thailand. Summerfield and Lawn (1987) reported that saturated soil maintained throught the growth cycle improved the water relations of soya bean, resulting in increased photosynthesis, nitrogen fixation and yield. Such benefits were observed when soya bean was cultivated in a saturated zone of soil 3 to 15 cm above a perched water table throught crop life (Troedson et al., 1985). The SSC crop produced as high as or in some cases even more yield than that from fully irrigated crop, when water is drained properly. However if not drained properly, great risks are there and the crop may fail. Such results require careful manipulation and control of the water table. In the shallow water table conditions, the medium maturing cultivars performed better than others (Timsina et al., 1992a). The responses suggest that if the field water level can be controlled different drainage management designs may be optimal for medium to late maturing types as compared to early maturing types. The depth to which the ground water table needs to be lowered to minimize damage to the root system and optimizing performance, appears to differ among cultivars. Raised beds are a viable management alternatives for partially alleviating shallow water table stresses. Risks in rainfed situations are always moderate to large, and depend on rainfall patterns at the specific locations.

Rosegrant et al. (1987) state that irrigated production is more profitable than rainfed production. This is true for most cereals and for other drought sensitive crops. In case of legumes in rice-based cropping systems such soy beans, the water requirement by irrigation is not very high as much of water required by the crop can be obtained from the capillary rise. Hence if the soy bean crop is grown in rainfed lowland situations, it gives fairly high yields and high net profits. Irrigated or the SSC soy bean crop, no doubt, produces a little higher yield than the rainfed one, it may not provide higher net profit significantly because of high cost of water and extra care and management required for such systems.

Production by the crop of soil N does not contribute a large financial benefit. Even a small benefit of soil N by growing soybeans is significant since the following rice crop will need reduced amount of chemical fertilizers. This has large implications since most farmers, on one hand, are not access to chemical fertilizers, and on the other hand, they have no surplus cash to buy a huge amount of such fertilizers. Inclusion of soy beans in the cropping systems enriches the soil fertility and increases the grain yield of the companion or the following crops. Hence it is significant to recognize because the soil cultivated with soybean will be more fertile, land will be gradually improved, and sustainable production of crops can be achieved.

Weeds are major problems but can be controlled by hand weeding or by mechanical removal (if in small scale) or by use of herbicides (if in large scale). Zero tillage on lowlands also reduces the weed population. Diseases and insect pests can be controlled with 2 to 3 sprayings. Care should be taken during sprayings as most farmers do not have knowledge and skills on pesticides, equipments, and spraying techniques. Misuse and overuse of chemicals contribute to pollution and may cause environmental hazards. Post harvest insects also deteriorate the quality of grains and cause yield reductions. Proper storage structures and frequent use of insecticides are necessary for the control of insects and pests during storage.

More care and management of soybean crop is needed when it is to be grown under SSC as it requires judicious control of water for drainage and irrigation. This requirement, that does not show up in the economic analysis, can be a large handicap for introduction of this technique (Lawn, CSIRO, personal communication).

5.2 Conclusions

Soya bean production in the Philippines can be profitable in all areas, provided that sufficient water is supplied by rainfall, ground water or irrigation. There is a better prospect of growing soya beans as a post-rice crop in rainfed and irrigated lowlands. In rainfed and irrigated uplands with lighter soils, maize is predominantly grown. However, growing of soya beans as a post-rice crop in rice-based systems, and as a pure crop, or as an intercrop with maize or rice in uplands requires lower inputs and provides higher grain yields and ultimately higher net profits than that from alternative crops.

The yields and the net profit for all land types are higher in Baguio, which has a cooler climate and the deep soils. In Davao, grain yields and net profits are fairly stable over the months due to less variation in temperature, radiations and rainfall. Fully irrigated crops (either in uplands or lowlands) show little seasonality in yields and net profits as temperatures are favorable throughout the year. The high yields and net profits simulated for Baguio indicate that fields at moderate to high latitude in the Philippines should get more attention as potentially important contributors to food and income generation. Crops grown in rainfed lowlands receive significant water from capillary rise, and produce pretty high yields. Yields obtained from such fields are less variable than that from the rainfed uplands.

Soya bean crop per se does not require any extra care and management and skills in comparison to cereals, except that pests and diseases should be controlled judiciously without resulting in environmental damage. However, special care, management, and skills are required if soya beans are to be grown in the SSC. This requirement, that does not show up in the economic analysis, can be a handicap for introduction of this new technique (Lawn, personal communication).

6. Recommendations and policy implications

The SOYCROS model documented here simulates the growth and yield of soybean cultivars of different durations for a range of land types and moisture regimes in the Philippines. It also permits a very quick and first financial analysis for soy bean production. The model can be used for Asian rice lands with varying moisture and water table depth regimes. The model is suitable especially when soya bean is grown as a post-rice crop in rice-based cropping systems. After changing the cultivar specific parameters , the model has been used for predicting cowpea yields for different growing situations in the rice-based cropping systems (Timsina et al., 1992a,b). Results on agronomic yields and economics of production, obtained from SOYCROS model, have implications to policy makers and planners, researchers and extension workers, and the farmers.

Implications to policy makers and planners: Policy makers and planners make decisions on priorities and allocation of funds for research, extension activities and other forms of support for different crops. They have to make such decisions considering the demand and use of a particular crop by different sectors. Results indicate that there are potential areas where soya bean yields could be as high as 4.2 t ha^{-1}. The current yields and volume of soya bean production, but its growing rate of consumption in the Philippines indicates that the crop should be considered to receive priority in terms of research and extension. SOYCROS identified potential soybean growing areas, predicted the potential yields, calculated the economics of production, and performed the uncertainty analysis to look at the changes in yields and net returns with changes in growing environments and inputs. Based on results of SOYCROS (as presented here and other analysis that could be performed), planners and policy makers can make decisions on whether to prioritize the soybean crop or not.

Sensitivity analysis with prices and costs can be performed with SOYCROS to determine optimum level of production. Hence under a fluctuating market prices and costs of inputs and outputs, one can see the changes in net profits from a soy bean crop grown under a given situation. Such sensitivity analysis can be very much useful to policy makers for making many kinds of decisions related to inputs and outputs.

Implications to researchers and extension workers: In the Philippines, IRRI and national institutes have been doing research on soya bean for last 15 years or more. A large part of research and extension activities includes introducing, evaluating, and recommending the cultivars for different areas. However no concrete recommendations have been made on what are the potential soybean growing areas, potential yields, and economics of production of such yields. Further no information are yet available on potential research areas that need to be focussed. SOYCROS model can identify the sensitive crop and soil parameters that need to be measured in future experimentations. For example, the model identified that ground water table depths and saturated hydraulic conductivities are two important parameters that must be measured in all future experiments. Most sensitive aspects such as pest resistance and flooding resistance can be determined in further research and be incorporated in SOYCROS. SOYCROS model, supplied with appropriate crop, soil, and weather data can quickly predict the yields for new situations, and thus extension services will be more effective and efficient.

In promising areas, few trials could be established in order to verify the predicted yields (see Timsina et al., 1992b).

Implications to farmers: Subsistence farmers in Asia follow intensive farming systems by growing different crops (either in sequence or in mixture) or mixed enterprises (crops, livestocks, trees etc.). Such systems require sustainable sources of soil nutrients for the systems to be productive and sustainable. Some farmers already grow soybeans. SOYCROS can demonstrate the yield potential along with a first view of its economics, and if extension workers interact with the farmers, many of them may take quick decisions on whether to grow soybean.

References

Alagos, M.J.C., 1990.
Performance of three soybean (Glycine max. L.) cutivars under varying water table depths. M.S. Thesis. University of the Philippines, Los Baños, Philippines.

Armstrong, W. 1980.
Root aeration in the wetland condition. In: Plant life in anaerobic conditions. Hook D.D and R.M.M. Crawford (eds). Ann Arbor Science Publishers Inc. pp 269-298.

Bohm, W. 1979.
Methods of studying root systems. Springer Verlag. Berlin.

Bottema, T. (ed.), 1986.
The soybean commodity system in Indonesia. BORIF-CRIFC-AARD, Bogor, Indonesia.

Carangal, V.R., 1986.
Soybean in rice based cropping systems: the IRRI experience. In: Soya bean in tropical and subtropical cropping systems. Sulzberger and McLean (eds.). AVRDC, Shanhua, Taiwan.

Clapp, J. 1971.
What row width? Soybean Digest, 31:12.

CSIRO, 1987. Annual Report 1986.
Division of Tropical Crops and Pastures, CSIRO, Brisbane, Australia.

De Datta, S.K. and Morris, R.A., 1983.
Systems approach for the management of fertilizers in rice and rice-based cropping sequences. Proceedings FAI Seminar on Systems Approach to Fertilizer Industry, New Delhi, India. 1-42 p.

Diputado, M.T. and D.A. del Rosario. 1985.
Effect of soil moisture stress and seed pre-treatment on germination and seedling establishment of cowpea. Phil. J. Crop Sci. 10: 43-48.

De Willigen, P. and M. Van Noordwijk, 1987.
Roots, plant production and nutrient use efficiency. Ph.D. Thesis. Agricultural University, Wageningen, The Netherlands.

Doorenbos, J. and A.H. Kassam, 1979.
Yield response to water. FAO Irrigation and Drainage Paper 33, FAO, Rome.

Escano, A., L. Ragus, M. Acompanado. 1985.
Agroclimatic requirements of cowpea and soybeans. First Cowpea and Soybean Training Course. Oct 21-Nov 29, 1985. IRRI, Los Baños, Philippines.

Gonzales, L.A., 1989.
Agricultural incentives and comparative advantage of food crops production in Indonesia and the Philippines. In: Comparative advantage analysis of agricultural commodities. Agricultural Economics Society of South East Asia, Manila, Philippines.

Herrera-Reyes, C.H., 1988.
Water balance characterization of rainfed ricelands. M.S. thesis, University of the Philippines, Los Baños, the Philippines.

Herrera-Reyes, C.H., and Penning de Vries, 1989.
Evaluation of a model for simulating the potential production of rice. Phil. J. Crop Sci. 14(1): 21-32.

IBM. 1975. Continuous System Modeling Program III, General System information manual (GH19-700) and users manual (SH19-7001-2). IBM Data processing division, White Plans, New York, USA.

Jackson, M.B. and M.C. Drew, 1984.
Effects of flooding on growth and metabolism of herbaceous plants. In: Flooding and plant growth. T.T. Kozlowski (ed). Academic Press, London pp 47-128.

Jackobs, J.A., Smyth, C.A. and D.R. Erickson, 1986.
International soya bean variety experiment, 11th report of results. International Agricultural Publications, INTSOY no 29, University of Illinois, Urbana-Champaign, USA.

Jansen, D. M. 1990.
Potential rice yields in future weather conditions in different parts of Asia. Neth. J. Agric. Sci. 38: 661-680.

Jones, J.W., K.J. Boote, S.S. Jagtap, G. Hoogenboom, and G.G Wilkerson. 1988.
SOYGRO V.5.41. Soybean crop growth simulation model user's guide. Florida Agricultural Experiment Station Journal No. 8304. February, 1988.

Keulen, H. van, 1975.
Simulation of water use and herbage growth in arid regions. Simulation Monographs. Pudoc, Wageningen. 150 pp.

Keulen, H. van, F.W.T. Penning de Vries, and E.M. Drees. 1982.
A summary model for crop growth. In: Simulation of Plant Growth and Crop Production. Penning de Vries, F.W.T. and H.H. Van Laar (eds.) Simulation Monographs, Pudoc, Wageningen. pp. 87-97.

Keulen, H. van, and N.G. Seligman. 1987.
Simulation of water use, nitrogen nutrition and growth of a spring wheat crop. Simulation Monographs, PUDOC, Wageningen. 310 p.

Lansigan, F.P., C.P. Medina, B.C. Legaspi, D.M. Macandog, G.U. Coronado, and M.J.C. Alagos. 1987.
Evaluation of the effects of weather patterns on yield of rainfed rice for selected sites in the Philippines. Case Studies in Crop Growth Simulation. F.W.T. Penning de Vries, D.M. Jansen, A.H. Bakema, R. Rabbinge, and D.P. Garrity. (eds) IRRI Internal Reports.

Lansigan, F.P., F.W.T. Penning de Vries, C.P. Medina, M.J.C. Alagos, and J.L. Orno, 1989.
Variability in rice and soybean yields due to weather fluctuations in the Philippines. Paper presented at the Workshop-Conference "Impact of weather in agricultural production and interdependence of trade among Pacific rim countries". Davis, California, June 21-28, 1989.

Lawn, R.J. & Byth, D.E., 1989.
Saturated soil culture, a technology to expand the adaptation of soybean. In: World soybean research conference IV, Buenos Aires, Argentinia.

Loomis, R.S., 1983.
Productivity of agricultural systems. In: Enyclopedia of Plant Physiology, Vol. 12D, 151-72, Springer Verlag, Heidelberg.

Malik, M., 1988.
Fear of flooding. Far Eastern Economic Review, 22 December 1988, p. 20-21.

Meek, B.D. & Stolzy, L.H., 1978.
Short term flooding. In: Plant life in anaerobic envir onments. Hook, D.D. and R.M.M. Crawford (eds). pp 351-374. Ann Arbor Scientific Publishers, Ann Arbor, Michigan, USA.

Microsoft. 1989.
Microsoft EXCEL, version 2.0. Microsoft Corporation, USA.

Nathanson, K., Lawn, R.J., De Jabrun, P.L.M. and Byth, D.E., 1984.
Growth, nodulation and N accumulation by soya bean in saturated soil culture. Field Crops Research, 8, 73-92.

Oldeman, L.R. and M. Frere. 1982.
A study of the agroclimatology of the humid tropics of Southeast Asia Technical Report. FAO, Rome. pp 158-164.

Padjung, Rusnadi, 1990.
Potential productivity and risks of different cropping patterns under rainfed condition at MAROS, South Sulawesi, Indonesia. M.S. thesis, University of the Philippines, Los Baños, Philippines.

Pandey, R.K, 1987.
A farmer's primer on growing soybean on riceland. International Rice Research Institute, Los Baños, the Philippines.

Pandey, R.K., R.A. Morris, and F.D. Whisler, 1987.
Water extraction patterns, water use and performance of ten upland crop species following rainfed lowland rice in the tropics. Phil. J. Crop Sci. 2(3):163-167.

PCARRD, 1987.
Soybean production after rice. In: Technology!, 9, 1-18, by the Philippine Council for Agricultural Research and Rural Development, Los Baños, the Philippines.

Penning de Vries, F.W.T., H.H. Van Laar, and Chardon M.C.M. 1983.
Bioenergetics of growth of seeds, fruits, and storage organs. In: Potential productivity of field crops under different environments. pp 37-59. International Rice Research Institute, Los Baños, Philippines.

Penning de Vries, F.W.T., Jansen, D.M., ten Berge H.J.M. and Bakema, A.H., 1989.
Simulation of ecophysiological processes in several annual crops. Simulation Monograph, PUDOC, Wageningen and International Rice Research Institute, Los Baños, Philippines.

Quebral, F.C., 1984.
Soybean as a crop in the Philippines. First orientation/training seminar on soybean production technology for rice based areas. Philippine Council for Agricultural Research and Rural Develoment, Los Baños, Philippines.

Rebancos, E.T. Jr. 1985.
Soil requirements and land preparation of grain legumes (Cowpea and Soybean). First Cowpea and Soybean Training Course. Oct 21-Nov 29 1985. International Rice Research Institute, Los Baños, Philippines.

Richardson, C.W. and Wright, D.A., 1984.
WGEN: a model for generating daily weather variables. USDA Agricultural Research Service no 8.

Rosegrant, M.W., Gonzales, L.A, Bouis, H.E. and Sison, J.F., 1987.
Price and investment policies for food crop sector growth in the Philippines. International Food Policy Research institute, Washington DC, USA.

Senthong C., and R.K. Pandey, 1989.
Response of five food legume crops to an irrigation gradient imposed during reproductive growth. Agronomy Journal, 81 (4), 680-686.

Sinclair, T.R, and C.T. de Wit. 1976.
Analysis of the carbon and nitrogen limitations to soybean yield. Agronomy Journal 68, 319-324.

Sinclair, T.R., 1986.
Water and nitrogen limitations in soybean grain production. I. Model development. Field Crops Research, 15, 125-141.

Sulzberger, E.W. & McLean, B.T., 1986 (Eds).
Soya bean in tropical and subtropical cropping systems. Asian Vegetable Research and Development Centre, Shanhua, Taiwan.
Supit, I., 1986.
Manual for generation of daily weather data. CABO-TT Simulation Report 7, Centre for Agrobiological Research, Wageningen, the Netherlands.
Summerfield, R.J. and R.J. Lawn. 1987.
Tropical grain legume crops: a commentary. Outlook on Agriculture. 16(4): 189-197.
Tanner, C.B and T.R. Sinclair, 1982.
Efficient water use in crop production: research or re-search. In: Limitations to efficient water use in crop production. Tailor, H.M., W.R. Jordan and T.R. Sinclair (eds). American Society Agronomy Monogrpahs, Madison, Wisconsin, pp 1-27.
Taylor, H.M., 1980.
Soya bean top and root response to temporary water table imposed at three different stages of growth. Agronomy Journal, 72, 341-346.
Tedia, K. 1988.
Crop water use, root distribution, plant growth and seed yield of soya bean genotypes as influenced by water stress and tillage. Ph.D. thesis. University of the Philippines, Los Baños, Philippines.
Timsina, J., D.P. Garrity, F.W.T. Penning de Vries, and R.K. Pandey. 1992a.
Yield stability of cowpea cultivars in rice based cropping systems: experimentation and simulation. Agric. Syst. (in press).
Timsina, J., F.W.T. Penning de Vries, and D.P. Garrity. 1929b.
Cowpea production in rice based cropping systems of the Philippines - extrapolation by simulation. Agric. syst. (in press).
Troedson, R.J., Garside, A.L., Lawn, R.J., Byth, D.E. and G.L. Wilson, 1986.
Saturated soil culture, an innovative water management option for soya bean in the tropics and subtropics. In: Soybean in Tropical and Sub-tropical Cropping Systems. Sulzberger E.W. and B.T. McLean (eds.). Asian Vegetable Research and Development Centre, Taiwan.
Turk, K.J., A.E. Hall and C.W. Asbell. 1980.
Drought and adaptation of cowpea. I. Infuence of drought on seed yield. Agronomy Journal 72, 413-420.
Wilkerson, G.G., Jones, J.W., Boote, K.J., Ingram K.I and J.W. Mishoe, 1983.
Modeling soya bean growth for crop management. Transactions American Society of Agricultural Engineers, 26, 63-73.
Whigham, D.K., 1983.
Soya bean. In: Productivity of field crops under different environments. pp 205-225. International Rice Research Institue, Los Baños, Philippines.
Woodhead, T., H.F.M. ten Berge, and E.M. de San Agustin. 1991.
Modeling upland rice hydrology. In: Systems Simulation at IRRI. F.W.T. Penning de Vries, M.J. Kroppf, P.S. Teng, and G.J.D. Kirk (eds.). IRRI Research paper series. No. 151. 53-60 p.
Woodward, 1976.
Photosynthesis and expansion of leaves of soybeans grown in two environments. Photosynthetica.

Appendix I:
Listing of SOYCROS

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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                            *
TITLE             SOYCROS (SEPTEMBER 1990)                   *
*        by F.W.T PENNING DE VRIES & M.J.C. ALAGOS           *
*                                                            *
* Sections with a *+ label are discussed in the              *
* CABO-TPE Simulation Report 25, CABO, 1992, entitled        *
*      OPPORTUNITIES FOR GROWING SOYA BEANS AFTER RICE       *
*      IN THE PHILIPPINES: AN EXPLORATION BY SIMULATION      *
*      by: F.W.T.PENNING DE VRIES, J.TIMSINA,                *
*          M.J.C.ALAGOS, R.K.PANDEY & L.VELASCO              *
*                                                            *
*  This listing is Appendix I. Variables specific to         *
*  SOYCROS are in Appendix II, sections with ** labels and *
*  all standard variables are discussed and defined in:      *
*        Simulation of ecophysiological processes            *
*        of growth of several annual crops                   *
*         by F.W.T.PENNING DE VRIES, D.M.JANSEN,             *
*            H.F.M.TEN BERGE & A.H.BAKEMA, 1989,             *
*         Simulation Monographs  PUDOC and IRRI              *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

FIXED IDATE,I,NL,ITYL,IRUN,INYR
FIXED YY,ITYP,IFILE,IFILE1
STORAGE TPHT(365),TPLT(365),HUAAT(365),RDTMT(365),WDST(365)
STORAGE RAINT(365),TKL(10),TYL(10),TYLU(10),TYLL(10)
STORAGE TRWL(10),WCLEQI(10),WCLMQI(10),KMSA1T(20),KMSA2T(20)
STORAGE KMSMXT(20),KSTT(20),MSWCAT(20),WCSTT(20)
/      COMMON /SLDPTH/ ZL(10)
/      COMMON /VOLWAT/ WCAD(10),WCFC(10),WCST(10),WCWP(10)
/      COMMON /HYDCON/ KMSMX(10),KMSA1(10),KMSA2(10),KST(10)
/      COMMON /PFCURV/ MSWCA(10)

INITIAL

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
** INITIALIZATION OF LAYER AND SPECIFIC SOIL WATER CONTENTS
*+ for different growing conditions specified by PARAMeter
*+ IRUN:Upland,Lowland,Irrigated,Rainfed
** Explanation in Section 5.1, 5.3, Subsection 5.4.5
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

PROCEDURE TYL,EES,CSA,CSB=PRSETS(IRUN)
*+ IRUN=1 UPLAND, RAINFED
*+ IRUN=2 UPLAND, IRRIGATED
*+ IRUN=3 LOWLAND, RAINFED
*+ IRUN=4 LOWLAND, SATURATED SOIL CULTURE
   IF (IRUN.GT.2) GO TO 200
      DO 100 I=1,NL
      TYL(I)  =TYLU(I)
 100  CONTINUE
      EES =EESU
      CSA =CSAU
      CSB =CSBU
      GO TO 400
 200  DO 300 I=1,NL
      TYL(I)  =TYLL(I)
 300  CONTINUE
      KSTT(17) =3.5
   IF (IRUN.GT.3) KSTT(17)=PKSTT
PARAM PKSTT =35.
*+high KSTT for IRUN=4 mimicks high rate of lateral flow
      EES =EESL
      CSA =CSAL
      CSB =CSBL
 400 CONTINUE
ENDPROCEDURE

PROCEDURE WCLQTI,WCUMI=PRWCLI(WCLEQI,WCLMQI,WCLISC)
   WCUMI  =0.
   DO 1 I=1,NL
      WCLQTI(I)=INSW(WCLISC,WCLEQI(I),WCLMQI(I))
      WCUMI    =WCUMI+WCLQTI(I)*TKL(I)*1000.
 1 CONTINUE
ENDPROCEDURE

   WCLISC=AND(-WCLIS,ZWI-TKLT)-0.5

PROCEDURE ZWI=PRZWI(IRUN,DATEB)
*+ Initialization of water table depth
   IF(IRUN.EQ.1) ZWI   =ZW1
   IF(IRUN.EQ.2) ZWI   =ZW1
   IF(IRUN.EQ.3) ZWI   =AMIN1(ZWMX,AFGEN(ZWTB3,DATEB-TAP))
   IF(IRUN.EQ.4) ZWI   =ZW4
PARAM ZWMX=1.5
*+ Maximum water table depth in rainfed lowland (IRUN 3)
ENDPROCEDURE

PROCEDURE WCLEQI,TKLT=PRWCLE(NL,TKL,TYL,ZWI)
   DO 2 I=1,NL
      ITYL    =TYL(I)
      KST(I)  =KSTT  (ITYL)
      KMSMX(I)=KMSMXT(ITYL)
      KMSA1(I)=KMSA1T(ITYL)
      KMSA2(I)=KMSA2T(ITYL)
      MSWCA(I)=MSWCAT(ITYL)
      WCST(I) =WCSTT (ITYL)
      WCFC(I) =FUWCMS(I,100.0)
      WCWP(I) =FUWCMS(I,1.6E4)
      WCAD(I) =FUWCMS(I,1.0E7)
 2 CONTINUE
   WCLCH,WLOCH,WCLEQI,EVSW,RUNOF,DRSL,WCUMCH,ZECH,TKLT...
      =SUSAWA(2,WCLQT,WLOQT,NL,TRWL,EVSC,RAIR,ZWI,TKL,...
      TYL,1.0,DTMIN,DTMX1,DTFX,WLOMX,ZEQT,CSA,CSB,CSC2)
ENDPROCEDURE

   ZEQTI =0.02*(1.-WCL1/WCST1)
   WCL1  =WCLQTI(1)
   WCST1 =WCST(1)

   TPSI  =(TPLT(IDATE)+TPHT(IDATE))/2.

   WRTI  =WLVI
   ALVI  =WLVI/(SLC*AFGEN(SLT,DSI))

PROCEDURE IDATE=PRFRST(DATEB)
   CALL SUWTRD(ITYP,IFILE,TPHT,TPLT,RDTMT,RAINT,WDST,HUAAT)
*+ Weather data from external files, named in WTRD.FIL
   IDATE =DATEB
   IF (IDATE.EQ.1) THEN
     YY=1
   ELSE
     YY=0
   ENDIF
```

```
ENDPROCEDURE

DYNAMIC
* * * * * * * * * * * * * * * * * * * *
*+ GERMINATION
* * * * * * * * * * * * * * * * * * * *

   PUSH  =INSW(INSW(GRMST-1.,0.,1.) + ...
           INSW(WLVI-WLV,1.,0.)-0.5,0.,1.)
*+ PUSH = 1. if conditions permit growth
   GRMST =INTGRL(0.,...
           INSW(AND(TIME-TAP,1.01*DSI-DS)-0.5, 0.,GRMR))
*+ Germination status: seed =0., germination =1.
   GRMR  =INSW(SCG-0.5,-AMIN1(GRMST,0.33),1.)/(GRMD*DELT)
*+ Rate of germination
PARAM GRMD  =4.
*+ Duration of germination in optimal conditions
   SCG   =AND(WCL1-FRFC*WCFC(1),FRST*WCST(1)-WCL1)
*+ Soil condition for germination (0. or 1.)
PARAM FRFC  =0.8, FRST=0.97
*+ Boundaries average water content toplayer for germination
   DATEG =INTGRL(0.,INSW(AND(GRMST-1.,0.5-DATEG)-0.5,...
          0.,(DATEB+TIME-TAP)/DELT))
*+ Date of germination
   FAILG =INSW(AND(TIME-30.-TAP,1.-GRMST)-0.5,0.,1.)
*+ Crop fails without germination within 30 d after the
*+ turnaround time ended.

* * * * * * * * * * * * * * * * * * * *
**WEIGHTS OF CROP COMPONENTS
**Explanation in sections 3.2, 2.2, 3.4
* * * * * * * * * * * * * * * * * * * *

   WLV   =INTGRL(WLVI,(GLV-LLV)*PUSH)
   WST   =INTGRL(WSTI,GST*(1.-FSTR)*PUSH)
   WSTR  =WST+WIR
   WIR   =INTGRL(0.,(GST*(FSTR*(FCST/0.444))-LSTR)*PUSH)
   WSO   =INTGRL(WSOI,GSO*PUSH)
   WEPSO =WSO*FEPSO
   WGY   =WEPSO/0.89
*+ Grain yield at 12% moisture content

   WRT   =INTGRL(WRTI,(GRT-LRT)*PUSH)
   WSS   =WLV+WST+WSO+WIR
   WCR   =WSS+WRT
   WLVD  =INTGRL(0.,LLV*PUSH)
   WRTD  =INTGRL(0.,LRT*PUSH)

* * * * * * * * * * * * * * * * * * * *
**GROWTH RATES AND LOSS RATES
**Explanation in sections 2.4, 3.2, 2.2
* * * * * * * * * * * * * * * * * * * *

   GLV   =CAGLV/CRGLV
   GST   =CAGST/CRGST
   GRT   =CAGRT/CRGRT
   GSO   =CAGSO/CRGSO
   LLV   =LLVA+LLVN
   LLVA  =WLV*AFGEN(LLVT,DS)
*+ Loss of leaves due to normal aging process
   LLVN  =INSW(PCEWA-0.5,WLV*PCEWA*0.1,0.)
*+ Loss of leaves under severe water stress
   LRT   =WRT*AFGEN(LRTT,DS)
   LSTR  =INSW(AFGEN(CASTT,DS)-0.01,WIR*0.1,0.)

* * * * * * * * * * * * * * * * * * * * * * * * *
**CARBOHYDRATE AVAILABLE FOR GROWTH, EXPORT
**Explanation in sections 3.2, 2.4, 2.3, 2.2
* * * * * * * * * * * * * * * * * * * * * * * * *

   CAGCR =PCGW*0.682-RMCR*0.682+LSTR*1.111*0.947
   CAGSS =CAGCR*AFGEN(CASST,DS)*CPEW
   CAGRT =CAGCR-CAGSS
   CAGLV =CAGSS*AFGEN(CALVT,DS)
   CAGST =CAGSS*AFGEN(CASTT,DS)
   CAGSO =CAGSS-CAGLV-CAGST

   CELV  =PCGW-(RMLV+RMST+0.5*RMMA)
   CELVN =INTGRL(0.,INSW(CELV,1.,-CELVN/DELT)*PUSH)

* * * * * * * * * * * * * * * * * * * *
**PHOTOSYNTHESIS, GROSS AND NET
**Explanation in sections 2.1, 3.3, 3.4
* * * * * * * * * * * * * * * * * * * *

   PCGW  =PCGC*PCEW
   PCGC  =PUPHOT(PLMX,PLEA,ALV,RDTM,DATE,LAT)

   PLMX  =(PLMXN*AFGEN(PLMTT,TPAD)*...
           LIMIT(200.,600.,SLA)/SLC)*PUSH
   PLMXN =INTGRL(PLMXP,(PLMXG-PLMXL))

   PLMXG =INSW(PCEWA-0.8,0.,(PLMXP-PLMXN)*(3.*GLV/WLV,...
           +INSW(DS-1.6,0.10,0.)))
   PLMXL =PLMXLW+PLMXLA
*+ Gain (G) and loss (L) of photosynthetic capacity
   PLMXLW=INSW(PCEWA-0.7,(PLMXN-PLMXP*0.25)*0.20...
           *(1.-PCEWA),0.)
*+ Loss photosynthetic capacity due to accumulated stress
   PLMXLA=PLMXN*AFGEN(PLMXLT,DS)
*+ Loss of photosynthetic capacity due to accelerated
*+ nitrogen remobilization ('self destruction hypothesis')
   PLEA  =PLEI*AFGEN(PLETT,TPAD)
   PLEH  =AFGEN(PLMHT,VPDC)

   PCGT  =INTGRL(0.,PCGW)
   RCRT  =INTGRL(0.,RMCR+RGCR)
   PCNT  =INTGRL(0.,PCGW-(RMCR+RGCR))

* * * * * * * * * * * * * * * * * *
**RESPIRATION
**Explanation in sections 2.4, 2.3
* * * * * * * * * * * * * * * * * *

   RMCT  =INTGRL(0.,RMCR*PUSH)
   RMCR  =(RMLV+RMST+RMSO+RMRT+RMMA)*PUSH
   RMLV  =WLV*RMCLV*TPEM*0.75
   RMST  =WST*0.010*TPEM+WIR*0.0
   RMRT  =WRT*0.015*TPEM
   RMSO  =AMIN1(1000.,WSO)*0.015*TPEM
   TPEM  =Q10**((TPAV-TPR)/10.)

   RMMA  =0.20*PCGW*0.5

   RGCR  =(RGLV+RGST+RGSO+RGRT+RLSR)*PUSH
   RGLV  =GLV*CPGLV
   RGST  =GST*CPGST
   RGSO  =GSO*CPGSO
   RGRT  =GRT*CPGRT
   RLSR  =LSTR*1.111*0.053*1.467

* * * * * * * * * * * * * * * *
**CARBON BALANCE CHECK
**Explanation in section 3.4
* * * * * * * * * * * * * * * *

   CKCRD =FUCCHK(CKCIN,CKCFL,TIME)
   CKCIN =(WLV-WLVI)*FCLV+(WST-WSTI)*FCST+...
          (WSO-WSOI)*FCSO+(WRT-WRTI)*FCRT+WIR*0.444
   CKCFL =PCNT*0.2727-(WLVD*FCLV+WRTD*FCRT)
```

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* * * * * * * * * * * * * * *
**LEAF AREA
**Explanation in section 3.3
* * * * * * * * * * * * * * *

   ALV   =INTGRL(ALVI,(GLA-LLA+GSA)*PUSH)
   GLA   =GLV/SLN
   LLA   =LLV/SLA
   GSA   =0.5*GST/SSC
   SLN   =SLC*AFGEN(SLT,DS)
   SLA   =(WLV+0.5*WST*(SLC/SSC))/ALV

* * * * * * * * * * * * * * * * * * *
**PHENOLOGICAL DEVELOPMENT OF THE CROP
**Explanation in section 3.1
* * * * * * * * * * * * * * * * * * *

   DS    =INTGRL(DSI,INSW(DS-1.,DRV,DRR)*PUSH)
   DRV   =DRCV*DRED*DREW*AFGEN(DRVTT,TPAV)
   DRED  =AFGEN(DRDT,DLP)
   DRR   =DRCR*AFGEN(DRRTT,TPAV)

*TITLE L2C, JULY 1987.
* * * * * * * * * * * * * * * * *
**EFFECTS OF WATER SHORTAGE
**Explanations in sections 4.2, 4.3
* * * * * * * * * * * * * * * * *

   CPEW  =AMIN1(1.,0.5+TRW/(TRC+1.E-10))
   DREW  =AFGEN(DRWT,TRW/(TRC+1.E-10))
   PCEW  =TRW/(TRC+1.E-10)*PUSH
   PCEWA =INTGRL(1.0,((PCEW-PCEWA)/3.)*PUSH)
*+ running average of day-to-day water stress

* * * * * * * * * * * * * * * * * * * * * * * * * * *
**POTENTIAL TRANSPIRATION AND DIFFUSION RESISTANCES CANOPY
**Explanation in sections 4.1, 4.4
* * * * * * * * * * * * * * * * * * * * * * * * * * *

   TRC   =TRCPR*(1.-EXP(-0.5*ALV))+TRCPD*AMIN1(2.5,ALV)
   TRCPR,TRCPD=SUEVTR(RDTC,RDTM,0.25,DLA/24.,TPAD,VPA,...
          RSLL,RSBL,RSTL)
   RSLL  =LIMIT(RSLLM,2000.,(CO2E-CO2I)/(PLNA+1.E-10)*...
          (68.4*24.0/1.6)-RSBL-RSTL)
   CO2I  =CO2E*FIEC
   RSLLM =(CO2E-CO2I)/(PLMX*0.9+1.E-10)*(68.4/1.6)-10.
   PLNA  =(PCGC/(DLA/24.)-RMLV*0.33)/(AMIN1(2.5,ALV+1.E-10))
   RSBL  =0.5*172.*SQRT(WDLV/(WDSAD*0.6))
   RSTL  =FURSC(WDSAD,AMIN1(2.5,ALV),PLHT,2.)
   TRRM  =AMIN1(TRRMM,TRC/(ZRT+1.E-10))
PARAM TRRMM =100.
*+ Maximum TRW of 10 mm d-1 for ZRT 0.1 m: estimate.

* * * * * * * * * * * * * * *
**ROOTED DEPTH AND CROP HEIGHT
**Explanation in section 4.2
* * * * * * * * * * * * * * *

   ZRT    =AMAX1(ZRTR,ZRTU)
*+ Rooted depth maximum of 'upland' and 'lowland' roots
   ZRTU  =INTGRL(ZRTI,(GZRTU-LZRTU)*PUSH)
   GZRTU =GZRTC*WSERT*TERT*AND(ZRTM-ZRTU,1.2-DS)
   LZRTU =AMAX1(1.E-5,(ZRTU-ZRTM)/TCLZRT)
*+ Growth and loss rate upland root system
PARAM TCLZRT=2.0
*+ Time constant (d) loss of root depth due to anaerobiosis

   ZRTR  =INTGRL(0.0,(GZRTR-LZRTR)*PUSH)
   GZRTR =GZRTC*0.5*TERT*AND(ZW-ZRTR,1.2-DS)*AND ...
          (WCL1-(WCST(1)-0.05),(WCST(1)-0.01)-WCL1)
   LZRTR =INSW(WCL1+0.01-WCST(1),0.,(ZRTR-0.02)/TCLZRT)
*+ Growth and loss of lowland root system

   ZRTM  =AMIN1(ZRTMC,ZRTMS,ZRTUW,TKLT)

PROCEDURE ZRTUW=PRZRT(WCLQT)
   ZRTUW =0.0
   DO 500 I=1,NL
     IF (WCST(I)-WCLQT(I).LT.0.05) GO TO 501
     ZRTUW =ZRTUW+TKL(I)
 500 CONTINUE
 501 CONTINUE
ENDPROCEDURE
*+ Depth first layer with too little O2 to grow upland roots

   WFSC  =(WFSCU*ZRTU+1.0*ZRTR)/(ZRTU+ZRTR)
*+Approximation of root system sensitivity to flooding

   PLHT  =AFGEN(PLHTT,DS)

* * * * * * * * * * * * * * *
**POTENTIAL EVAPORATION SOIL
**Explanation in section 5.1
* * * * * * * * * * * * * * *

   EVSC  =EVSPR*EXP(-0.5*ALV)+EVSPD
   EVSPR,EVSPD=SUEVTR(RDTC,RDTM,RFS,1.00,TPAV,VPA,...
          0.00,RSBS,RSTS)
   RFS   =RFSD*(1.-0.5*WCL1/WCST1)
   RSBS  =172.*SQRT(WDCL/WDSS)
   WDSS  =FUWRED(WDLV,ALV,PLHT,WDSAV)
   RSTS  =FURSC(WDSAV,1.,0.1*PLHT,0.63*PLHT)
   EVP   =1.0*(0.75*(RDTN/2.47E6)+(1.0-0.75)*0.27...
          *(1.+WDSAV*0.864)*(FUVP(TPAV)-VPA)*10.)
   RDTN  =RDTM-(RLWO-RLWI)*(RDTM/(0.75*RDTC))
   RLWI  =4.8972E-3*(TPAD+273.)**4*...
          (0.618+0.0365*SQRT(10.*VPA))
   RLWO  =4.8972E-3*1.00*(TPAD+273.)**4

* * * * * * * * * * * * * * *
* WEATHER DATA AND TIME
* * * * * * * * * * * * * * *

   RDTM  =RDTC*(PARA+PARB*NRATIO)
   NRATIO=AFGEN(OCTAS,RDTMT(IDATE))
*+ radiation input data (RDTMT) is in OCTAS.
FUNCTION OCTAS=0.,1.0, 1.,0.96, 2.,0.85, 3.,0.75,...
               4.,0.65, 5.,0.56, 6.,0.47, 7.,0.38, 8.,0.29
*+ Mean n/N values, Latitude 10-15o N (Table 45 Reddy, 1974)
   PARAM PARA=0.25, PARB=0.45
*+ for dry tropical zones (Frere and Popov, 1979); for humid
*+ tropical zones: PARA=0.29, PARB=0.42; for cool and
*+ temperate zones: PARA=0.18, PARB=0.55

   RDTC,DLA,DLP=SUASTR(DATE,LAT)

   TPAV  =(TPLT(IDATE)+TPHT(IDATE))/2.
   TPAD  =(TPHT(IDATE)+TPAV)/2.

   WDSAV =AMAX1(0.2,WDST(IDATE))
   WDSAD =1.33*WDSAV
   VPA   =AMIN1(FUVP(TPAD),HUAAT(IDATE))
   RAIN  =RAINT(IDATE)

   VPDC  =(FUVP(TPAD)-VPA)*AMIN1(1.,30./RSTL)
   DSLR  =INTGRL(1.,INSW(RAIR-0.5,1.,1.00001-DSLR)/DELT)
   CO2E  =340.*0.88**(ELV/1000.)
   TPS   =INTGRL(TPSI,(TPAV-TPS)/5.)
```

```
PROCEDURE IDATE,DATE,FDD,TDATE=PRNEYR(DATEB)
   DATE  =AMOD(DATEB+TIME+364.-TAP,365.)+1.
   IDATE =DATE
   IF ((IDATE.EQ.1).AND.(YY.NE.1)) THEN
    IFILE1=IFILE+1
    CALL SUWTRD(ITYP,IFILE,TPHT,TPLT,RDTMT,RAINT,WDST,HUAAT)
*+Reading weather data for next year (overlapping year)
   ENDIF
   IF (KEEP.NE.0) YY=0
ENDPROCEDURE

* * * * * * * * * * * * * * * * * * * * * * * * *
**SOIL WATER, PONDED WATER, DEPTH EVAPORATION FRONT
**Explanation Sections 5.3, 5.4.4, 5.4.5
* * * * * * * * * * * * * * * * * * * * * * * * *

   WCLQT =INTGRL(WCLQTI,WCLCH,10)
   WLOQT =INTGRL(WLOQTI,WLOCH)
   WCUM  =INTGRL(WCUMI ,WCUMCH*1000.)
   ZEQT  =INTGRL(ZEQTI ,ZECH)
   WCL1  =WCLQT(1)

   WCLCH,WLOCH,WCLEQI,EVSW,RUNOF,DRSL,WCUMCH,ZECH,TKLT=...
      SUSAWA(2,WCLQT,WLOQT,NL,TRWL,EVSC,RAIR,ZW,TKL,TYL,...
      1.0,DTMIN,DTMX1,DTFX,WLOMX,ZEQT,CSA,CSB,CSC2)

*+ Irrigation equals 0., but for IRUN 2 and IRUN = 4.
   IRRI  =FCNSW(FLOAT(IRUN)-2.0.,AMAX1(0.,...
          0.8*CEVPIP*IRPER),0.)+ FCNSW(FLOAT(IRUN)-4....
          0.,AMAX1(0.,EVSC+TRW-RAIN),0.)

   CEVP  =INTGRL(0.,EVP)
   CEVPIP=INTGRL(0.,EVP-RAIN-CEVPIP*IRPER/DELT)
   IRPERC=INTGRL(0.,(1.-INSW(IRPERC-FIRRI,0.,IRPERC))/DELT)
   IRPER =INSW(IRPERC-FIRRI,0.,1.)

   RAIR  =RAIN+IRRI
*+ Sum of irrigation and rain

PROCEDURE ZW   =PRZW(IRUN,DATE,DSLR)
*+ Water table depth in different management situations.
   ZW3   =AMIN1(ZWMX,AFGEN(ZWTB3,DATE)+(DSLR-1.)*...
          (0.04-0.02*AND(DATE-152.,334.-DATE)))
   IF(IRUN.EQ.1) ZW    =ZW1
   IF(IRUN.EQ.2) ZW    =ZW1
   IF(IRUN.EQ.3) ZW    =ZW3
   IF(IRUN.EQ.4) ZW    =ZW4
ENDPROCEDURE

   WLOMX = INSW(FLOAT(IRUN)-3.5,WLOMXN,0.)

* * * * * * * * * * * * * * * * * * * * * * * *
**ACTUAL TRANSPIRATION AND EFFECT WATER STRESS
**Explanation Subsections 4.2.2, 5.3.7
* * * * * * * * * * * * * * * * * * * * * * * *

   TRWT  =INTGRL(0.0,TRW)
PROCEDURE WSE,TRW,TRWL,WSERT=...
          PRTRAN(TRC,ALV,WCLQT,ZRT,TRRM,PUSH)
   TRW   =0.0
   ZLL   =0.0
   WSERT =0.0
   DO 3 I=1,NL
    WSE    = ...
    FUWS(TRC,ALV,WCLQT(I),WSSC,WFSC,WCWP(I),WCFC(I),WCST(I))
    ZRTL    =AMIN1(TKL(I),AMAX1(ZRT-ZLL,0.))
    WLA     =AMAX1(0.,(WCLQT(I)-WCWP(I))*TKL(I)*1000.)
    TRWL(I)=(AMIN1(WSE*ZRTL*TRRM,WLA/DELT))*PUSH
    TRW     =TRW+TRWL(I)
    WSEE    =INSW(AND(WCLQT(I)+0.05-WCST(I),ZRT-0.02)-0.5,WSE,0.)
*+ Water stress effect on roots in a saturated layer
     IF(ZRT.LT.(ZLL+TKL(I)).AND.(ZRT.GE.ZLL)) WSERT =WSEE
     ZLL    =ZLL+TKL(I)
  3 CONTINUE
ENDPROCEDURE

   TERT  =AFGEN(PLNTT,TPS)

* * * * * * * * * * * * * * *
**WATER BALANCE CHECK
**Explanation Section 5.4.4
* * * * * * * * * * * * * * *

   CKWIN =INTGRL(0.,(WCUMCH+WLOCH)*1000.)
   CKWFL =INTGRL(0.,RAIR-RUNOF-EVSW-TRW-DRSL)
   CKWRD =FUWCHK(CKWFL,CKWIN,TIME)

* * * * * * * * * * * * * * * * * * * * * * * *
**              CROP MANAGEMENT
* * * * * * * * * * * * * * * * * * * * * * * *
PARAM IRUN   =1
PARAM DATEB =(9.,40.,68.,99.,129.,160.,190.,221.,252.,...
               282.,313.,343.)
*+ Crop sown at DATEB: simulation starts TAP days earlier

PARAM WLVI  =32.,  WSTI  =16., WSOI  =0.
PARAM DSI   =0.09, ZRTI  =0.05

PARAM TAP   =15.
*+ Turn-Around Period between previous crop and soya bean
PARAM FIRRI =14.
*+Interval of irrigation events

* * * * * * * * * * * * * * * * * * * * * * * *
**             RUN CONTROL AND OUTPUT
* * * * * * * * * * * * * * * * * * * * * * * *

PARAM NYR=20.
*+Total number of years used for simulation
PARAM ITYP=1, IFILE=1
*+ Choose weather data format, year number

METHOD RECT
TIMER DELT  =1.,TIME  =0.,FINTIM=1000.,PRDEL =5.
PARAM DTMIN =0.1, DTMX1 =0.1, DTFX  =0.03
FINISH DS   =2.0, CELVN =3., TPAV  =3., FAILG =1.

PRINT DATE,WGY,DS,WLV,WSTR,ALV,GRMST,ZRT, ...
      PCEW,TRW,ZW,CEVSW,CRAIN,CDRSL,  ...
      WCLQT(1),WCLQT(2),WCLQT(3),WCLQT(7)

PROCEDURE BBB=PRDBG(TIME)
  CALL DEBUG(10,DTIME)
*+ Call for complete data dump at time DTIME.
PARAM DTIME=1000.
PARAM DTIME=0.
ENDPROCEDURE

*+ Additional output variables
   WLVT  =WLV+WLVD
   WLVST =WLVT+WST+WIR
   WLVSO =WLVST+WSO
   HI    =WSO/WSS
   RSH   =RMLV+RMST+RMSO+RMMA+RGLV+RGST+RGSO+RLSR

   CIRRI =INTGRL(0.,IRRI)
   CEVSW =INTGRL(0.,EVSW)
   CRAIN =INTGRL(0.,RAIN)
   CDRSL =INTGRL(0.,DRSL)
```

```
   WUPC  =TRC *1.E4/(PCGC+1.E-10)
   WUPT  =TRWT*1.E4/(PCGT+1.E-10)
   WUPA  =(TRWT+CEVSW)*1.E4/(PCGT+1.E-10)
   WUE   =(TRWT+CEVSW)*1.E4/WSS
*Different expressions of water use efficiency

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                      DATA SETS
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*GlYCINE MAX (L.)Merrill (soybean) cv. SJ.2

**PHOTOSYNTHESIS AND RESPIRATION
FUNCTION PLMXLT=0.,0.0, 1.6,0.0, 2.1,0.10
*+ Loss of maximum leaf photosynthesis due to age
PARAM PLMXP =40..   PLEI  =0.48
FUNCTION PLMTT =-1.0,0.001, 0.00,0.001, 10.0,0.300,...
                20.,0.600, 25.0,0.800, 30.0,1.000,...
                35.,1.000, 40.0,0.800,...
                45.,0.400, 50.0,0.001
FUNCTION PLMHT = 0.0,1.000, 0.01,1.000, 0.80,1.000,...
                1.2,1.000, 1.40,0.990, 4.00,0.99
FUNCTION PLETT =-1.0,1.000, 0.00,1.000, 10.,1.000,...
                20.,0.900, 30.0,0.600, 40.,0.200,...
                50.,0.01

PARAM CRGLV =1.687, CRGST =1.603, CRGSO =2.161, CRGRT =1.534
PARAM CPGLV =0.790, CPGST =0.540, CPGSO =1.238, CPGRT =0.537
PARAM FCLV  =0.459, FCST  =0.494, FCSO  =0.527, FCRT  =0.467
PARAM RMCLV =0.03,  TPR   =30.,   Q10   =2.

**BIOMASS PARTITIONING AND AGING
FUNCTION CALVT =0.0,0.71, 0.25,0.61, 0.5,0.65, 0.75,0.85,...
               1.0,0.70, 1.20,0.49, 1.4,0.31, 1.60,0.00,...
               1.8,0.00, 2.10,0.
FUNCTION CASTT =0.0,0.29, 0.25,0.39, 0.5,0.35, 0.75,0.15,...
               1.0,0.30, 1.2,0.51, 1.4,0.29, 1.60,0.00,...
               2.1,0.
FUNCTION CASST =0.0,0.50, 0.5,0.700, 1.0,0.80, 1.20,1.00,...
               2.1,1.

PARAM FSTR  =0.18, FEPSO =0.8, GSORM =0.50

FUNCTION LLVT  =0.0,0.000, 0.5,0.000, 0.75,0.007,...
               1.0,0.010, 1.2,0.015, 1.4,0.0160,...
               1.6,0.017, 1.8,0.020, 2.1,0.1
*+last value is 0.1. to mimick accelerated senescence.

FUNCTION LRTT  =0.0,0.000, 1.0,0.000, 2.1,0.

**PHENOLOGICAL DEVELOPMENT AND LEAF AREA
PARAM DRCV =0.0303, DRCR =0.0164
FUNCTION DRVTT=-1.0,0.01, 0.00,0.01, 10.,0.50, 20.0,0.9,...
               27.,1.00, 30.0,1.10, 40.,1.20, 45.0,1.2
FUNCTION DRRTT=-1.0,0.01, 0.00,0.01, 10.,0.50, 20.0,0.5,...
               27.,1.00, 35.0,1.00, 45.,1.0

FUNCTION DRDT =1.,1., 24.,1.
FUNCTION DRWT = 0.,1., 1.,1.

PARAM SLC   =400.,  SSC  =2100., WDLV=0.03
FUNCTION SLT  =0.0,0.80, 1.0,0.8, 1.2,1., 1.5,1.1,...
              1.8,1.25, 2.1,1.25
FUNCTION PLHTT=0.0,0.00, 1.0,1.0, 2.1,1.

PARAM WSSC=0.8, WFSCU=0.4, FIEC=0.64
*+ WFSCU increased from 0.2 to 0.4: soybean tolerates excess
*+ water better than most legumes (RKP): Troedson, 1980.

PARAM ZRTMC=1.8, GZRTC=0.028

**SOIL DATA FOR UPLAND AND LOWLAND, FOR MODULE L2SS
PARAM NL    =7
TABLE TKL(1-7)=2*0.1,5*0.20, WCLMQI(1-7)=7*0.36
TABLE TYLU(1-7)=2*9.,5*15., TYLL(1-7)=2*15.,5*17.
*+Soil type for 'upland' (U) and 'lowland' (L) conditions

PARAM ZW1   =10.0, ZW4   =0.1
FUNCTION ZWTB3 =0.,1.10, 120.,1.10, 152.,0.35, 334.,0.35,...
               365.,1.10
*+ Water tables IRUNs 1 (2), 3, 4.
INCON WLOQTI=0.0
PARAM WCLIS = 1., WLOMON=0.02

**SURFACE AND OTHER SOIL CHARACTERISTICS
PARAM FRNOF =0.0, RFSD  =0.2,  WDCL  =0.05,  ZRTMS =1.2
PARAM EESU  =20., CSC2  =0.05, CSAU  =0.005, CSBU  =5.
PARAM EESL  =10., CSAL  =0.20, CSBL  =5.
*+ Evaporation constants upland soil (ten Berge 16/3/1990)

**CHARACTERISTICS SOIL TYPES 1-20
TABLE KMSA1T(1-20)=...
.1960,.1385,.0821,.0500,.0269,.0562,.0378,.0395,.0750,.0490,...
.0240,.0200,.0231,.0353,.0237,.0248,.0274,.0480,.0380,.1045
TABLE KMSA2T(1-20)=...
 .08,  .63, 3.30,10.90,15.00, 5.26, 2.10,16.40,  .24,22.60,...
26.50,47.30,14.40,33.60, 3.60, 1.69, 2.77,28.20, 4.86, 6.82
TABLE KMSMXT(1-20)=...
 80.0, 90.0,125.0,275.0,165.0,100.0,135.0,200.0,150.0,130.0,...
300.0,300.0,300.0,200.0,300.0,300.0,300.0, 50.0, 80.0, 50.0
TABLE KSTT(1-20)  =...
1120.00,300.00,110.00, 50.00,  1.00,  2.30,   .36, 26.50,...
  16.50, 14.50, 12.00,  6.50,  5.00, 23.50,  1.50,   .98,...
   3.50,  1.30,   .22,  5.30
TABLE MSWCAT(1-20)=...
.0853,.0450,.0366,.0255,.0135,.0153,.0243,.0299,.0251,.0156,...
.0186,.0165,.0164,.0101,.0108,.0051,.0085,.0059,.0043,.0108
TABLE WCSTT(1-20) =...
.3950,.3650,.3500,.3640,.4700,.3940,.3010,.4390,.4650,.4550,...
.5040,.5090,.5030,.4320,.4750,.4450,.4530,.5070,.5400,.8630
TABLE KSTT(15)=10.
*+KSTT (15) changed from 1.5 to 10. to increase drainage

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*+ RUNS AND RERUNS
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

*APARRI WEATHER
PARAM LAT   =18.2, ELV   =3.
PARAM DATEB =(9.,68.,129.,190.,252.,313.)
END
PARAM IRUN   =2
END
PARAM IRUN   =3
END
PARAM IRUN   =4
END

TERMINAL
   CALL SUWRIT(INYR,IYR,IFILE,IRUN,DATEG,WGY,CRAIN,TRWT,CIRRI)
*+ write results run to external file
STOP
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      SUBROUTINE
SUWRIT(INYR,IYR,IFILE,IRUN,DATEG,WGY,CRAIN,TRWT,CIRRI)
c Version 1.1, Jan 1989
c Author: Don Jansen and Jacque C. Alagos.
c To write output to an external file 'Rx.My', which is in
c a 'comma delimited format', to be used with MS-EXCEL.
      IMPLICIT REAL (A-Z)
      CHARACTER*15 FNAME(80)
```

```
      INTEGER INYR,IYR,IFILE,IIFILE,IIIFILE,IRUN,IDATEG
      DATA FNAME /'R1.N1','R1.N2','R1.N3','R1.N4','R1.N5',
     $ 'R1.N6','R1.N7','R1.N8','R1.N9','R1.N10',
     $ 'R1.N11','R1.N12','R1.N13','R1.N14','R1.N15',
     $ 'R1.N16','R1.N17','R1.N18','R1.N19','R1.N20',
     $ 'R2.N1','R2.N2','R2.N3','R2.N4','R2.N5',
     $ 'R2.N6','R2.N7','R2.N8','R2.N9','R2.N10',
     $ 'R2.N11','R2.N12','R2.N13','R2.N14','R2.N15',
     $ 'R2.N16','R2.N17','R2.N18','R2.N19','R2.N20',
     $ 'R3.N1','R3.N2','R3.N3','R3.N4','R3.N5',
     $ 'R3.N6','R3.N7','R3.N8','R3.N9','R3.N10',
     $ 'R3.N11','R3.N12','R3.N13','R3.N14','R3.N15',
     $ 'R3.N16','R3.N17','R3.N18','R3.N19','R3.N20',
     $ 'R4.N1','R4.N2','R4.N3','R4.N4','R4.N5',
     $ 'R4.N6','R4.N7','R4.N8','R4.N9','R4.N10',
     $ 'R4.N11','R4.N12','R4.N13','R4.N14','R4.N15',
     $ 'R4.N16','R4.N17','R4.N18','R4.N19','R4.N20'/
      DATA IIIFILE /0/,IIFILE/0/
      IDATEG=INT(DATEG)
      IF (IIIFILE.NE.IFILE+(IRUN-1)*INYR) THEN
         IIIFILE=IFILE+(IRUN-1)*INYR
         OPEN (12,FILE=FNAME(IIIFILE),STATUS='NEW')
         IIFILE=1
      ENDIF
222   IF (IIFILE.EQ.1) THEN
         IYR=IFILE+1900
         WRITE(12,123)IYR
123      FORMAT(I6)
         WRITE(12,555)IRUN,IDATEG,WGY,CRAIN,TRWT,CIRRI
555      FORMAT('IRUN,DATEG,WGY,CRAIN,TRWT,CIRRI'
     $ ,/,I4,',',I3,',',3(F7.2,','),F7.2)
      ELSE
         WRITE(12,556)IRUN,IDATEG,WGY,CRAIN,TRWT,CIRRI
556      FORMAT(I4,',',I3,',',3(F7.2,','),F7.2)
      ENDIF
      IIFILE=IIFILE+1
      RETURN
      END

      SUBROUTINE SUWTRD(ITYP,IFILE,TPHT,TPLT,RDTMT,RAINT,WDST,HUAAT)
c Version 1.1, 18 March 1989; Author: Don Jansen
c to read weather-data from various source files:
c Input: ITYP, integer*4
c        ITYP = 1  from files with data in PCSMP tables (as used
c                  in the MACROS models)
c        ITYP = 2  from files with data in the format of the
c                  Agroclimate Service Unit of IRRI
c        ITYP = 3  from files with data in other format: user has
c                  to define his/her own reading subroutine: it
c                  should be called:
c                  SUWTR3(FNAME,TPHT,TPLT,HUAAT,RDTMT,WDST,RAINT)
c                  This SUWTR3 should be compiled with the main
program)
c        IFILE, integer*4, number of file to be read: file-names are
c                  listed in file WTRD.FIL
c
c Output:
c        TPHT, real*8, 365 dimensions, Maximum Temperature: Degrees
C
c        TPLT, real*8, 365 dimensions, Minimum Temperature: Degrees
C
c        HUAAT,real*8, 365 dimensions, Air Humidity: kPa
c        RDTMT,real*8, 365 dimensions, Total Daily Global Radiation:
c                                      MJ m-2 d-1
c        WDST, real*8, 365 dimensions, Average Daily Wind Speed: m
s-1
c        RAINT,real*8, 365 dimensions, Daily Rainfall: mm d-1
c
c Error conditions (written into the FOR06.DAT):
c        ERR = 8.1: ITYP<1, or ITYP > 3
```

```
c        ERR = 8.2: IFILE<1, or IFILE larger than number of files in
c                   WTRD.FIL, or not one single file-name per line
in
c                   WTRD.FIL

      IMPLICIT REAL(A-Z)
      INTEGER I,ITYP,IFILE
      CHARACTER*1 FDUMMY
      CHARACTER*60 FNAME,FNAMEL
      DIMENSION TPHT(365),TPLT(365),HUAAT(365),RDTMT(365),WDST(365)
      DIMENSION RAINT(365)
      DATA FNAMEL/'NOTAFILEYET'/
      CALL SUERRM(8.1,ITYP*1.,1.,3.,6.)
      OPEN(31,FILE='WTRD.FIL',STATUS='OLD')
c reading of WTRD.FIL to find filename (FNAME) of file to be read
      IF(IFILE.GT.1) THEN
         DO 1 I=1,IFILE-1
            READ(31,1001,END=998) FDUMMY
1001        FORMAT(A1)
1        CONTINUE
      ENDIF
      READ(31,1002,END=998) FNAME
1002  FORMAT(A60)
      CLOSE(31)
      IF(FNAME.EQ.FNAMEL) GOTO 999
      FNAMEL=FNAME
      DO 3 I=1,365
         TPHT(I)=-99.
         TPLT(I)=-99.
         WDST(I)=-99.
         HUAAT(I)=-99.
         RDTMT(I)=-99.
         RAINT(I)=-99.
3     CONTINUE
      GOTO 2
998   CALL SUERRM(8.2,IFILE*1.,1.,1.*(I-1),6.)
2     IF(ITYP.EQ.1) THEN
         CALL SUWTR1(FNAME,TPHT,TPLT,RDTMT,RAINT,WDST,HUAAT)
      ELSEIF(ITYP.EQ.2) THEN
         CALL SUWTR2(FNAME,TPHT,TPLT,HUAAT,RDTMT,WDST,RAINT)
      ELSE
         CALL SUWTR3(FNAME,TPHT,TPLT,HUAAT,RDTMT,WDST,RAINT)
      ENDIF
      WRITE(6,1003)FNAME
1003  FORMAT(//,' FOR NEXT RUN, WEATHER DATA FROM FILE: ',A60)
999   RETURN
      END


      SUBROUTINE SUWTR1(FNAME,TPHT,TPLT,RDTMT,RAINT,WDST,HUAAT)
c reading from files with PCSMP tables (as used by MACROS-models)
c Version 1.0, 9 Febr. 1989; Author: Don Jansen
      IMPLICIT REAL(A-Z)
      INTEGER I,I1,I2
      CHARACTER*6 F(2)
      CHARACTER*60 FNAME
      DIMENSION X(366)
      DIMENSION TPHT(365),TPLT(365),HUAAT(365),RDTMT(365),WDST(365)
      DIMENSION RAINT(365)
      OPEN(31,FILE=FNAME,STATUS='OLD')
1     READ(31,1001,ERR=1,END=999) F(1),F(2)
1001  FORMAT(2A6)
      IF((F(1).NE.'TABLE ').AND.(F(1).NE.' TABLE')) GOTO 1
      I=1
2     I1=I
      READ(31,*,ERR=2,END=3) (X(I),I=I1,365)
3     IF(I.GE.365) THEN
         IF((F(2).EQ.' TPHT(').OR.(F(2).EQ.'TPHT(1').OR.
     $    (F(2).EQ.'TPHT( ').OR.(F(2).EQ.'TPHT (').OR.
     $    (F(2).EQ.'TPHT  ').OR.(F(2).EQ.' TPHT ').OR.
```

```
      $   (F(2).EQ.'TMPHT ').OR.
      $   (F(2).EQ.'TMPHT(').OR.(F(2).EQ.' TMPHT')) THEN
            DO 4 I2=1,365
              TPHT(I2)=X(I2)
 4          CONTINUE
          ELSEIF((F(2).EQ.' TPLT(').OR.(F(2).EQ.'TPLT(1').OR.
      $   (F(2).EQ.'TPLT( ').OR.(F(2).EQ.'TPLT (').OR.
      $   (F(2).EQ.'TPLT  ').OR.(F(2).EQ.' TPLT ').OR.
      $   (F(2).EQ.'TMPLT ').OR.
      $   (F(2).EQ.'TMPLT(').OR.(F(2).EQ.' TMPLT')) THEN
            DO 5 I2=1,365
              TPLT(I2)=X(I2)
 5          CONTINUE
          ELSEIF((F(2).EQ.' HUAAT').OR.(F(2).EQ.'HUAAT(').OR.
      $   (F(2).EQ.'HUAAT ').OR.(F(2).EQ.'TMPDT ').OR.
      $   (F(2).EQ.'TMPDT(').OR.(F(2).EQ.' TMPDT')) THEN
            DO 6 I2=1,365
              HUAAT(I2)=X(I2)
 6          CONTINUE
          ELSEIF((F(2).EQ.' RDTMT').OR.(F(2).EQ.'RDTMT(').OR.
      $   (F(2).EQ.'RDTMT ')) THEN
            XWAR=0.
            DO 7 I2=1,365
              RDTMT(I2)=X(I2)
              IF((X(I2).EQ.0.).AND.(XWAR.EQ.0.)) THEN
                WRITE(6,1002) FNAME
 1002 FORMAT(//,' ******* WARNING: IN FILE ',A60,/,
      $' ******* RDTMT IS IN SHUNSHINE HOURS OR IN OCTAS',/,
      $' ****** CHECK CONVERSION METHOD IN THE MAIN PROGRAM ',//)
                XWAR=1.
              ENDIF
 7          CONTINUE
          ELSEIF((F(2).EQ.' RAINT').OR.(F(2).EQ.'RAINT(').OR.
      $   (F(2).EQ.'RAINTB').OR.(F(2).EQ.'RAINT ')) THEN
            DO 8 I2=1,365
              RAINT(I2)=X(I2)
 8          CONTINUE
          ELSEIF((F(2).EQ.' WDST(').OR.(F(2).EQ.'WDST(1').OR.
      $   (F(2).EQ.'WDST (').OR.(F(2).EQ.'WDST  ').OR.
      $   (F(2).EQ.' WDST ')) THEN
            DO 9 I2=1,365
              WDST(I2)=X(I2)
 9          CONTINUE
          ENDIF
          GOTO 1
        ENDIF
        GOTO 2
 999  CONTINUE
      CLOSE(31)
      RETURN
      END


      SUBROUTINE SUWTR2(FNAME,TPHT,TPLT,HUAAT,RDTMT,WDST,RAINT)
c reading of weather data from files with standard format of the
c AGROCLIMATE SERVICE UNIT of IRRI, with the exeption that a first
c line is added containing the year-number (format I2)
c Version 1.0, 9 Febr. 1989; Authors: Teng Reyes and Don Jansen
c Units in these files:
c             Rainfall                    *10 mm
c             Solar Radiation             *1  mWhr/cm2
c             Maximum Temperature         *10 oC
c             Minimum Temperature         *10 oC
c             Wind Speed                  *10 m/s
c             Actual Vapor Pressure       *10 mb
C After conversion in this subroutine the output becomes
C    Output:  Rainfall              (RAINT)       mm
C             Solar radiation       (RDTMT)       MJ/m**2
C             Maximum temperature   (TPHT)        oC
C             Minimum temperature   (TPLT)        oC
C             Wind speed            (WDST)        m/s
C             Actual vapor pressure (HUAAT)       kPa
C
      IMPLICIT REAL(A-Z)
      INTEGER I
      INTEGER*2 IYEAR
      CHARACTER*60 FNAME
      DIMENSION TPHT(365),TPLT(365),HUAAT(365),RDTMT(365),WDST(365)
      DIMENSION RAINT(365)
      OPEN(31,FILE=FNAME,STATUS='OLD')
      READ(31,1000)IYEAR
      WRITE(6,1001) IYEAR
 1001 FORMAT(//,' *** WEATHERDATA FOR THE YEAR ',I2,'  ***',//)
 1000 FORMAT(I2)
      DO 1 I=1,365
      READ (31,1002)
RAINT(I),RDTMT(I),TPHT(I),TPLT(I),WDST(I),HUAAT(I)
 1002 FORMAT(2X,F4.0,5X,3F3.0,11X,F2.0,F3.0)
      IF (RAINT(I).LT.0.) RAINT(I)=0.
      RAINT(I)=RAINT(I)/10.
      TPHT(I)=TPHT(I)/10.
      TPLT(I)=TPLT(I)/10.
      WDST(I)=WDST(I)/10.
      HUAAT(I)=HUAAT(I)/10./10.
      RDTMT(I)=RDTMT(I)*0.036
 1    CONTINUE
      CLOSE (31)
      RETURN
      END

      SUBROUTINE SUWTR3(FNAME,TPHT,TPLT,HUAAT,RDTMT,WDST,RAINT)
c reading from files with PCSMP tables (as used by MACROS-models)
c Version 1.0, 9 Febr. 1989; Author: Don Jansen
      IMPLICIT REAL(A-Z)
      INTEGER I
      CHARACTER*60 FNAME
      DIMENSION TPHT(365),TPLT(365),HUAAT(365),RDTMT(365),WDST(365)
      DIMENSION RAINT(365)
c      WRITE(6,1000)
c1000  FORMAT(//,' *** SUBROUTINE SUWTR3 HAS NOT BEEN PROVIDED
***',//)
c      STOP '*** SUBROUTINE SUWTR3 HAS NOT BEEN PROVIDED *** '
      OPEN(31,FILE=FNAME,STATUS='OLD')
      DO 1 I=1,365
         READ(31,1000,END=999) RAINT(I),TPHT(I),TPLT(I),RDTMT(I),
     $                   HUAAT(I),WDST(I)
1000  FORMAT(25X,3F7.1,21X,3F7.1)
1     CONTINUE
999   RETURN
      END

ENDJOB
```

Appendix II:
Listing of variables of SOYCROS

A MACROS Model to Study Soybean Growth and Development

(Supplement to Listing 12 of F.W.T. PENNING de VRIES et al, 1989. Simulation of Ecophysiological Processes of Growth of Several Annual Crops, PUDOC Wageningen)

CDRSL	Cumulative capillary rise	mm
CEVPIP	Cumulative evaporation for current irrigation period	mm
CEVSW	Cumulative evaporation	mm
CIRRI	Cumulative irrigation	mm
CRAIN	Cumulative rainfall	mm
CSA(U,L)}	Soil evaporation constants based on soil	
CSB(U,L)}	type chosen for upland (U)and lowland (L)	$cm^2\ d^{-1}$
EES(U,L)	Extinction coefficient for evaporation based on soil type chosen for upland (U) and lowland (L)soil	m^{-1}
FAILG	Trigger for seedling to grow when soil moisture is adequate	-
FIRRI	Irrigation interval, starting at TIME=0.	d
FRMC	Fraction of moisture content in the first layer needed for germination of crop	-
GZRT(U,R)	Growth rate of ZRT (U,R)s	
ID(1-7)	Counter to accumulate rainfall of preceding 7 days before start of simulation	-
IFILE	Number indicating year to be read	-
IRPER(C)	Counter to calculate each irrigation schedule	-
IRRI	Full irrigation defined as 0.8 of class A pan evaporation of the current irrigation period.	$mm\ d^{-1}$
ITYP	Number indicating type of weather data format	-
LLV(A,N)	Loss of leaf weight due to aging (A), and severe water stress (N)	$kg\ ha^{-1}\ d^{-1}$
LZRT(U,R)	Loss rate of ZRT(U,R)	$m\ d^{-1}$
PUSH	Trigger for crop growth to start	-
PUSHG	Trigger to evaluate moisture content suitable for germination	-
PCEWA	Running average of day-to-day water stress	-
PKSTT	Parameter KST to mimick high rate of lateral flow and maintain saturation	-
PLMLXT	Relation of PLMXLA to DS	-

	alleviation of stress	g CO_2 ha^{-1} d^{-1}
PLMXL	Loss of photosynthetic capacity of leaves at severe water stress conditions	g CO_2 ha^{-1} d^{-1}
PLMXLA	Loss of photosynthetic capacity of leaves mimicking accelerated senescence or the 'self destructive hypothesis'	g CO_2 ha^{-1} d^{-1}
PLMXLW	Loss of photosynthetic capacity of leaves due to accumulated water stress	kg CO_2 ha^{-1} d^{-1}
PLMXN	Maximum rate of leaf photosynthesis for standard conditions;its value decreases with rate PLMXL due to water stress, low N and/or age, and recovers with rate PLMXG	kg CO_2 ha^{-1} d^{-1}
RAINP	Cumulative rain of preceding week at TIME=0	mm
RAIR	Rain plus irrigation	mm d^{-1}
RUN	Parameter to indicate growing condition of crop	
	RUN 1 Rainfed upland	-
	RUN 2 Irrigated upland	-
	RUN 3 Rainfed lowland	-
	RUN 4 Saturated culture	-
SUWTRD	Subroutine used to read weather data from various source files with different formats	
TATIME	Turn around time between rice and soybean crop	days
TCLZRT	Time constant for loss rate of roots	d
TRRMM	Upper limit of water uptake per rooted layer	mm d^{-1} m^{-1}
TYL(U,L)	Number indicating soil type of compartment for upland and lowland soil	
WFSCU	Sensitivity of "upland" root system to flooding	
WGY	Grain yield with 12% moisture content	kg ha^{-1}
WUE	Water use efficiency, relative to total biomass	kg H_2O kg^{-1} DM
ZRT(U,R)	Rooting depth of "upland" (U) and "lowland" (R) root system	m
ZRTUW	Growth of upland root system as a function of water content evaluated per layer	m d^{-1}
ZWI	Water table pattern based on particular growing conditions	m
ZWMX	Maximum water table depth	m

Appendix III:

Listing EXCEL-macro for yield probabilities

```
          FILELIST                 INSTRUCTIONS AND DESCRIPTIONS

Specify path/filename of data         CTRL+SHIFT+S (Shortcut key)
=HIDE()                            The path or filename of your database
"=IF(ALERT(""Have you entered      must be specified in the command:
the necessary data needed
to run this EXCEL-MACROS?
If  you already did, press <OK>,
otherwise <CANCEL>"",1),
GOTO(B6),Messages())"

"=OPEN(""TUG-R4A.CSV"")"         "<--OPEN(""filenameB.CSV"") see col B row 6."
=ECHO(FALSE)
"=FORMULA.GOTO(""R1C1"")"
"=SELECT(""R[1]C[5]"")"           File HEADING.XLS contains the
"=OPEN(""HEADING.XLS"")"          "variables DATEB, WGY,CIRRI"
"=SELECT(""R1C1:R3C65"")"         for the months JANUARY to DECEMBER
=COPY()
"=ACTIVATE(""TUG-R4A.CSV"")"        "<-- ACTIVATE(""filename.CSV"")"
=PASTE()
=CANCEL.COPY()
=ECHO(FALSE)
"=ACTIVATE(""HEADING.XLS"")"
=FILE.CLOSE()
=ECHO(TRUE)
=SetCritDatab()


            SELECTION               Specification of RUN number and
          Selection of data         diffent DATEB values
=ECHO(FALSE)
"=SELECT(""R4C6"")"
"=FORMULA(""4"")"                   "<--- Specify RUN number
in FORMULA ("" "")"
"=SELECT(""R4C7"")"
"=FORMULA(""9"")"                   "<--- Specify 1st DATEB
in FORMULA ("" "")"
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""40"")"                  "<--- Specify 2nd DATEB
```

```
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""68"")"                    "<--- Specify 3rd DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""99"")"                    "<--- Specify 4th DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""129"")"                   "<--- Specify 5th DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""160"")"                   "<--- Specify 6th DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""190"")"                   "<--- Specify 7th DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""221"")"                   "<--- Specify 8th DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""252"")"                   "<--- Specify 9th DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""282"")"                   "<--- Specify 10th DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""313"")"                   "<--- Specify 11th DATEB
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()
"=SELECT(""r4c7"")"
"=FORMULA(""343"")"                   "<--- Specify 12th DATEB
```

```
in FORMULA ("" "")"
=SELECT.END(2)
=Extraction()


                 CHECK
       Checking of database
=GOTO(Rank)
"=IF(ALERT(""Data for a month the extracted database
will be compared with the original database.
PROCEDE?"",1)=FALSE,GOTO(Rank))"
"=SELECT(""R36C11"")"
"=FORMULA(""CHECK"")"
"=SELECT(""R26C12"")"
"=FORMULA(""ORIGINAL COLUMN"")"
"=SELECT(""R1C1"")"
"=SELECT(""R[1]C:R[1]C[3]"")"
=COPY()
"=SELECT(""R27C12"")"
=PASTE()
=CANCEL.COPY()
"=SELECT(""r4c7"")"
"=FORMULA(""343"")"
=SetCritDatab()
"=SELECT(""R27C12:R27C14"")"
=EXTRACT(FALSE)
"=SELECT(""RC"")"
"=SELECT(""RC[-1]"")"
"=FORMULA(""YEAR"")"
"=SELECT(""R[1]C"")"
"=FORMULA(""1"")"
"=SELECT(""RC:R[19]C"")"
"=DATA.SERIES(2,1,1,1,)"
"=SELECT(""r1c1"")"
"=FORMULA.FIND(""DEC"",1,2,2)"          <--- Specify corresponding MONTH
"=SELECT(""RC:R[21]C[2]"")"             of entered DATEB
value for CHECKING
=COPY()
"=SELECT(""R26C16"")"
=PASTE()
"=SELECT(""R25C16"")"
"=FORMULA(""GATHERED VALUES"")"
=Continuation()
"=IF(ALERT(""To check, choose OK button; then this
MACROS will be terminated. After visual check, press CTRL +o
to proceed. If visual check is not necessary, choose CANCEL
button to proceed with RANKing and SORTing
database."",1)=TRUE,HALT())"
```

RANKSORTTAB
"Ranking , Sorting and Tabulating Database"

Extracted database will be ranked in descending order to determine yield levels with a 25, 50 75 % probability to be exceeded.

```
"=IF(ALERT(""Data will be sorted in descending
order after which  DATEB  and  GRAIN YIELD
will be extracted from the database.
PROCEDE?"",1)=FALSE,HALT())"
=ECHO(FALSE)
"=SELECT(""r1c1"")"
"=FORMULA.FIND(""year"",1,2,1,1)"
=CLEAR(1)
"=SELECT(""r[1]c:r[20]c[3]"")"
"=SORT(1,""RC[3]"",2)"
"=SELECT(""RC[2]:R[20]C[3]"")"
=COPY()
=FORMULA.GOTO($L$51)
=PASTE()
=CANCEL.COPY()
"=FOR(""i"",1,11)"
"=SELECT(""r1c1"")"
"=FORMULA.FIND(""year"",1,2,1,1)"
=CLEAR(1)
"=SELECT(""r[1]c:r[20]c[3]"")"
"=SORT(1,""RC[3]"",2)"
"=SELECT(""RC[2]:R[20]C[3]"")"
=COPY()
=Transfer()
=NEXT()
=FORMULA.GOTO($L$51)
"=FOR(""count"",1,12,1)"
=COPY()
"=SELECT(""R[-1]C"")"
=PASTE()
=CANCEL.COPY()
"=SELECT(""R[1]C:r[20]C"")"
=EDIT.DELETE(1)
"=SELECT(""RC[1]"")"
=NEXT()
=SELECT.END(1)
=SELECT.END(1)
"=SELECT(""R[-1]C[-1]"")"
"=FORMULA(""DATEB"")"
"=SELECT(""R[1]C"")"
"=FORMULA(""1"")"
"=SELECT(""RC:R[19]C"")"
"=DATA.SERIES(2,1,1,1,)"
=SELECT.END(3)
"=SELECT(""rc:r[20]c[12]"")"
=COPY()
```

```
=NEW(1)
=PASTE()
=CANCEL.COPY()
"=SAVE.AS(""TUG-R4A.XLS"",1,"""",FALSE)"          "<--Specify filename
                                                     of worksheet
(""filename.XLS"")"
=ECHO(FALSE)
"=ACTIVATE(""TUG-R4A.CSV"")"
=CLOSE()
"=ACTIVATE(""TUG-R4A.XLS"")"
=ECHO(TRUE)


          PROBABILITIES
=ECHO(FALSE)
"=SELECT(""R1C1:R1C13"")"
=COPY()
=SELECT.END(4)
"=SELECT(""R[3]C"")"
"=PASTE.SPECIAL(3,1,FALSE,TRUE)"
=SELECT.END(3)
=SELECT.END(3)
"=IF(ALERT(""Choose appropriate CTRL key for the number
of years used in simulation... ""),3)"
"=IF(ALERT(""CTRL+f for 15 years, CTRL+x,for 16 years,
CTRL+v for 17 years, CTRL+e for 18 years, CTRL+n for 19
years, CTRL+y for 20 years.""),2)"
=ECHO(TRUE)
=RETURN()


"The 25, 50, & 75% probability for 15 years are"
called and calculated in this section.

=ECHO(FALSE)
The 25 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,3)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans25()

The 50 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,7)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans50()
```

The 75 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.

```
"=FOR(""i"",1,11)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans75()
=Graphing()
=ECHO(TRUE)
=RETURN()
```

"The 25, 50, & 75% probability for 16 years are"
called and calculated in this section.

```
=ECHO(FALSE)
```

The 25 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.

```
"=FOR(""i"",1,3)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans25()
```

The 50 % probability(AVERAGE VALUE) of exceeding
a particular yield level is chosen.

```
"=FOR(""i"",1,7)"
"=SELECT(""R[1]C"")"
=NEXT()
=YAverage()
=YTrans50()
```

The 75 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.

```
"=FOR(""i"",1,13)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans75()
=Graphing()
=ECHO(TRUE)
=RETURN()
```

"The 25, 50, & 75% probability for 17 years are"
called and calculated in this section.

```
=ECHO(FALSE)
```

The 25 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.

```
"=FOR(""i"",1,3)"
"=SELECT(""R[1]C"")"
```

```
=NEXT()
=YAverage()
=YTrans25()

The 50 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,9)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans50()

The 75 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,13)"
"=SELECT(""R[1]C"")"
=NEXT()
=YAverage()
=YTrans75()
=Graphing()
=ECHO(TRUE)
=RETURN()

"The 25, 50, & 75% probability for 18 years are"
called and calculated in this section.
=ECHO(FALSE)
The 25 % probability(AVERAGE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,3)"
"=SELECT(""R[1]C"")"
=NEXT()
=YAverage()
=YTrans25()

The 50 % probability(AVERAGE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,9)"
"=SELECT(""R[1]C"")"
=NEXT()
=YAverage()
=YTrans50()

The 75 % probability(AVERAGE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,15)"
"=SELECT(""R[1]C"")"
=NEXT()
=YAverage()
=YTrans75()
=Graphing()
```

```
=ECHO(TRUE)
=RETURN()

"The 25, 50, & 75% probability for 19 years are"
called and calculated in this section.
=ECHO(FALSE)
The 25 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,4)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans25()

The 50 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,9)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans50()

The 75 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,14)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans75()
=Graphing()
=ECHO(TRUE)
=RETURN()

"The 25, 50, & 75% probability for 20 years are"
called and calculated in this section.
=ECHO(FALSE)
The 25 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,4)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans25()

The 50 % probability(AVERAGE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,9)"
"=SELECT(""R[1]C"")"
=NEXT()
=YAverage()
```

```
=YTrans50()

The 75 % probability(SINGLE VALUE) of exceeding
a particular yield level is chosen.
"=FOR(""i"",1,16)"
"=SELECT(""R[1]C"")"
=NEXT()
=SelectYield()
=YTrans75()
=Graphing()
=ECHO(TRUE)
=RETURN()

              GRAPHING
"=IF(ALERT(""Procede with graphing of data points?"",1)=FALSE,GOTO(B409))"
=ECHO(FALSE)
"=SELECT(""R1C1"")"
=CLEAR(1)
"=FORMULA.FIND(""DATEB"",1,2,2,1)"
"=SELECT(""r[1]c:r[1]c[3]"")"
=INSERT(2)
"=SELECT(""rc[1]"")"
"=FORMULA(""25%"")"
"=SELECT(""rc[1]"")"
"=FORMULA(""50%"")"
"=SELECT(""rc[1]"")"
"=FORMULA(""75%"")"
=SELECT.END(1)
=SELECT.END(1)
"=SELECT(""RC:R[12]C[3]"")"

          Graphing X, Y1 Axis"
=NEW(2)
"=GALLERY.LINE(1,TRUE)"
"=SELECT(""Axis 1"")"
"=SCALE(TRUE,TRUE,1000,TRUE,TRUE,FALSE,FALSE,FALSE)"

=ATTACH.TEXT(1)
"=FORMULA(""=""""TUGUEGARAO IRRIGATED UPLAND"""""")"
<-- Type Chart Title
=ATTACH.TEXT(2)
"=FORMULA(""=""""GRAIN YIELD (kg ha-1)"""""")"
<-- Type Y-axis Title
=ATTACH.TEXT(3)
"=FORMULA(""=""""DATE OF SOWING (Julian date)"""""")"  <--Type X-axis Title
"=SIZE(400,300)"
=LEGEND(TRUE)
"=SELECT(""Legend"")"
=FORMAT.LEGEND(1)
"=SELECT(""Axis 1"")"
```

```
"=PATTERNS(0,1,1,2,2,1,4)"
"=SELECT(""Axis 2"")"
"=PATTERNS(0,1,1,2,2,1,4)"
"=SAVE.AS(""TUG-R2G.XLC"",1,"""",FALSE)"           "<--Specify filename chart
(""filename.XLC"")"
=RETURN()
"=(ALERT(""N O T E : CTRL+g to graph data points"",2))"
=RETURN()

          Graphing X, Y1, Y2 Axis"
"=SELECT(""R26C1"")"
"=SELECT(""RC:R[12]C[4]"")"
=NEW(2)
=COMBINATION(3)
"=SELECT(""Axis 1"")"
"=SCALE(TRUE,TRUE,1000,TRUE,TRUE,FALSE,FALSE,FALSE)"

=ATTACH.TEXT(1)
"=FORMULA(""=""""TUGUEGARAO RAINFED UPLAND"""""")"
<-- Type Chart Title
=ATTACH.TEXT(2)
"=FORMULA(""=""""GRAIN YIELD  (kg ha-1)"""""")"        <--Type Y-axis Title
=ATTACH.TEXT(3)
"=FORMULA(""=""""DATE OF SOWING (Julian date)"""""")"  <--Type X-axis Title
"=SIZE(400,300)"
"=SELECT("""")"
"=FORMULA(""=""""(mm)"""""")"
"=FORMAT.MOVE(367.5,143.25)"
=LEGEND(TRUE)
"=SELECT(""Legend"")"
=FORMAT.LEGEND(1)
"=SELECT(""Axis 1"")"
"=PATTERNS(0,1,1,2,2,1,4)"
"=SELECT(""Axis 2"")"
"=PATTERNS(0,1,1,2,2,1,4)

"=SCALE(1,1,1,FALSE,FALSE,FALSE)"
"=SELECT("""")"
"=SELECT(""Axis 3"")"
"=PATTERNS(0,1,1,2,2,1,4)"
"=SCALE(TRUE,500,100,TRUE,TRUE,FALSE,FALSE,FALSE)"

"=OVERLAY(4,FALSE,FALSE,FALSE,FALSE,FALSE,FALSE,0,50,0,
4,FALSE)"
"=SELECT(""S4P1"")"
"=PATTERNS(0,1,1,2,2,,,,TRUE)"
"=SELECT(""S1P3"")"
"=PATTERNS(1,,,,0,1,1,2,FALSE)"
"=SELECT(""S2P1"")"
"=PATTERNS(1,,,,0,2,1,2,FALSE)"
```

```
"=SELECT(""S3P1"")"
"=PATTERNS(1,,,,0,3,1,2,FALSE)"
"=SAVE.AS(""TUG-R3.XLC"",1,"""",FALSE)"      "<--Specify filename chart
(""filename.XLC"")"
=ECHO(FALSE)
"=ACTIVATE(""TUG-R3.XLS"")"
=FILE.CLOSE()
=RETURN()

               MESSAGES
"=UNHIDE(""soymac.xlm"")"
"=IF(ALERT(""Search for arrows (<--) pointing to
statements that need input information by CTRL+A.
Then editinformation. Then CTRL+a again. After
editing press CTRL+SHIFT+S to restrat
the MACRO."",2)=TRUE,SELECT(""r4c3""))"
"=FORMULA.FIND(""<--"",1,2,1,1)"
=HALT()

              EXTRACTION
"=SELECT(""R[-1]C"")"
=SELECT.END(2)
=SELECT.END(2)
"=SELECT(""RC:R[20]C[2]"")"
=EXTRACT(FALSE)
"=SELECT(""RC"")"
"=SELECT(""RC[-1]"")"
"=FORMULA(""YEAR"")"
"=SELECT(""R[1]C"")"
"=FORMULA(""1"")"
"=SELECT(""RC:R[19]C"")"
"=DATA.SERIES(2,1,1,1,)"
=RETURN()

                       TRANSFER
=FORMULA.GOTO($L$51)
=SELECT.END(2)
"=FORMULA.GOTO(""RC[1]:R[20]C[1]"")"
=PASTE()
=RETURN()

                 YIELD PROBABILITIES
Selection of yield probabilities (for single values)
"=SELECT(""R[1]C:R[1]C[12]"")"
=COPY()
=RETURN()

                 Yield Data Transfer
Yield data for the 25% probability
=SELECT.END(4)
```

```
=SELECT.END(4)
"=SELECT(""RC[1]"")"
"=PASTE.SPECIAL(3,1,FALSE,TRUE)"
=SELECT.END(1)
=SELECT.END(3)
=SELECT.END(3)
=RETURN()

Yield data for the 50% probability
=SELECT.END(4)
=SELECT.END(4)
=SELECT.END(2)
"=SELECT(""rc[1]"")"
"=PASTE.SPECIAL(3,1,FALSE,TRUE)"
=SELECT.END(1)
=SELECT.END(1)
=SELECT.END(3)
=SELECT.END(3)
=RETURN()

Yield data for the 75% probability
=SELECT.END(4)
=SELECT.END(4)
=SELECT.END(2)
"=SELECT(""rc[1]"")"
"=PASTE.SPECIAL(3,1,FALSE,TRUE)"
=SELECT.END(1)
=SELECT.END(1)
=RETURN()

                    AverageYield
"=SELECT(""R[3]C:R[3]C[12]"")"
=INSERT(2)
"=SELECT(""RC[1]"")"
"=FORMULA(""=average(R[-2]C:R[-1]C)"")"
=COPY()
"=SELECT(""RC:RC[11]"")"
=PASTE()
"=SELECT(""rc[-1]"")"
"=FORMULA(""MEAN"")"
"=SELECT(""RC:RC[12]"")"
=COPY()
=RETURN()

                    SETCRITDATEB
Criteria and Database Selection
"=SELECT(""R3C6:R4C8"")"
=SET.CRITERIA()
"=SELECT(""R2C1:R280C3"")"
=SET.DATABASE()              <--- Enter the DATABASE RANGE:ie
```

```
r2c1:r540c4
=ECHO(TRUE)                    Database is from row 2 column 1 to
=RETURN()                      row 540 column 4
```

Appendix IV:

A sample output of the procedure listed in Appendix III

Case	Month	Yield kg	Water Req	Net Returns (P/ha)
Upland Rainfed 25%	JAN	2000	0	4991.777
	FEB	3000	0	11586.51
	MAR	4000	0	18181.24
	APR	5000	0	24775.96
	MAY	7000	0	37965.42
	JUN	8000	0	44560.15
	JUL	7500	0	41262.79
	AUG	6500	0	34668.06
	SEP	5500	0	28073.33
	OCT	5500	0	28073.33
	NOV	5000	0	24775.96
	DEC	4500	0	21478.6

	Month	Yield kg	Water Req	Net Returns (P/ha)
50%	JAN	2500	0	8289.142
	FEB	3500	0	14883.87
	MAR	4500	0	21478.6
	APR	5500	0	28073.33
	MAY	7500	0	41262.79
	JUN	8500	0	47857.52
	JUL	8000	0	44560.15
	AUG	7000	0	37965.42
	SEP	6000	0	31370.69
	OCT	6000	0	31370.69
	NOV	5500	0	28073.33
	DEC	5000	0	24775.96

	Month	Yield	Water Req	Net Returns (P/ha)
75%	JAN	3000	0	11586.51
	FEB	4000	0	18181.24
	MAR	5000	0	24775.96
	APR	6000	0	31370.69
	MAY	8000	0	44560.15
	JUN	9000	0	51154.88
	JUL	8500	0	47857.52
	AUG	7500	0	41262.79
	SEP	6500	0	34668.06

OCT	6500	0	34668.06
NOV	6000	0	31370.69
DEC	5500	0	28073.33