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H4.SMR/1304-16

"COLLEGE ON SOIL PHYSICS"

12 March - 6 April 2001

Modeling Hydrologial Processes for Guiding Soil and Water Conservation Practices

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EUROPEAN SOCIETY OF SOIL CONSERVATION
Meeting on
THE SOIL AS A STRATEGIC RESOURCE: DEGRADATION PROCESSES AND CONSERVATION MEASURES
Tenerife-Fuerteventura-Lanzarote (Canary Islands, Spain)
11-15 July. 1995

MODELING HYDROLOGIAL PROCESSES FOR GUIDING SOIL AND WATER CONSERVATION PRACTICES

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INTRODUCTION

The soil moisture regime, determined by changes in water content with time, is the main factor conditioning the crop growth and production. It is mainly conditioned by soil physical properties affecting the capacity and possibilities of infiltration, retention and drainage of rainwater. Limitations to root growth will also determine the possibilities of access of roots to the soil depth where water remains available for plant use during the different crop growing periods. Most of the soil conditions affecting the soil moisture regime and root growth may be modified by soil and crop management practices.

Soil degradation processes have direct negative effects on crop production, and offsite effects on increased risks of catastrophic floods, sedimentation, landslides, etc., and on global climatic changes. Water, that is often the main limiting factor of crop production, is also the main factor directly or indirectly responsible for soil and land degradation processes. The control of soil degradation and derived effects will depend on an appropriate land use and management planning. A prerequisite is an adequate identification and evaluation of the degradation processes, and of the relations cause-effects of the different problems. Among the different land degradation processes, soil water erosion, soil compaction and soil sealing and crusting, and combination of them, are the ones with major direct effects on crop production.

The processes of soil physical degradation, caused by the interactions soil-climate-management, generally result on unfavorable, and sometimes drastic, changes in the soil moisture regime, and in the possibilities of root development and activity. Therefore, it becomes very important to predict risks of soil physical degradation, and to predict effects on the soil moisture regime and root development of different crops and soil management systems and practices, under particular climatic conditions.

Drought stress and waterlogging are important constraints to plant growth and crop production . They are generally the result of inadequate amount, distribution and variability of rainfall, and of reduced water holding capacity and infiltration rates of the soil, which may also lead to accelerated runoff and erosion (Pla, 1988b). Cropping systems and land management practices leading to soil degradation, with further loss of soil chemical and physical fertility, may result in a decreased productivity and increasing production risks.

In order to develop and select the best possible alternatives for management of crops and soils, to increase the amount of rainfall available for crop production, minimizing the amount and duration of water surplus or deficit, to increase productivity, it is required: 1) to determine the effect of soil surface sealing and effective rooting depth in relation to the amount and distribution of rainfall, on the soil water regime during the different growth periods of the crop in selected seasons. Most hydrologists ignore the surface sealing effects, assuming that water infiltration is only influenced by the physical properties of the soil bulk; 2) to assess the amount of rainfall available for crop production, and to estimate the amount of water surplus or water deficit, and their duration, for each growing period in a particular season.

Being the soil surface the zone where the distribution of the available water is initiated, and also being this zone the more accessible to modification by man, the solutions are generally directed to protect or to modify its properties to maintain or improve infiltration, and to reduce runoff and evaporation. This may be achieved either by maintaining an organic mulch cover, by conditioning (Verplancke et al, 1983; Pla et al, 1981; Pla, 1992a), or by tillage. The use of large amounts of crop residues as a protective surface mulch, has many practical limitations for its application to large agricultural areas (Unger, 1978; Pla et al, 1987), especially in the semiarid tropics. Improvement of aggregates trough tillage usually is not lasting because of the low stability of surface soil aggregates to raindrop impact (Pla et al, 1979). The lasting effects may be achieved by stabilizing the surface soil structure by the use of non-expensive soil conditioners (De Boodt, 1972; Pla, 1975), if it is economically justified.

The aim of this paper is to show how the use of computer simulation modeling of soil hydrological processes may facilitate the development and choice of soil management strategies to minimize risks, both of crop production and of soil degradation.

MODELING HYDROLOGICAL PROCESSES RELATED TO SOIL AND WATER CONSERVATION PRACTICES

Loss of soil productivity is the main long term effect of soil degradation on-site, with generally faster and stronger negative consequences in tropical regions. Short term effects on crop production are mainly due to the effects of soil degradation processes in the soil water regime, depending on the variability of rainfall amount and distribution.

The choice of alternative soil surface management strategies to minimize risks in a highly variable climate can be facilitated using computer simulation models. Physical and biological responses to management treatments are often erratic and unpredictable, as a result of interactions between weather and the soil-crop system. Physically-based computer simulation models are also needed to interpret short term data in the context of long-term climate records. The simulation of the important processes is essential to determine the longer-term outcome of management on water balance, soil erosion and crop yields.

Considerable data have been obtained about soil losses from different soils and cropping systems, but very few assessments of the effects of those losses on soil productivity have been done. Approaches based on rainfall alone assume that plant production is related more to the availability and use of water, and only indirectly to its supply. But water use is generally less than rainfall when runoff or percolation below the root zone are present. These approaches also ignore the water storage capacity of the soil, and consider all rainfall of equal value irrespective of distribution and concentration. Some other early approaches tried to relate crop yield to topsoil depth affected by soil erosion removal, but the relations were site and time specific, and only valid for each combination of climate and soil properties.

More recently it has been proposed to quantify the long term effects of erosion and soil degradation in general on soil productivity, viewing the soil as the environment for root growth and water depletion. Projections about the effects of soil degradation on crop productivity are difficult to validate. The difficulties to separate the effects of different degradation processes, the short term and site specific nature of most erosion and soil degradation studies, and the inadequacy of available data base required for assessment are the main constraints for those projections.

The aims of soil management is to reduce risk for short term crop production, and to maintain stability of productivity over the long term. The development and application of new technologies to reach those aims, if done trough field experiments, need to be run in a number of places and for long enough to collect data in a representative sample of soils and the variable climate. Simulation modeling using fairly simple approaches, may provide in a short term useful indications to select management practices and farming systems, under a range of soil and climate conditions (Littleboy et al, 1994). This often requires the use of physically process-based models, where the large number of important variables and their complex interactions can be integrated (Pla, 1994). Climate variability, and the associated high risks of crop yield and food production in many regions of the world, require strategies based on models using real-time information on soils, climate and crops, for decision making. Modern computer technology permits to store, process and interpret a large amount of soil, climate and crop data.

Simulation models may be used as independent diagnostic criteria for risk of crop production, and for risks and effects of soil degradation processes. If properly used, they can provide the scientific basis for evaluating the production and environmental impact of proposed land use changes, and the consequences of climatic variations. The models have to be able to predict approximately what is occurring under field conditions. They may be very simple, or they can be extremely complex, requiring many resources (time, equipment, manpower) and input information which is seldom available, making less complex models often more suitable for practical purposes. Most of the models developed for simulating water balances do not take into account the important effects of surface sealing, runoff, and effective soil rooting depth (LHome and Eldin, 1985). The main difficulty to take those factors into account has been the big gap still existing between theoretical and applied soil hydrology.

The models used in predicting crop performance, and soil degradation processes derived of the impact of land use and management practices in the soil hydrology, must include weather (mainly rainfall) variability in space and time, and soil properties and their spatial variability. The required data about soil properties are those influencing water entry and retention in the soil, limits of water retention capacity of the soil, loss of water by evaporation, and environment for root growth. Methods to approximate the needed soil properties from existing soil taxonomic data have been proposed, when there are no possibilities for direct measurement of those soil attributes. But when the used correlations have not been obtained in situ, the possibilities of large errors in the output of the models are very high. The weather data required for the models are the ones influencing potential water supply to the crop and to runoff, and evapotranspiration. These include daily values of rainfall, and monthly values of solar radiation and of maximum and minimum temperatures. When long term weather records or daily rainfall are not available, an alternative procedure is to use stochastic time-series modeling, to generate a sequence of weather data similar to historical sequences (Ritchie et al, 1990).

Following this approach, there was developed the simulation model "SOMORE" (Pla 1988; 1992; 1996), which simulates the evolution of the soil water balance in the soil profile with a time step of one day, using easily obtainable soil and meteorological data as input. It may be used to predict the soil moisture regime, including waterlogging, rainfall losses by surface runoff, surface drainage and internal drainage, under different given conditions of soils, topography, climate, vegetation, crops and management. The model accounts for infiltration of rainfall into the soil as limited by surface sealing effects and limiting layers (natural or induced by management) close to the soil surface, and for internal drainage or subsurface runoff as affected by rainfall infiltration, effective root depth and saturated hydraulic conductivity of the limiting soil layer. The predictions may be used to identify the more probable degradation processes, and for the selection of the best alternatives, with more probabilities of success, of soil and water conservation practices for each combination of soils, climate and topography.

The model "SOMORE" is based on a description of the more important hydrologic processes in soils, as influenced by use and management, under semiarid to subhumid climates. In the model some simplifications in the formulation of the different hydrological processes, which have proved not to have significative effects on the required precision of the output, have been necessary in order to reduce the number and kind of input parameters from climate, soils and plants, to make the model applicable. "SOMORE" requires as basic inputs before starting simulation, the soil conditions having the main influence on infiltration rates, on runoff losses, on internal drainage, on soil moisture retention and evapotranspiration, and on root development. Such conditions are expressed through parameters based on field and laboratory measurements or estimates, using simple methodologies and equipment, sufficiently accurate to cover the needs at the least possible cost. For the effective rooting depth (or depth of the limiting layer) there must be defined water content at saturation, liquid limit, field capacity or drained upper limit, and permanent wilting point, which may be measured under field (preferably) or laboratory conditions, or estimated through pedotransfer functions. The main output of the model is the soil moisture regime of the soil in a daily basis, including the average soil moisture at root depth, and water losses by runoff or internal drainage. The soil moisture is updated at one day (24 hours) interval, depending on inputs of rainfall and evapotranspiration, and outputs of runoff and internal drainage. Waterlogging and runoff are dependent on the relation between rainfall intensity, infiltration rate and water capacity of the soil overlying the limiting layer, affected or not by the sealing effect and slope gradient.

The predicted soil moisture regime may be interpreted in relation to drought or excess water problems in the overlying soil, at different times and growth stages of a particular vegetation or crop, and also in relation to irrigation and drainage requirements, possibilities and convenience of tillage operations, and erosion hazard by different processes. To preview the possible influences of different combinations of soil and water management on the soil moisture regime, there is required a previous identification and evaluation of the main critical factors affecting problems of soil degradation and of water supply to crops. The rainfall data are used to simulate the behavior of a particular condition or management system in different years, and therefore, based on that previewed behavior it would be possible to select or design the best systems of soil and water management to control soil degradation with a probabilistic approach. It is also possible to predict the soil degradation (mainly erosion) processes and effects, with different return periods, for each condition or proposed land use and management. The selection of certain return periods is important because they largely determine the requirements of management practices and structures in relation to costs and benefits, for different levels and probabilities of risks. A particular season or year is described or analyzed in relation to the long term variability, based on rainfall records from the past. The prediction of concentration of surface and subsurface runoff, and of the conditions of soil moisture, permits to preview which days, weeks, months or years have the greatest flood, erosion and sedimentation hazard, and what would be the most probable process of soil erosion (Pla, 1992; 1993; 1996). This is more useful for designing erosion control strategies than the use of empirical models which have proved not to be able to predict the time and probabilities of occurrence of concentrated runoff and erosion, and mush less landslides and mass movements in general.

APPLICATION OF THE MODEL "SOMORE" FOR GUIDING SOIL AND WATER CONSERVATION PRACTICES

As examples of the application of "SOMORE" for modeling hydrological processes and guiding soil and water conservation practices, three situations with different soils, climate, topography, cropping and management conditions in tropical Latin America are presented. The same approach could be used for any other climates and combination of conditions. In all three cases, most of the basic information on soils and climate required to feed the computer simulation program was available. In the first two cases (Fig. 1-5) the results have been validated through field experiments and measurements, while in the last situation (Fig. 6) the validation has been done through field observations and historical evidence.

1st example (Fig. 1-3)

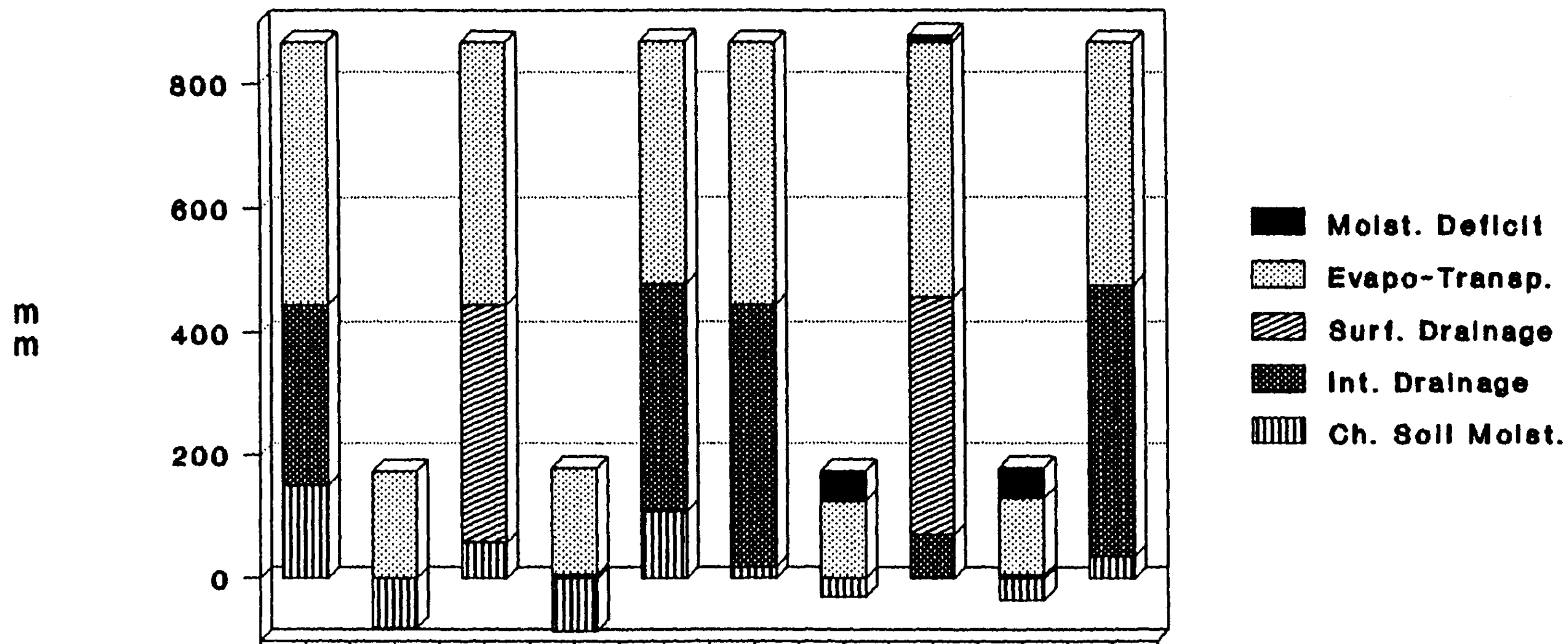
The soil is a silt loam CAMBISOL (US Soil Taxonomy:Inceptisol), developed from recent alluvial materials, in the nearly level Western Plains of Venezuela, under a tropical sub-humid climate, with most of the rainfall concentrated in a rainy season of 6-7 months. The land in the area is mostly used for rainfed seasonal crops, highly mechanized, in a cropping sequence that includes corn (Zea mays; LGP 80-100 days) and cotton as the main crops in the rainy season, and sesame (Sesamum indicum; LGP 100-130 days)), sunflower or sorghum in the post-rainy season. Some of the lands are also used under irrigation for crops like rice and sugarcane. The main identified problems for rainfed crops (sequence maize-sesame) are waterlogging and excessive soil moisture during the rainy season, and water deficits in the post-rainy dry season. The main causes of those problems appear to be the surface sealing of the bare soil receiving the raindrop impacts, and the formation of compacted plow or harrow pans at 10-15 cm depths, restricting both root penetration and water flow.

Figures 1-3 try to summarize some of the results obtained when using the "SOMORE" model to simulate the influence of different values of those limiting factors (sealing and compaction) in the soil water balance and soil moisture regime, during a year with annual rainfall close to average. The soil in the selected site, with surface soil structure already degraded, has a minimum infiltration rate of ponded water of 10 mm/hour, which under raindrop impact decreases to approximately 2 mm/hour. The plow pan, which is already formed after 5-10 years of continuous cultivation using disk harrow as the main tillage tool, has a Ksat of approximately 1 mm/hour. Figure 1 shows that even in bare soil, when the rooting depth (60 cm) is not restricted by a shallow compacted pan, both in the rainy and post-rainy seasons there would not be moisture deficits for the whole growing periods of corn and sesame. The difference between the non-drained and the surface drained fields, is the way (surface or internal drainage) the excess water during the rainy season is lost. When the effective rooting depth is reduced to 15 cm, due to the plow pan, and without surface drainage system, there are not water deficits in the rainy season crop (corn), but there would be high probabilities of strong critical water deficits in the post-rainy season crop (sesame). With a surface drainage system to control waterlogging in the rainy season, there is the possibility of causing some water deficits in the rainy season corn, maintaining the same probabilities of water deficits for the following sesame crop.

Figure 2a shows how the problems of waterlogging and excessive soil moisture may be solved with an effective surface drainage system, without causing problems of moisture

Fig. 1.- Water Balance (Si-Lo CAMBISOL)

Maize(M)-Sesame(S) / 15-60 cm root depth
Rain: Average /B=Bare;C=Cover;D=Drainage



	60cm B M	60cm B S	60cm BDM	60cm BDS	60cm C M	15cm B M	15cm B S	15cm BDM	15cm BDS	15cm C M
Moist. Deficit	0	0	0	0	0	0	49	12	49	0
Evapo-Transp.	422	173	422	173	390	422	124	410	124	390
Surf. Drainage	0	0	388	5	0	0	0	388	5	0
Int. Drainage	295	0	0	0	372	427	0	69	0	442
Ch. Soil Moist.	150	-79	57	-84	107	18	-30	0	-35	35

Fig.2a.- Soil Moisture Regime (CAMBISOL)
Maize growing period / 60cm Root Depth
Flat/Bare/Drain.(Aver. Rain;RP:2 Years)

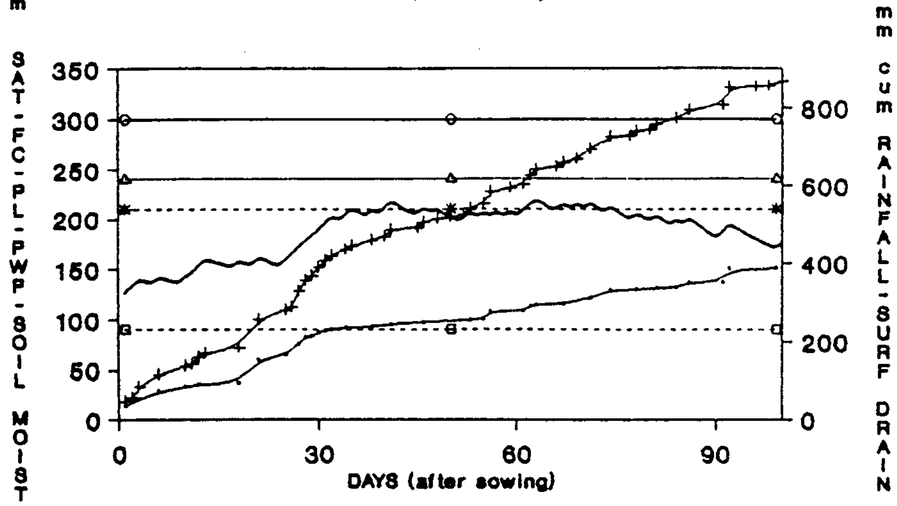


Fig.2b.- Soil Moisture Regime (CAMBISOL)
Sesame growing period / 60cm Root Depth
Flat/Bare/Drain.(Aver.Rain; RP:2 Years)

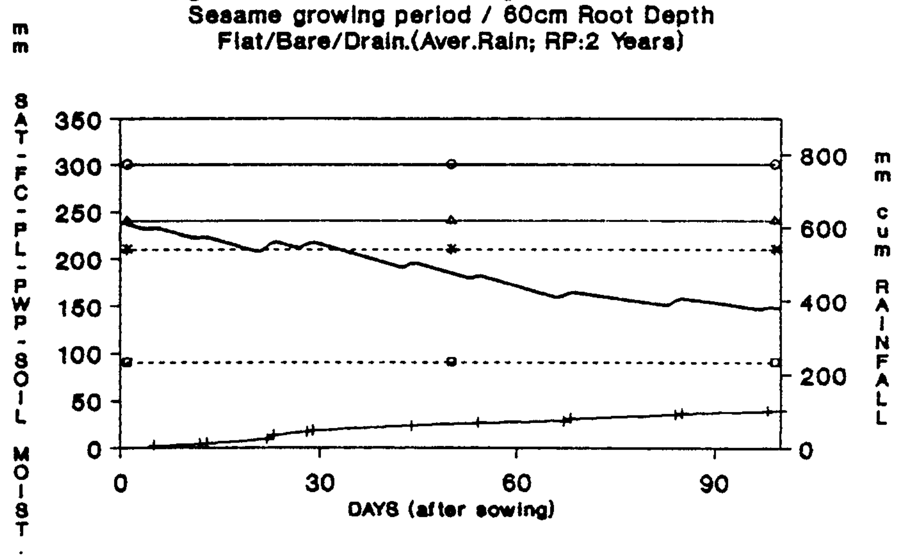


Fig.2c.- Soil Moisture Regime (CAMBISOL)
Maize growing period / 60cm Root Depth
Flat/Cover/No Drain(Aver.Rain;RP:2Years)

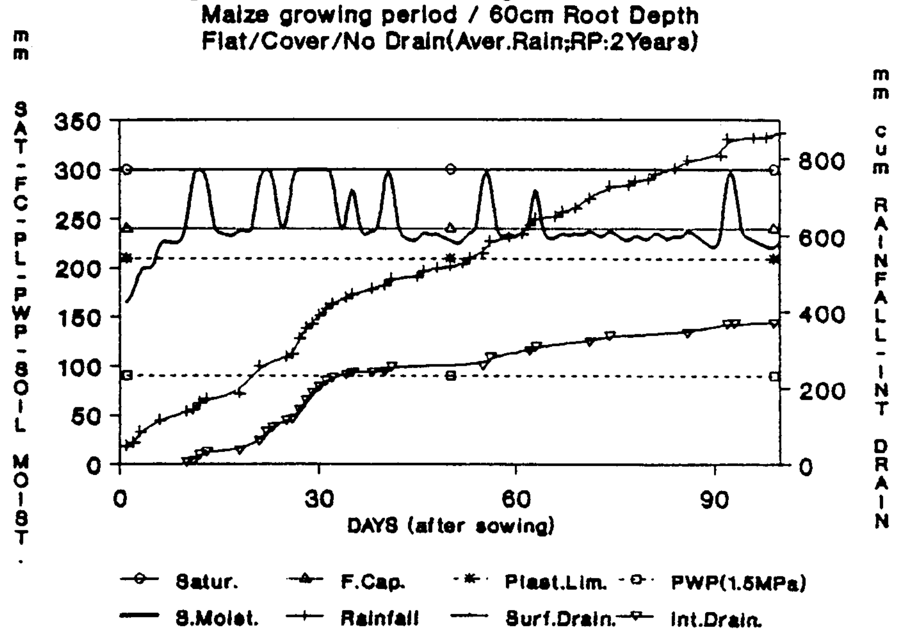


Fig.3a.- Soil Moisture Regime (CAMBISOL)
Maize growing period / 15cm Root Depth
Flat/Bare/No Drain.(Aver.Rain;RP:2Years)

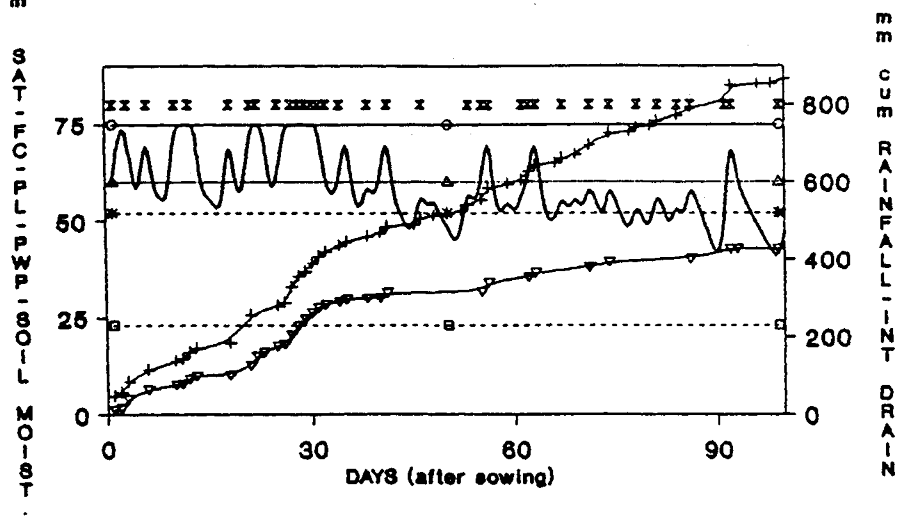


Fig.3b.- Soil Moisture Regime (CAMBISOL)
Sesame growing period / 15cm Root Depth
Flat/Bare/No Drain.(Aver.Rain;RP:2Years)

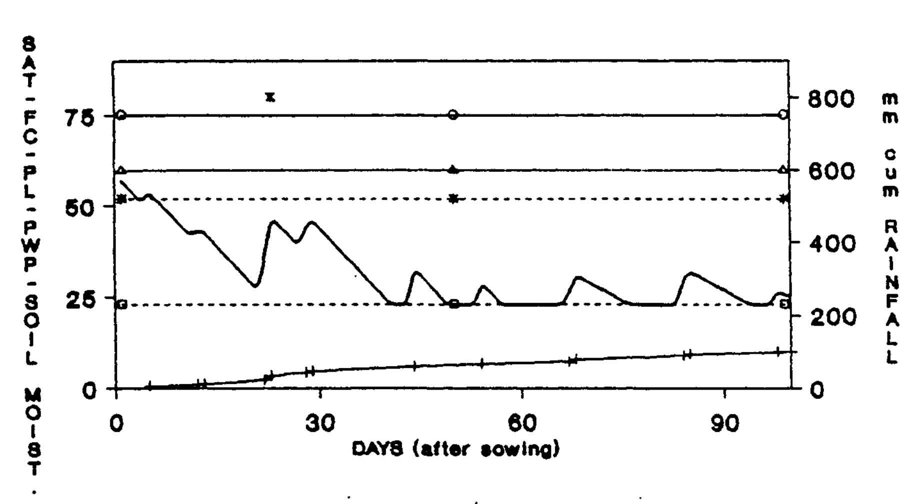
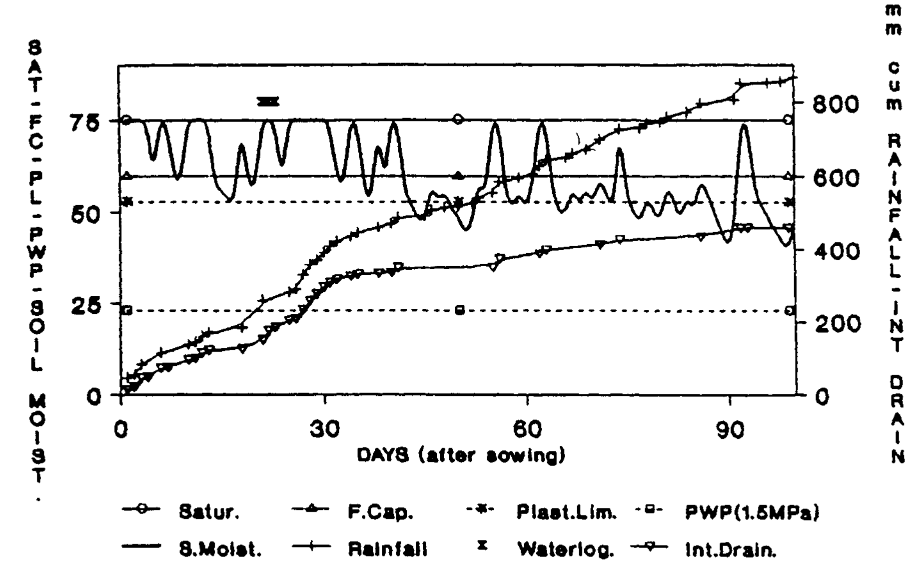


Fig.3c.- Soil Moisture Regime (CAMBISOL)
Maize growing period / 15cm Root Depth
Flat/Cover/No Drain(Aver.Rain;RP:2Years)



deficits for any of the two crops(Fig. 2a, 2b), if there is no restriction for root growth. The simulation gives an approximation of the expected volume of water to be drained, required for the design and preview of costs of the drainage system. During the growing period of corn, in figures 2 and 3 there is shown when the soil moisture would be above the plastic limit, as an indicator of conditions not favorable for tillage operations and traffic. This is an example of other possible uses of the simulated prediction of soil moisture regime.

Figure 3a shows that when the effective rooting depth is reduced to 15 cm in bare soil and with average rainfall, we may expect both waterlogging and soil moisture excess from the beginning of the rainy season, and at intervals during the whole period, but specially from the 10-40 days after planting. Although no moisture deficits are probable in the rainy season crop, they may be extreme in the sesame crop, specially after the first 40 days of the growing period. The drainage of excess water (Fig. 1) would solve the problems of waterlogging and excess soil moisture, but would create some water deficits at the end (85-90 days after planting) of the growing period of corn (or earlier if the planting was delayed by unexpected early storms, or other reasons), and will maintain the extreme water deficits for sesame after the first 40 days of its growing period. The use of mulch cover and no tillage, both without (60 cm)(Fig. 2c) or with (15 cm) restricted root growth (Fig. 3c), in a year with average rainfall (and of course if the year is more humid) will deteriorate the problems of excess soil moisture for the rainy season crop (corn) during the whole growing period, but specially during the first critical 45 days.

In this case, it may be concluded that the management efforts would have to be directed to find and apply practices to maintain or increase the effective rooting depth, to improve surface drainage, and to maintain or improve the structure stability (levels of organic matter) in the surface soil; and not so much to use cropping and tillage systems that maintain a residue mulch cover in the soil surface, which may cause severe problems (poor aeration, weeds, diseases, etc.) derived of long periods of excess soil moisture in the soil, and the development of shallow hanging water tables.

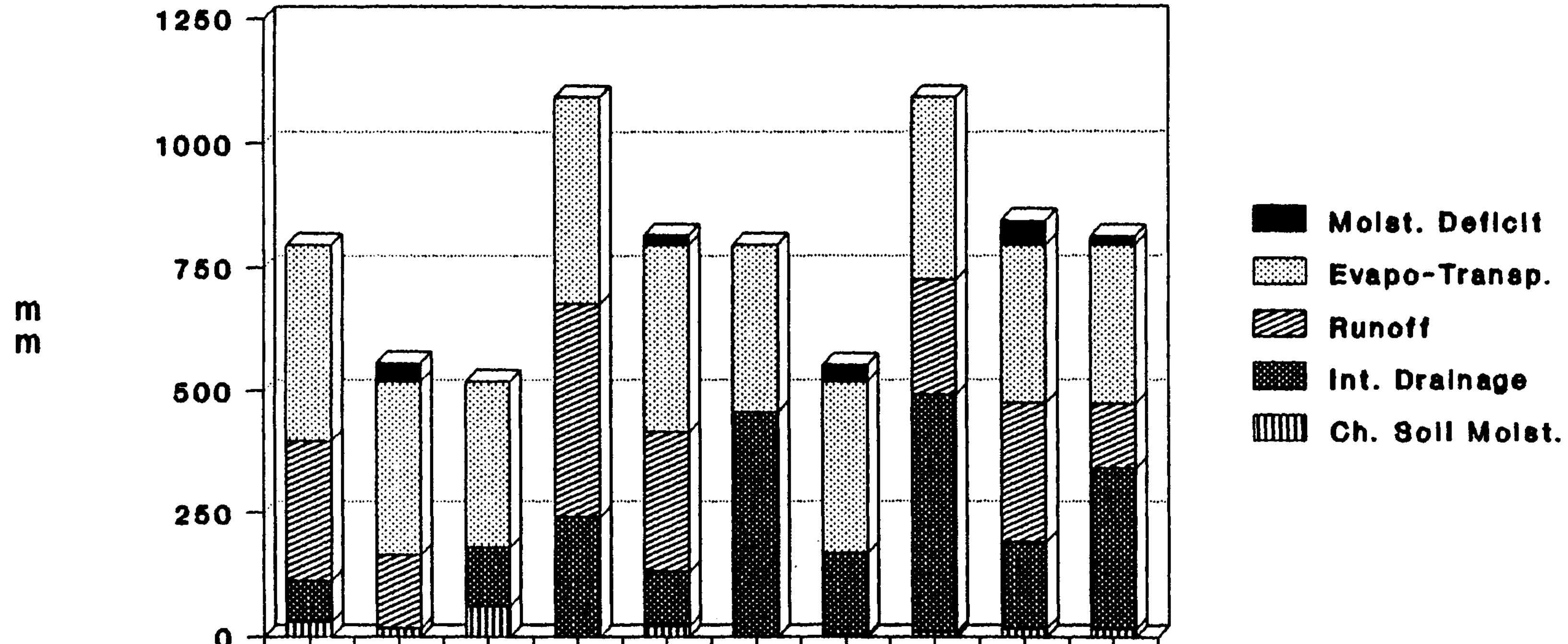
<u>2nd example (Fig. 4-5)</u>

The soil is a sandy loam LIXISOL (US Soil Taxonomy: Alfisol) from the Central Plains of Venezuela. The climate is tropical moist semiarid, with strong seasonal distribution and high variability of rainfall from one year to another, and in the same year. Cropping is reduced to rainfed sorghum (Sorghum bicolor), with a length of growing period (LGP) of 90-110 days, and corn (Zea mays) with a LGP of 80-100 days. The plant residues are used as forage for cattle in the dry season. The main constraints for a high and sustained productivity have been identified as soil moisture deficits and surface soil water erosion. Sealing effect on bare soils appear to be the main cause of concentrated runoff during intense storms, causing water and soil losses. The root growth is limited by the presence of an argic B horizon at 20-40 cm depth, which gets closer to the soil surface (10 cm or less) due to the accelerated erosion when they are cultivated. Shallow (10-15 cm) clean tillage, using mostly disc harrow, also contribute to the shallow root growth.

Fig.4.- Water Balance(Sand-Loam LIXISOL)

Sorghum grow. period/10-40cm Root Depth

B=Bare;C=Cover/Rain:H=High;A=Aver.;L=Low



	40cm B A	40cm B L	40cm C L	20cm B H	20cm B A	20cm C A	20cm C L	10cm C H	10cm B A	10cm C A
Moist. Deficit	0	38	0	0	19	0	34	0	49	17
Evapo-Transp.	399	355	340	416	381	340	352	367	321	323
Runoff	285	147	0	436	285	0	0	233	285	133
Int. Drainage	82	0	118	240	109	454	162	482	174	324
Ch. Soil Moist.	30	17	61	0	21	2	5	10	16	16

Fig.5a.- Soil Moisture Regime (LIXISOL)
Sorghum growing period / 20cm Root Depth
6% Slope/Bare (High Rain. RP:10 Years)

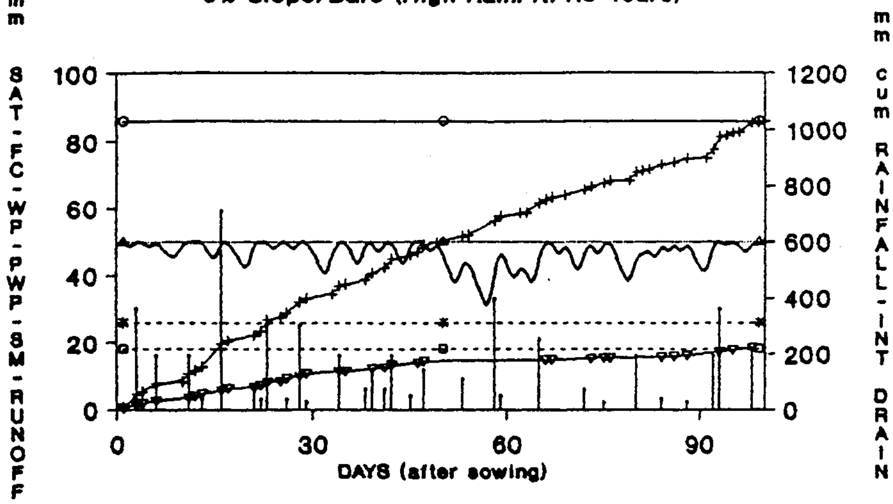


Fig.5b.- Soil Moisture Regime (LIXISOL)
Sorghum growing period / 20cm Root Depth
6% Slope/Bare (Average Rain; RP:2 years)

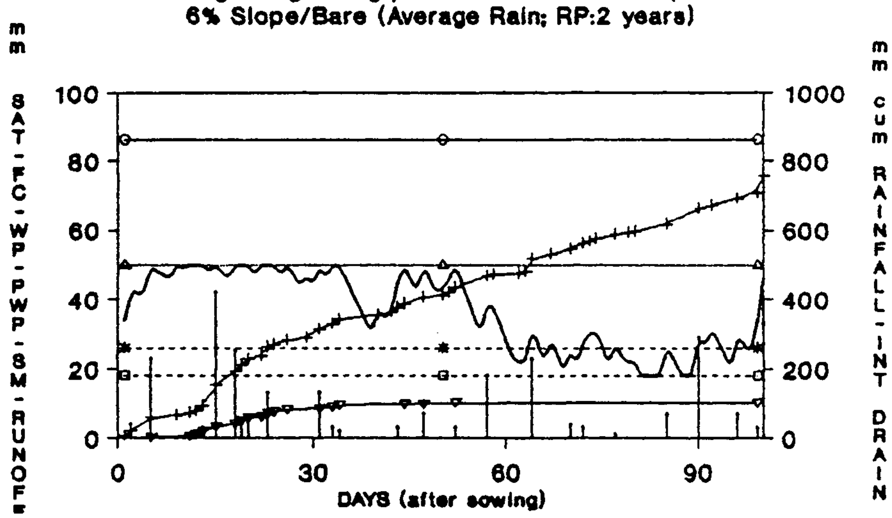


Fig.5c.- Soil Moisture Regime (LIXISOL)
Sorghum growing period / 20cm Root Depth
6% Slope/Cover (Average Rain;RP:2 Years)

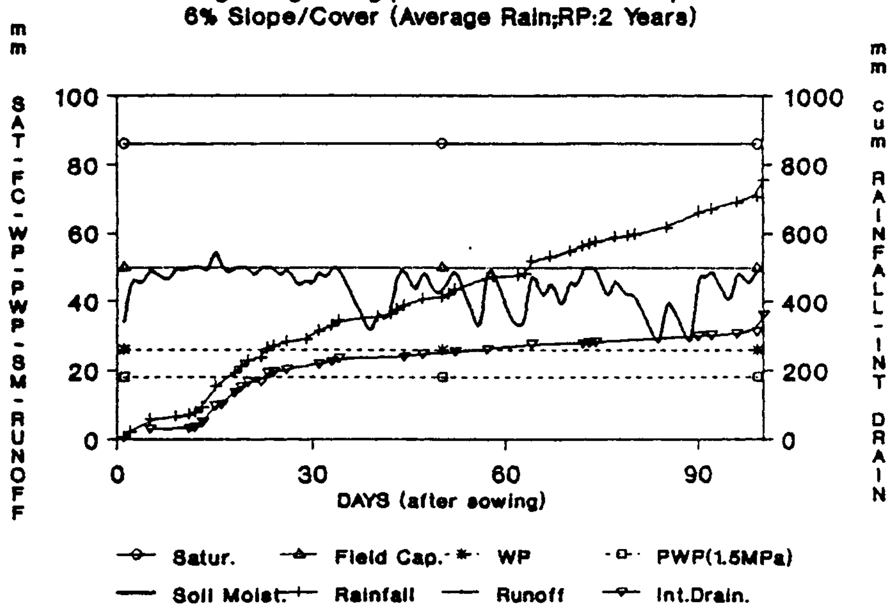


Fig.6a.- Soil Moisture Regime (ANDOSOL)
Rainy Season/No Comp. Layer 40cm Depth
30% Slope (High Rain; RP:10 Years)

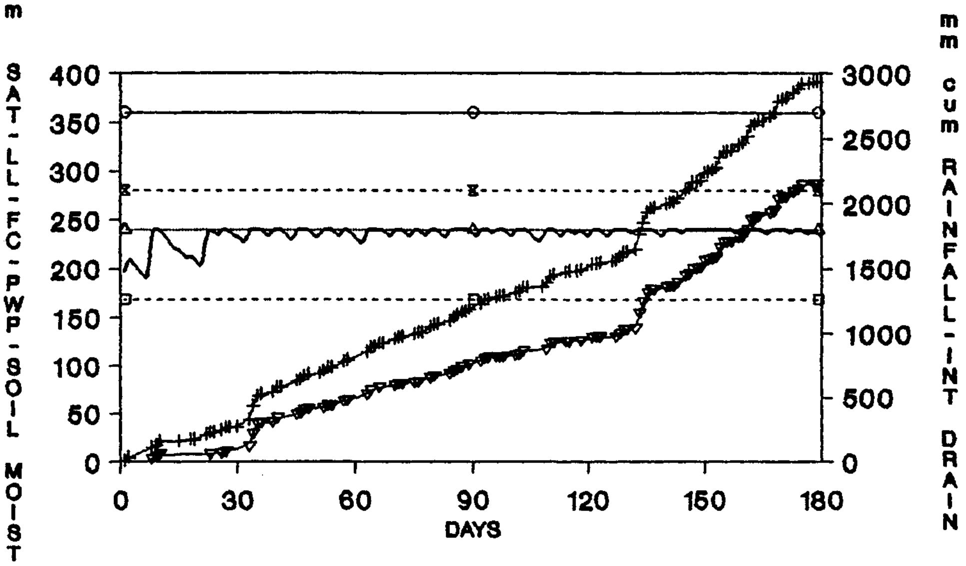


Fig.6b.- Soil Moisture Regime (ANDOSOL)
Rainy Season / Compact. Layer 20cm Depth
30% Slope (Average Rain; RP:2 Years)

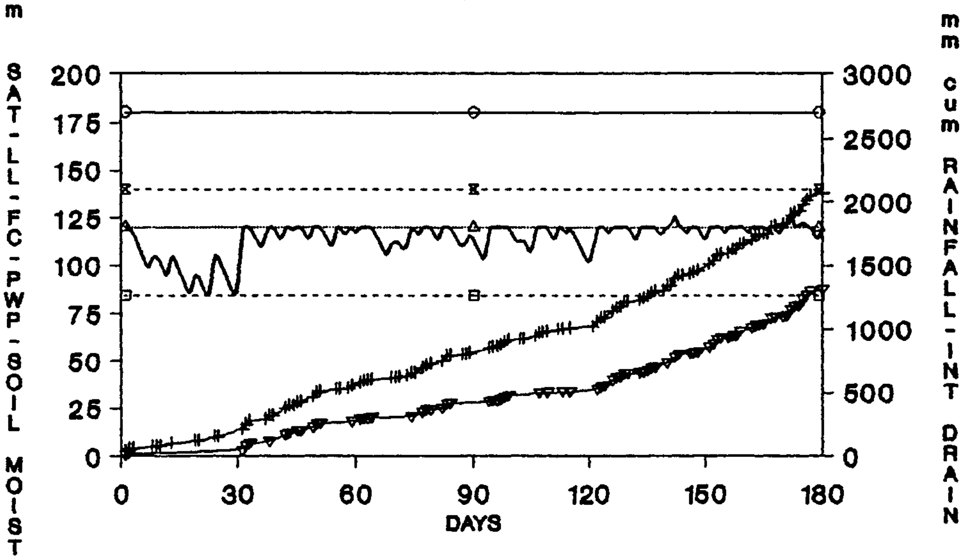
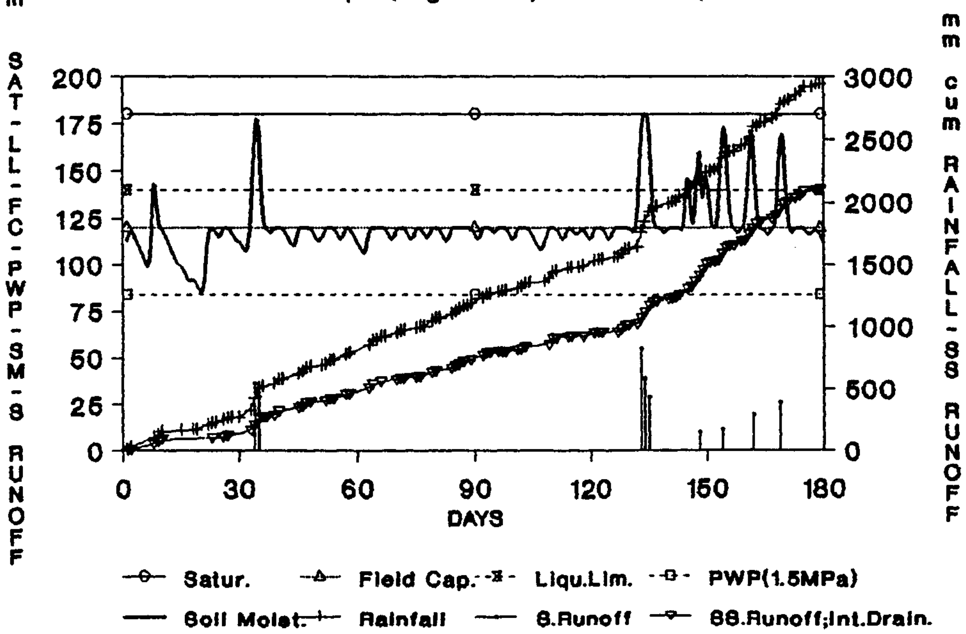


Fig.6c.- Soil Moisture Regime (ANDOSOL)
Rainy Season / Compact. Layer 20cm Depth
30% Slope (High Rain.; RP:10 Years)



The soil in the selected site has a 6% slope, and a minimum infiltration rate of 80 mm/hour, which under raindrop impact decreases (sealing effect) to 8mm/hour. The average saturated hydraulic conductivity (Ksat) of the argic B horizon is close to 2 mm/hour. Average rainfall intensity of the main storms is generally higher than 60 mm/hour. In the calculation of the water balance components and of the soil moisture regime, during the growing period of grain sorghum, there were simulated the conditions of: 1) bare soil (sealing effect) and mulch covered soil (no sealing effect); 2) rooting depths from 40 cm (maximum) to lower values (20 and 10 cm) reached due to shallow tillage and soil erosion; 3) rainy seasons of years with annual rainfall close to average (return period-RP of two years), exceptionally high (RP of ten years) and exceptionally low (RP of ten years). Figure 4 shows the resulting water balance for various simulated combinations of different climate, soil and management factors. It is clearly observed, how the sealing effect (bare soils) increases the problems of runoff (and of potential erosion) specially as rainfall increases; and of the problems of water deficits, specially in drier years and with shallower root growth. Shallower root growth and soil cover increase water losses by internal drainage (percolation below the root depth), and increases the possibilities of subsurface runoff. Although high rainfall and/or high root depth prevent moisture deficits during the growing period of sorghum in bare soil, the high runoff and high erosion hazard will make that situation non sustainable, as it is observed in practice.

Figure 5a-5b show the daily moisture regime in a bare tilled soil, during the growing period of sorghum, under two climatic conditions (high and average rainfall) and 20 cm rooting depth. It may be seen how the deeper rooting depth (Fig.4), and the higher rainfall prevent water deficits. But the concentrated runoff, specially in the first 1/3 of the growing period (with scarce canopy cover), will probably cause accelerated soil erosion , and flooding and sedimentation in the lower areas of the landscape. Figure 5b show how under average rainfall, bare soil and shallow rooting depth, the runoff and potential soil erosion are more critical in the first 1/3 of the growing period, while water deficits are concentrated in the last 1/3, coinciding with the critical reproductive and grain formation period. From that we may expect a good vegetative growth, but reduced (with average rainfall) or no (with low rainfall) grain production. The plant population may be also reduced by seedling losses with the concentrated runoff and erosion at that stage. Figure 5c show how the soil moisture regime is affected by soil cover, preventing runoff (and erosion), and water deficit, even with relatively shallow (20 cm) rooting depth and average rainfall.

In this case, it may be concluded that the marked sealing effect is clearly the main cause of concentrated runoff (30-50 % of the total rainfall in the rainy season), erosion and moisture deficits, in bare soil with moderate slopes. Under those conditions, effective rooting depths below 30-40 cm may be critical for rainfed grain sorghum (and corn) production most of the years, with average or low rainfall. Vegetative growth (and production of forage) would not be affected at the same level. Therefore, land management practices will have to be addressed to reduce runoff maintaining the soil surface protected (mulch of crop residues or cover crop), mainly during the first 1/3 of the rainy season and of the growing period of sorghum; and if necessary to control runoff with conservation practices like strip cropping, mixed cropping, ridges, terracing etc. This would have to be complemented with tillage practices (deep plowing, chiseling) to favor deeper root development. The selection or test of the different alternatives would depend on the probabilities of risks of crop (grain or forage) production, or of soil erosion, or on the effects of the water balance on the hydrology of the watershed, for each combination of factors.

3rd example (Fig. 6)

The soil is an ANDOSOL, with very steep slopes (30-50%), developed on young volcanic ash, located in Costa Rica, in an area under tropical humid climate. The land has been mainly used for pastures or permanent crops like coffee, but in the last decades it has been increasingly used for intense, seasonal or annual mechanized crops, like potatoes. Under these new management conditions, and due to the tillage operations in humid soil, there are developed compacted layers at 15-20 cm depth, where there is a drastic reduction in the Ksat. The main problem identified in the field is the concentrated and many times catastrophic erosion, mainly through landslides and mass movements, in years and periods with concentrated rainfall events. The selected site for the simulation has a surface soil with microaggregates very stable to wetting and raindrop impact, without any sealing effects and with minimum infiltration rates higher than 100 mm/hour. At 20 cm depth there is a compacted layer with Ksat of about 2 mm/hour.

In a year with exceptionally high rainfall, but without a layer restricting internal drainage in the soil profile (Fig. 6a), or in a year with average rainfall and a compacted layer at 20 cm depth (Fig. 6b), we may not expect conditions (soil moisture above liquid limit, and concentrated subsurface runoff) favorable for landslides or mass movements. The combination of a year with high rainfall (RP of 10 years) and the presence of a compacted layer at 20 cm restricting internal drainage (Fig. 6c), create conditions in the periods 30-40, and 135-170 days, which may lead to accelerated erosion through landslides and mass movements (Pla, 1992b). In these soils, the very high water content at liquid limit and saturation (Pinzón, 1993), and the viscous fluid consistence of the surface soil (with stable and light small aggregates) at soil moisture higher than liquid limit, are factors which make them very susceptible to landslides.

In this case, it may be concluded that the problem of erosion or runoff has nothing to do with surface sealing effects, but it is mainly caused by the combination of high surface infiltration rates, restricted drainage at shallow depth, loss of the anchorage effect of roots of permanent vegetation or crops, and concentration of rainfall events. Due to the very unstable nature of these soils when they are very wet, it will be very difficult to prevent soil erosion in years with high concentrated rainfall, when the anchorage effect and water consumption of permanent vegetation or perennial crops has been lost. Therefore, the management systems must have as the first choice, the use of those soils under subhumid or humid climates for permanent pastures or perennial crops. Additional practices, specially if the land has to be used for annual mechanized crops, must include prevention or elimination of shallow layers restricting internal drainage, and construction of terraces with drainage ditches across the slope, to intercept and discharge subsurface (and surface) runoff, at intervals and with capacities depending on the slope, and on the amount and probabilities of

Fig.6a.- Soil Moisture Regime (ANDOSOL)
Rainy Season/No Comp. Layer 40cm Depth
30% Slope (High Rain; RP:10 Years)

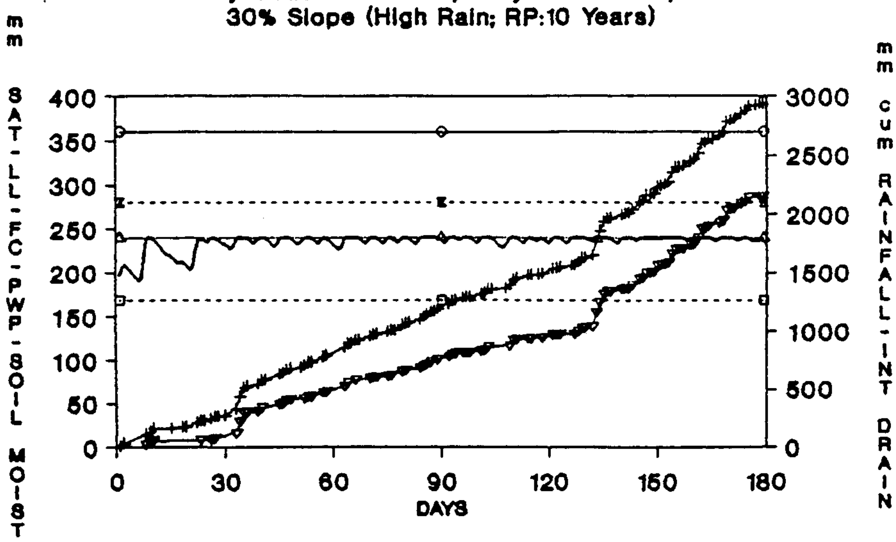


Fig.6b.- Soil Moisture Regime (ANDOSOL)
Rainy Season / Compact. Layer 20cm Depth
30% Slope (Average Rain; RP:2 Years)

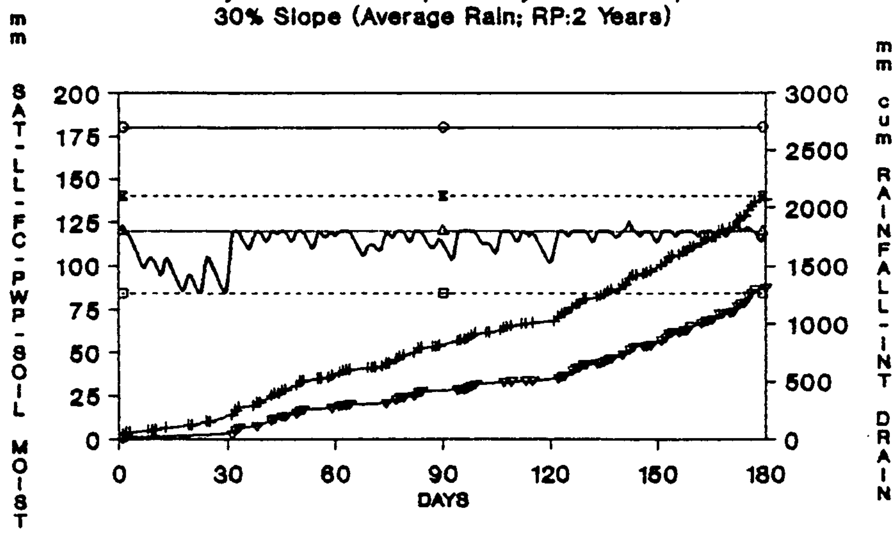
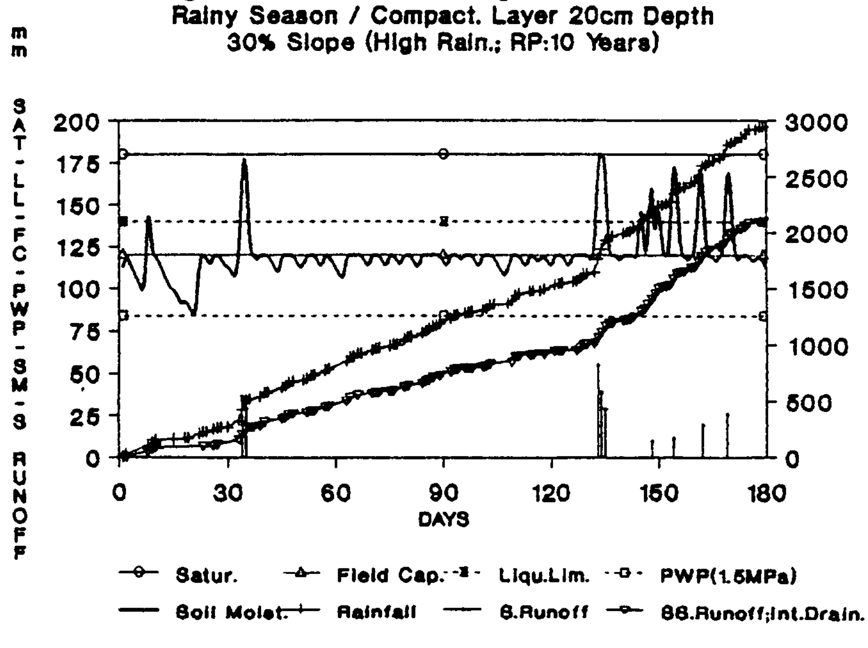


Fig.6c.- Soil Moisture Regime (ANDOSOL)
Rainy Season / Compact. Layer 20cm Depth
30% Slope (High Rain.; RP:10 Years)



subsurface (and surface) runoff. This information may be obtained trough the simulation of the water balance and soil moisture regime with the model "SOMORE".

Besides the examples presented here, there may be many other applications based on the interpretation of the simulated water balances and soil moisture regimes, including the best choice of different crops or varieties, and cropping periods or sequences, and the determination of requirements and the best periods for complementary irrigation, tillage operations, fertilization, application of pesticides, etc., for more effectivity and lower possibilities of pollution of surface or underground waters. The examples also show how the consideration of the very common and different surface sealing effects, and limitations to root growth and internal drainage by shallow profile layers, may change substantially the effective length of the growing period. There is also shown how important may be the identification of the most probable periods of extreme (excess or deficit) soil moisture levels in relation to the growing period and growing stage (vegetative, reproductive, yield formation) of the different actual and potential crops and varieties, in order to guide the best alternatives of cropping and management practices.

GENERAL CONCLUSIONS

The model "SOMORE" allows to determine water storage at root depth, runoff, waterlogging, drainage, and water deficits (and irrigation requirements) on a daily, monthly, yearly, and growing period basis. These estimates of the soil water regime, could be very useful: 1) to diagnose the main factors responsible for the present and future soil water limitations, and the amount and timing of water stress strongly affecting crop yields; 2) to preview the effects of different soil and water management practices in order to select the most appropriate ones for each case. The correspondence found between the measured and predicted soil water regimes for critical periods of the same growing season (Pla, 1988b, 1992a) show that it is possible to get fairly good estimates when the correct assumptions are made, particularly with respect to infiltrability (sealing effect), runoff, surface drainage, and deep percolation of rainfall water, and about the effective available soil water storage capacity.

The relative importance of management and environmental constraints is quantified by the model "SOMORE". This allows to select the long term practices best adapted to the local environment. The model also enables to quantify the weather and soil related variability effects on crops, and to explore ways of matching crops and cropping systems and land management with environment. It also provides information about when and what are the needs of supplemental irrigation water, about the most suitable time to conduct primary tillage, about possibilities of groundwater pollution by pesticides, fertilizers, etc. The prediction of concentration of surface and subsurface runoff, and of the conditions of soil moisture, permits to preview which days, weeks, months or years have the greatest flooding, erosion and sedimentation's hazard, and what would be the most probable process (surface or mass movements) of erosion (Pla, 1992b, 1993). This is more useful for designing erosion control strategies than the use of empirical models like USLE, which have proved not to be able to predict the time and probabilities of occurrence of concentrated runoff and erosion, and much less of landslides and mass movements (Pla, 1996). The aim of soil and water management is not always to increase infiltration, depending on the climate, soil, crop and possibilities of increasing levels of groundwater, groundwater recharge, and use or collection of runoff for other uses. In those cases the model "SOMORE" also gives an insight to these different possibilities.

With the "SOMORE" model, many simulated experiments can be conducted to show which alternatives of soil management, crops and cropping sequences and systems. This will help to save many resources, increasing the efficiency and probabilities of success of field experiments. The use of the model may substitute most of the costly trial and error approach to test cropping and management systems, to find the most acceptable balance between productivity and variability (risk). It may be concluded that "SOMORE" is a management model, because its main purpose is to study the effect of management decisions on soil water balances and soil moisture regime in relation to degradation processes and crops; but it may be also used for research, to test hypotheses in relation to the hydrological processes described and simulated by the same model. When used in combination with physical experiments and field scale evaluation and demonstration, this model may be a valuable tool for developing more profitable and sustainable cropping systems.

ABSTRACT

Soil degradation processes have direct effects on crop production, and off-site effects on increased risks of catastrophic floods, sedimentation, landslides, etc., and on global climatic changes. The control of soil degradation and derived effect, will depend on an appropriate use and management planning. A prerequisite is an adequate identification and evaluation of the degradation processes, and of the relations cause-effects of the different problems. Relationships among soil physical characteristics and soil hydrological properties are the starting point to simulate or to predict dynamic soil processes, including water supply, erosion hazard, etc. With the use of physically process-based models it is possible to integrate the large number of important variables and their complex interactions to deduce probabilities and risks of soil degradation. The use of the model "SOMORE", developed with the purpose of predicting soil hydrological processes under different combinations of soils, climate, crops and management is demonstrated. The required inputs of the model are generally available, or easily measured, information about climate, soils and crops. The predictions may be used for selection, with a probabilistic approach, of the best alternatives of soil and water conservation practices and systems for each set of conditions. Application of this approach to several agroecological regions of tropical Latin America, with actual or potential problems of soil degradation, are presented. The results of the different simulations demonstrates the great and decisive influence of surface sealing and limited root growth or limited internal drainage, on the water balance and soil moisture regime for a particular climate. The close agreement between the model results and field evidence or experimental results, indicates that reliable estimates of soil water balance and soil moisture regimes can be obtained using "SOMORE". This model has proved to be more precise, useful, and of

practical value, adapted to the real agronomic conditions, than the commonly used climatic water balances, based on relations between the rainfall and the potential evapotranspiration, without taking into consideration the influence of the particular hydrological and mechanical soil properties, specially of surface sealing and shallow compacted layers, influencing infiltration, runoff, internal drainage, and root growth (effective soil depth).

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