Application Of Rainfall Analysis, Biophysical Modeling And Gis To Agroclimatic Decision Support In Madiama Commune, Mali (West Africa) [1]

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ABSTRACT

An analysis and understanding of the intimate relationships between the weather, soils and agricultural production systems, and especially the complexities associated with the variability and distribution of rainfall and soil type are essential elements in improving crop production and agricultural planning decision making. In the present paper, knowledge from the analysis of historical rainfall records and predictive information based on the "response farming" approach have been combined with GIS and biophysical simulation modeling of soil water balance and crop production functions to assess the agroclimatic performances of a 90-day millet cultivars in Madiama, Mali. For each of two groups of rainfall onset date (early and late), the crop water stress, crop yields as well as overall stress indices in reference to yield potential permitted by different soils under low and optimum nitrogen input levels have been simulated, analyzed and mapped to illustrate how this approach could work for advisors and farmers in the study region. From the analysis of the rainfall records good relationships are found between rain onset dates and seasonal rain amounts and duration. Also, the Cropping System Simulation Model (CropSyst) used in combination with the weather analysis is found to be a useful tool in aiding determine soil suitability of crops, screen technologies and build recommendations packages for a response farming type approach.

INTRODUCTION

The commune of Madiama, which is the study area, is about 25 kilometers from Djenné (capital of the administrative Circle) and 120 kilometers southernmost of Mopti (capital of the 5th Region of Mali). It lies between 13° 45 N to 13° 52 N, and 4° 22 W to 4° 30 W. It is part of the Niger Delta region and located in the north-central part of the republic of Mali. The commune that comprises 11 villages has a total land area of 16970 hectares (169.7 square kilometers), or about 66 square miles. Madiama region is characterized by a short rainy season (3 to 4 months), considerable variability in the rainfall amount and distribution, with high radiation loads and temperatures during the growing season which influence annual crops and pastures potential because of the continuous and high evaporative demand from the atmosphere. Like in other areas of the West African semi-arid Sahel region, the study zone has suffered diminished food production on a per capita basis since the early 1970's.

Although exacerbated by population growth, the fundamental problem is physical. Long-term

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rainfall throughout the region declined dramatically in the early 1970's and has not since returned to earlier levels. Seasonal rainfall regimes are inherently variable and uncertain, and our science has not been able to effectively cope with it.

The need for a secure food supply must be carefully considered when evaluating sustainable agricultural practices for the region. Farmers in the region are more concerned with the avoidance of disaster years than aiming solely at higher yields. They view each year as different and unique. They consider rainfall as the principal factor determining crop production. Low yields are often related to late start of rains, a drought period after planting or too much rain in late July and early August, impeding grain development. In good rainfall years, production levels are sufficient regardless of land quality where crops can be grown. Consequently, one of the key impediments that limit productivity and food security for rainfed agriculture is seasonal variability and uncertainty of rainfall. Both deficit and excessive rainfall can create serious management problems for rainfed farmers, as there are important differences in the production potential in wetter years versus drier years. Therefore, a better understanding and early predictability of the rainfall potential for a given season could be an important step in designing appropriate strategies for improved food production in the west African Sahel region. There is a pressing need to identify and promote dry land agriculture practices that better utilize the available rainfall.

In this uncertain environment where annual crops' performances vary greatly from season to season, subsistence farmers have traditionally responded by applying some management decisions to conform with projected rainfall – but with some limited success. Many farmers plant dry, mix varieties and follow varying management strategies to minimize risks. Still, in years of scarce rainfall the precarious balance between subsistence and survival is broken and very often hunger and starvation are the main corollaries. Efforts by agricultural scientists and farmers to determine optimal farming technologies and cropping systems are greatly complicated by the complex nature of the combination of seasonal rainfall variability, crop cultivars, management practices and soil types. Efficient methods that introduce flexibility in the cropping system to more closely match variation in seasonal rainfall with feasible technologies most likely to approach optimal resource and management combinations for given soils are needed in order to contribute to a more secure and reliable food supply.

Previous analyses of the historical daily rainfall data for location in Niger, Burkina Faso, Kenya (Sivakumar, 1988, 1990, Ian Stewart, 1988) suggest that prediction of the rainy season potential in order to tailor optimal cropping systems during the growing season may be possible. It was also suggested that application of this information could be further improved by integration of this analysis with soils and crops information and the use of cropping simulation models. Cropping systems simulation models can play a strategic role in evaluating existing and alternative farming systems in high-risk rainfall variability prone dry land agriculture. Today, we possess the needed historical records (e.g. rainfall), research tools and computing power to sort through the complexities and give farmers the information they need to greatly increase their yields and returns per unit of rainfall received.

We can introduce new technologies suitable to biophysical conditions (weather, soils, crops) that may strongly affect the risk structure. Assessment of soils, weather and management schemes using computerized tools such as simulation models and GIS could help in screening suitable technologies dependent on weather regime and soil types. This in turn may call for changes in recommended practices and decision-making processes. Furthermore, when our recommendations are finalized, we can utilize our computerized datasets (displayed for example as maps) to inform the farmers – on a localized basis, and clear terms than do their tradition – of the real risk structure they are facing and the possible technological responses based on the weather patterns and rainfall onset date of a given season.

In the present work, knowledge from the analysis of historical rainfall records and predictive information based on the "response farming" approach (Ian Stewart, 1988) have been combined with GIS and biophysical simulation modeling of soil water balance and crop production functions to assess the agroclimatic performances of some millet cultivars in Madiama. For each of two groups of rainfall onset date (early and late), the simulated crop yields, crop water stress, as well as overall stress indices in reference to yield potential permitted by different soils under low and optimum nitrogen input levels have been computed and mapped.

The overall purpose of this study is to show the potential for long-tern and short-term rainfall probability analysis on the basis of onset dates, and the applicability of simulation modeling to agroclimatic analysis and the choice of technologies for tactical response farming in Madiama area. The useful biophysical information generated from these analyses could guide the choice of optimum cropping systems and is simple to transmit to both advisers and farmers. This screening methodology used in the present study aims at reducing the cost and time required to develop and choose farming systems technologies to be included in a tactical response farming during the growing season. Our contribution, which is a work in progress, seeks to minimize risks of cropping failure as much as possible by using predictive capabilities based on dates of onset of rains and generating information that could help in tailoring appropriate recommendations for a given cropping season.

METHODOLOGIES

1. Long-term and seasonal analyses and characterization of Rainfall

a. *Database*

Historic daily weather data (solar radiation, rainfall, air temperature) from 1950 to 1999 for Mopti, Djenné, Sofara were obtained from the Meteorogical Service of the government of Mali. An automatic weather station with data logger was installed by SANREM in Madiama since June1999. The station allows the recording of daily and hourly data on rainfall amount and intensity, air and soil temperatures, solar radiation, wind speed and relative humidity. Individual rain gauges are also installed in each of the other 10 villages of the commune. These compiled weather data were used for the rainfall analyses and the simulation modeling.

b. *Long-term Analysis*

To understand and characterize the long-term agro-climatic conditions in Madiama, the general trend of historical rainfall amounts from 1950 to 2000 has been determined and plotted. To take into account the change in rainfall patterns since the droughts of the 1970's in the Sahel region, the period 1950 to 2000 was divided into 1950-69 and 1970-00, and annual averages were computed for the two periods. Then the most recent records from 1970 to 2000 were retained as most representative actual weather conditions in the study area. Using the last 31 years of records from 1970 to 2000, long-term rainfall amounts and variability are described and assessed through the analysis of annual and , monthly totals. Also, a dekadal (every ten-day) reliability analysis was done from the daily rainfall and confidence limits (median, lower and upper quartiles) statistics plotted to represent trends throughout the year. An estimate of potential evapotranspiration (PET), computed from the model CropSyst, was superimposed on the ten-day graph, which allows an examination of periods of adequate rainfall and risk periods.

c. *Seasonal Rainfall Predictions and Reliability Analysis*

In order to determine agroclimatic indicators that would help foster decision that would guide the choice of management practices in response to seasonal rainfall variability the "response farming" approach which is to predict and respond has been evaluated (Stewart, 1987). Linear relationships between date of onset of rains to length of growing season and total rainfall amounts have been evaluated and two groups of onset dates identified. To investigate the onset relationships for each season, the records from 1970 to 2000 was analyzed, to quantify possible ranges of rainfall behavior and probabilities within ranges. The analysis consists of 3 parameters computed from the daily rainfall data in each year of the 31-year record from 1970 to 2000:

- The dates of onset and end of rains – the date of onset is considered as the first day after June 1st when stored soil water equals at least 40 mm (Stewart, 1987) and/or when rainfall accumulated over 3 consecutive days is at least 20 mm and when no dry spell within the next 30 days exceed 7 days. The final date of rains is considered as that date after September 1 following with no rain occurring over a period of 20 days (Sivakumar, 1988).

- The length (duration) of the rainy season for each year – this duration is taken as the number of days from the date of onset to the final rain date.

- The seasonal total amount of rains at different phases and all year long is the total rainfall from onset to end of rains.

An early and late onset dates were determined by considering the median date of onset from the 31-year rainfall record. Dates before the median date were considered early and those after the median were considered late onset dates.

2. Simulation Modeling and Agroclimatic Assessment

The cropping systems simulation model CropSyst was used in the present study. CropSyst is a multi-year, multi-crop, daily time-step simulation model developed to serve as an analytical tool for investigating the effect of cropping systems management on crop productivity in relation to environmental patterns such as soils and weather. The model integrates several components and different management options, and simulates the soil water budget, soil-plant nitrogen budget, dry matter production, yield, etc. Details on management options and model components can be found in the model's user's manual (Stöckle and Nelson, 1993) and elsewhere (Stöckle et al., 1994, Badini et al., 1997).

Although many other biophysical parameters could be included to evaluate the suitability of crops in a given environment, in the present work the model was used to only assess the water-limited growth environment of a 90-day millet cultivars and the impacts of nitrogen fertilization in years of early and late onset of rains. The components of CropSyst used are: the soil water balance and the crop growth models.

a. Database

To be able to run CropSyst, input data describing the location, weather, soils, crops and management from the study site were used.

Location and weather database – parameters characterizing the site of interest are name (Madiama), latitude, longitude, elevation and daily rainfall as well as minimum and maximum temperatures. Actual weather data from 1970 to 2000 were used.

- Soil database – using data provided by the Soil Survey of Madiama Commune (O.

Badini and L. Dioni, 2001) and seasonal monitoring data from the site, a soil parameter file was constructed for each of the 7 land units identified in the commune. These units are: hydromorphic flood plains (*unit Ci*), hydromorphic alluvial levees or sand banks (*unit Tr*), old levees and alluvial terraces (*unit t1*), old alluvial plains and terraces (*unit Ca*), the plains of sandy to loamy materials (*unit t2*) and land underlain by laterite (*unit Vi*). Chemical tests data as well as soil physical data on texture, bulk density, field capacity and permanent wilting point (PWP) water content for each unit were provided.

- Crop database – from our existing database, a 90-day millet cultivar called *Sagnori* in local language was used. Calibration for the millet cultivars was performed using field data collected in Madiama on phenological events (emergence, flowering and maturity dates), maximum rooting depth, maximum Leaf Area Index (LAI) yield and harvest index data.

- Management database – two fertilization levels were used - no nitrogen (0 N) to represent traditional low input system and optimum nitrogen (N) to represent improved systems. A millet monoculture was simulated with a 10% surface residue and a simple ridging system with soil conservation practice factor P set to 0.9.

b. Simulation and output analysis

After calibration of the crop cultivars, the databases for soils, weather, crops and management have been combined through a simulation rotation table in CropSyst to simulate soil water balance and crop yield potential in years of early and late rain onset dates as a function of soil types and nitrogen (N) input levels. The outputs of the soil water budget and the crop production functions obtained from the simulation were used either singly or in combination to compute agroclimatic indices that helped determine the development and the water-limited growth environment of the millet cultivars *Sagnori.* The biophysical decision indicators used are:

- The crop water stress index, which is the ratio between actual transpiration (Ta) and maximum (potential) transpiration (Tmax) during the crop growth cycle. This quantity is used as indicator of the plant response to environmental conditions. The values range from 0 to 1. Where 0 is no stress and 1 is maximum stress. Under very limited water conditions or high crop water demand, the deficit can be so severe as to cause crop failure as thus the ratio becomes close to1.

- The crop yields and overall stress index in reference to yield potential permitted by different soils under low and optimum nitrogen input levels have been computed. In the present study, the overall stress index (OSI) corresponds to (1- ratio of actual yield to maximum yield). OSI integrates light, temperature, water and nitrogen stress indices. A value of 0 is no stress and 1 is maximum stress. This index is indicator of the riskiness of growing a given crop in a given environment and can help in the choice of technologies and crops in relation to onset dates.

RESULTS & DISCUSSIONS

1. Rainfall long-term and seasonal analyses and characterization

1.1. Long-term Rainfall Patterns

a) Rainfall Amounts and Distribution

In areas such as the study region where pronounced seasonal patterns of rainfall are influenced by changes in solar energy and pressure patterns (Sivakumar et al., 1984), mean annual rainfall could help provide useful assessment of agricultural potential. The annual rainfalls, the long-term mean and the general rainfall trend in the area of Madiama in the period from 1950 to 2000 are plotted in Figure 1. The annual rainfall in the commune and surrounding area varies considerably from year to year, a very common characteristic in the semi-arid tropics. From 1950 to 2000, the mean annual rainfall is 544 mm. The lowest annual rainfall of 274 mm was recorded in 1987 while the highest annual rainfall in the past 51 years was 914 mm, received in 1957.

Figure 1 shows that years of above average and below-average rainfall tend to come in clusters as seen throughout the Sahel. With an average of 636 mm, the annual rainfalls during 1950-69 were consistently above the long-term average of 544 mm with percentage deviation from the mean only around 10%. The average rainfall for the last 31 years starting around 1970 was about 482 mm. In about 70% of these years, annual rainfall was below the 51-year average of 544 mm with percentage deviation from the mean reaching 50% in some cases (e.g. 1987) (Figure 2). The average rainfall loss between the two periods is around 154 mm. A trend of declining rainfall over the last three decades is therefore evident (Figures 1 & 2). These data show that analysis based on the records of the most recent 30 years is more reliable for characterizing the current rainfall patterns of the study zone (O. Badini, 2001). Therefore, we will use the period (1970-2000) for the assessment of agro-climate in the study site and possibly elsewhere in the region.

b) Long-term Rainfall Variability and Probability Analysis

As shown in the previous section, limiting water availability is one of the main constraints to rainfed crop production in Madiama and the region. But even more critical for agriculture than the actual amount of rainfall or change of seasons is rainfall variability. The mean annual rainfall patterns show a large standard deviation and a high coefficient of variation (CV). For the last 31 years, the mean annual rainfall of 482 mm has a Standard Deviation (variance) of 140 mm and a Coefficient of Variation (CV) of 29 per cent. Annual rainfall probabilities in years out of 10 are plotted in Figure 3. For example, there is a chance of obtaining 885 mm in the area in only 1 year out of 10. In 4 years out of 10, the area is likely to receive only 486 mm per year. In the probability analysis of the monthly rainfall data for the last 31 years in Djenné-Madiama area (Figure 4), rainfall in June can be expected to be at least 12 mm 9 years out of 10 and 83 mm only 1 year out of 10. Rainfall in May and October is unlikely 7 years out 10. This confirms the duration of the season to 3 or 4 months.

Dekadal (every 10-day period) rainfall reliability is plotted in Figure 5. When the median (2 out of 4 years or 50%) rainfall exceeds PET, crops will not suffer water stress. This corresponds for example, to the period from July 29 to September 1 in Madiama area. If the lower quartile (rainfall exceeded in 3 out of 4 years or 75%) falls below 0.5*PET, crops will probably suffer if they are at full leaf canopy or at a sensitive stage of growth. This corresponds to the period after the first decade of September for Madiama. Upper quartile (in 1 out of 4 years or 25%) values greatly in excess of 2*PET indicate the possibility of flooding in lowland sites, as well as water logging and accelerated soil erosion on upland sites. Fungal diseases or spoilage of ripening crops may also occur at times of excessive rainfall (Mutsaers and al., 1997).

c) Applications

Knowledge of long-term rainfall estimates in a given geographical region enables the development of suitable strategies for agricultural planning and implementation (Sivakumar et al., 1984). Agronomists and agricultural engineers to plan water management for crop production and design water collection and storage systems often use frequency analysis of rainfall records. The idea is that the past gives a clue about what to expect in the future.

1.2. Seasonal Rainfall Predictions to Guide Farm Decisions

Development of a region for agriculture, and of individual farms in a region, is in essence a one-time activity, which must consider all the long-term variability in climate such as presented above. However, producing a crop on a certain field in the current rainfall season raises a host of different considerations. More precise information about expected rainfall would be helpful to the farmer at the start of the season and in the early part of the season when basic decisions are being made about how to maximize production and returns per unit of rainfall in the approaching season. The potential for predictability of rainfall amounts and duration based on the rainfall onset dates of the coming season such as proposed by the "response farming" approach (Stewart, 1988) has been evaluated in the present study.

a) Analysis of Seasonal Rainfall Behavior

The rainfall amounts and duration relationships to onset dates have been evaluated in Madiama. The analysis of the last 31 years (1970-2000) of the rainfall records in the Madiama area shows that rainy period duration has a strong correlation (R Square = 0.68) with total rain (Figure 6). The same strong relationship (R Square of 0.76) is noticed between rain duration and date of onset (Figure 7). It is clear that the range of duration of rainfall as well as the expected rainfall amounts, both diminish with each day onset is delayed. Based on the median onset date of June 26, two groupings of onset dates have been identified in Figure 7. One representing "early onset" seasons (16 years) with onset dates before June 26, and the other "late onset" years (15 years) with onset dates after June 26.

Looking at the entire 31-year record (Table 1.1) there is a great range of variability. It shows that onset may occur as early as June 6 or as late as July 30, a span of 55 days. As well, rainfall amounts could vary from 274 mm to 801 mm and season duration may vary from 60 days to 140 days. This represents the advisors and farmer's dilemma when information is lacking as to the significance of the date of onset. It is impossible or near impossible to select crops and cultivars with optimal or near-optimal maturities with such a great range of uncertainty. However, if we divide the Madiama rainfall record on the basis of whether onset occurs by June 26 or after, major differences are revealed in all the season characteristics of interest to the farming community and meaningful recommendations that matter to the people can be implemented. Looking at Table 1.2, the 2 groupings differ in 2 essential features: First, we see that the median rainfall in early season is higher (529 mm), while that of late season is very low (432.5 mm). For the farmer this means emphasis on different crops, different input levels and many other possible measures. Also, we see that the median season duration is much longer (105 days) in early seasons and much shorter (74 days) in late seasons. This again calls for emphasis on different crops and cultivars with different maturity dates.

b) *Applications*

For the farmer, determining that a season at hand would be part of early or late onset years based on when the rain starts, means emphasis on different crops and different levels of inputs. It means different land preparation, different tillage practices or different plant populations. Traditional farmers in much of the Sahelian zone are aware of these relationships, but with the changing world they cannot keep pace with decreasing rainfall. Tradition and limited personal experience and memory are not match for long term weather records and use of computerized analyses such as allowed here. An example of the evaluation and use of such technology is given in the next section.

2. Simulation Modeling and Agroclimatic Assessment

Simulation modeling is evaluated here as a tool that can contribute to the generation of biophysical agroclimatic indicators of the suitability of crops and management technologies that could be used in a recommendation package for years of early or late onset dates of rainfall. The outputs from the soil water budget and crop production modeling were used either singly or in combination to compute the following biophysical indicators: (1) Crop Average Water Stress Index (AWSI); (2) Crop Yields and (3) Overall Stress Index (OSI). Relationships between these indicators and onset dates have been established to evaluate their potential in screening appropriate technologies. Also, These biophysical indicators have been mapped to visually show their spatial distribution and their classes as a function of soil types. Differences are most seen by looking at the maps' legends.

2.1. Crop Average Water Stress Index relationships to onset dates and crop yields

The Crop Water Stress Index (AWSI) was computed to allow better insights in terms of understanding the relationships between crop, weather and soil in the study zone. It is used as an indicator of the plant response to environmental conditions and could help in the choice of crops or soils best suitable to given conditions. Figures 8a and 8b show maps of water stress index throughout the commune. Overall values for water stress in the study zone ranged from 0.04 to 0.6 as a function of soil type and onset dates of rains. A value of 0 represents no stress (optimum growth condition for a crop in regard to water limitation) and a value of 1 represents very high stress level. As expected, early onset dates with higher amounts of rainfall have lower stress levels compared to late onset dates regardless of soil type and input levels (see maps' legends). Overall, AWSI increased with delay in rain onset and with increase in nitrogen level when plant requirement for water is higher.

2.2. Yields relationships to onset dates and nitrogen (N) inputs

Figures 9a and 9b show the yields relationships to onset date, N inputs and soil water limitations. Soils with higher water holding capacity such as Ci and Ca have higher yields levels regardless of input levels or date of rain onset. Shallow soils such as Vi (< 40 cm deep) have shown total crop failure (less than 100 kg/ha) regardless of input level or onset date. Overall, yields decreased with delayed rain onset regardless of input levels. But fertilization level is found to have a higher impact on yield increase in early onset years than in late onset years.

To better illustrate the importance of onset dates, probabilities of simulated millet yields categories were presented in Table 2. Considering the case of millet yield with no nitrogen input, overall odds are almost evenly split between a good crop (36%), a fair crop (27%) and a poor to failure crop (37%). The same observation is true even in case of fertilization. But a radical shift occurs between early and late onset seasons. Early seasons have a 56% probability of a good crop with only 19% chance of failure. With late seasons there is only 14% of chance of good crop against 57% chance of crop failure. These categories are only illustrative but the analysis made possible by the simulation modeling shows that less water demanding crops should be substituted in late seasons.

2.3. *Overall Stress Index (OSI) relationships to onset dates, nitrogen inputs and crop yields*

In the present work the OSI is considered as a biophysical indicator of crop yield potential permitted by different soils under low and optimum nitrogen input levels. It integrates most of the biophysical limitations in crop growth including light, temperature, water and nitrogen. A value of 0 indicates no stress and a value of 1 is maximum stress. The OSI allows one to determine the best soil with less risk of crop failure associated in years of early or late onset dates.

Overall, OSI in early onset years is lower (ranging from 0.08 to 0.09) than in late onset years (0.05 to 0.30) (Figures 10a and 10b). In early onset years, average water holding soils such as t1 and t2 showed the lowest risk with OSI values of 0.08 and 0.09 (Fig. 10b). Soils with high water holding capacity such as Ci and Ca are not suited to millet in early onset years in the present case because certainly of water logging, higher humidity, lower radiation and temperatures that will contribute to delay crop development and growth. However, in late onset years the higher OSI levels are noticed for average water holding soils such as t1 and t2 (Fig. 10a). Overall, OSI and riskiness levels increased with delay in rain onset. Late onset years have higher OSI levels. But soil type needs to be considered for optimizing management dependent on late or early years.

APPLICATIONS

With the help of soils, weather, crops and management databases in association with cropping systems simulation models and GIS, we could offer better insights through long term screening and analysis about what crop, technology or cropping system could fit better to the environment at hand. Another major application will be to provide plant breeders with a better representation of the situation actually faced by farmers for whom breeding programs are undertaken. Also, extrapolation of findings to other similar environments can be facilitated.

CONCLUSIONS

The present contribution deals with rainfall analysis, soil-water and crop production simulation modeling useful for the suitability assessment of crops and management to be recommended in a response farming approach.

Rainfall data and simulated soil water and crop yields from the study site are used to illustrate how this approach might work for farmers in the Madiama region and beyond.

For this illustration, analysis of the last 31-year rainfall of the study region has shown the high variability and low reliability of the weather. However, strong relationships exist between the time of rain onset and the rainfall duration and expectations as shown in previous studies. The earlier the onset, the higher the expectations for duration and total rain. Also, relationships between onset date, agroclimatic indices (water stress and overall stress) as well as crop yields have been evaluated and are satisfactory. Water stress indices always increased with delay in rain onset and yield decreased with late onset regardless of fertilization levels.

Although, some farmers in the region are well aware of the implications of late onset and do respond to it with some measures to insure survival level production, they may be less aware of the good implications of an early onset of rains and how they might benefit from increased input levels and other measures in these years. The information generated from the present study shows that farmers might for example better profit from increased inputs levels in early onset years and that could mean improving subsistence level production to economic level production.

As might be, the relationships and information determined in the present work are illustrative and represent a work in progress but their interest is twofold: 1) to show that they may be a real benefit to be gained from weather analysis integrated to simulation modeling in a response farming approach and 2) to suggest the establishment of a research activity based on the response farming approach where flexible recommendations will be evaluated and applied in the study region and beyond.

Table 1.1: Range of Values (Variability) of cropping season rainfall characteristics, including date of onset, rainfall amount and duration. Presented first for all years, then for early onset versus late onset years.

No. of years	**Onset period**	**Onset date**	**Prediction date**	**Amount (mm)**	**Duration (days)**
		---------------------***Range of Values***------------------------			
31	All	June 6-July 30	N/A	274-801	61-40
16	Early	June 2-June 26	Onset to June 26	406-801	93-140
15	Late	June 28-July 30	June 27 on	274-617	61-98

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characteristics, including date of onset, rainfall amount and duration. Presented first for all years, then for early onset versus late onset years.

No. of years	**Onset period**	**Onset date**	**Prediction date**	**Amount (mm)**	**Duration (days)**
		---------------------***Median Values***------------------------			
31	All	June 27	N/A	502.5	98
16	Early	June 11	Onset to June 26	529	105
15	Late	July 8	June 27 on	432.5	74

T 2: E

of Simulated Millet Yields Probabilities with no Nitrogen and (Optimum N) inputs in Early and Late Onset Years

			EXPECTED YIELDS CATEGORIES		
Onset period	No of years	Onset date	Good Crop (> 800 kg/ha)	Fair Crop (400-800 kg/ha)	Poor/failure Crop (< 400 kg/ha)
			--------------**Probabilities (%)**-------------		
All	30	June 6-July 30	36 (40)	27 (27)	37 (33)
Early	16	June 2-June 26	56 (50)	25 (31)	19 (19)
Late	14	June 28-July 30	14 (28)	29 (21)	57 (51)

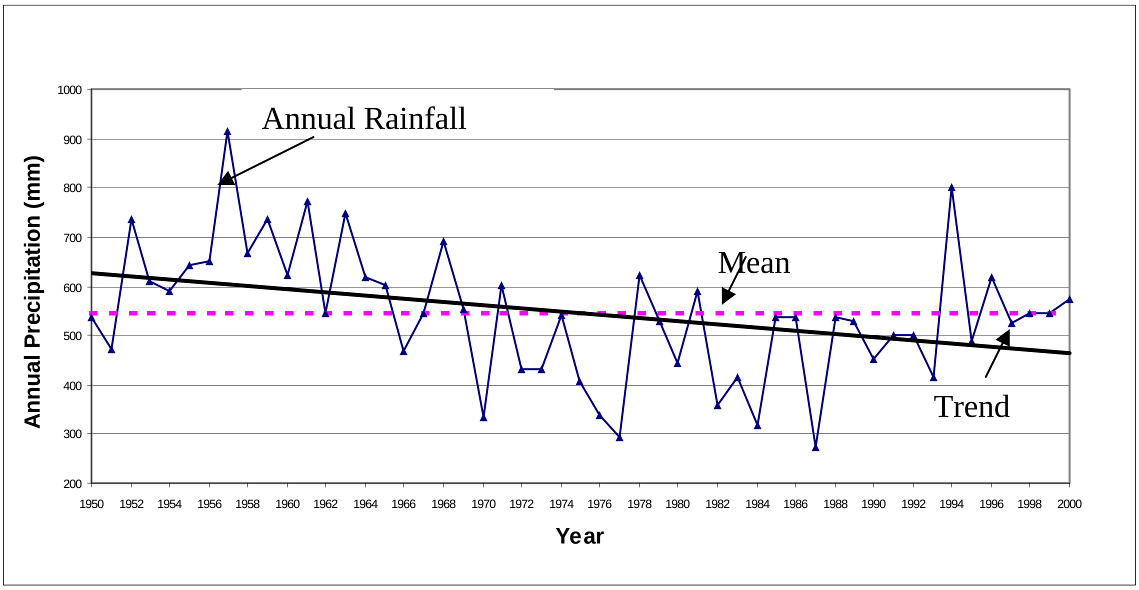

Figure 1: Precipitation Distribution, Mean and Trend from 1950 to 2000 in Djenné-Madiama

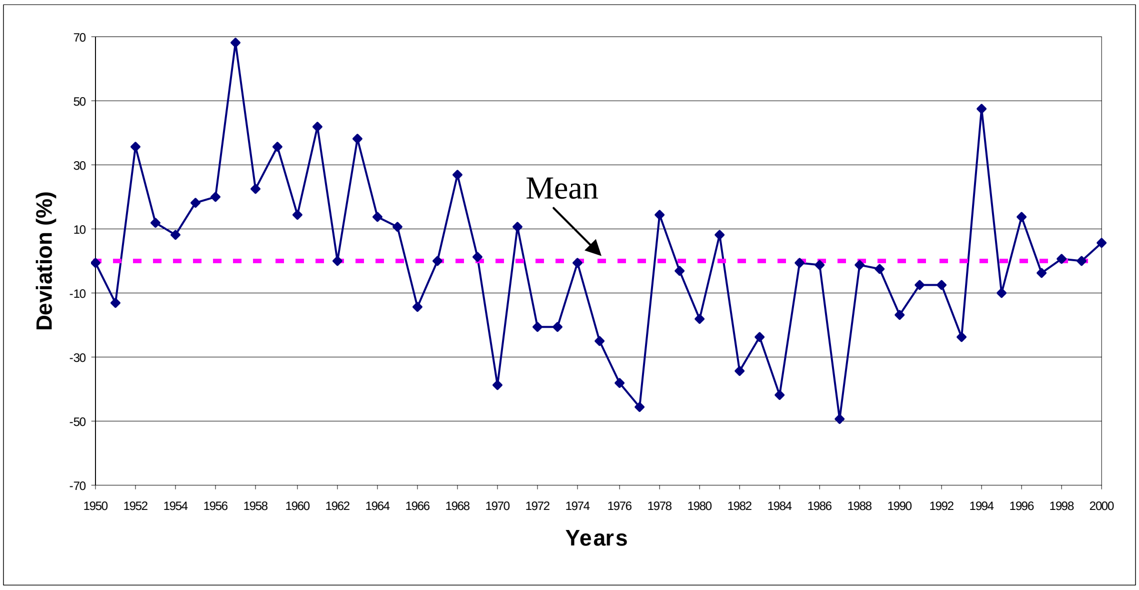

Figure 2: Rainfall Variability as a Percentage of Deviation from the long-term mean (544 mm) for the Study Area

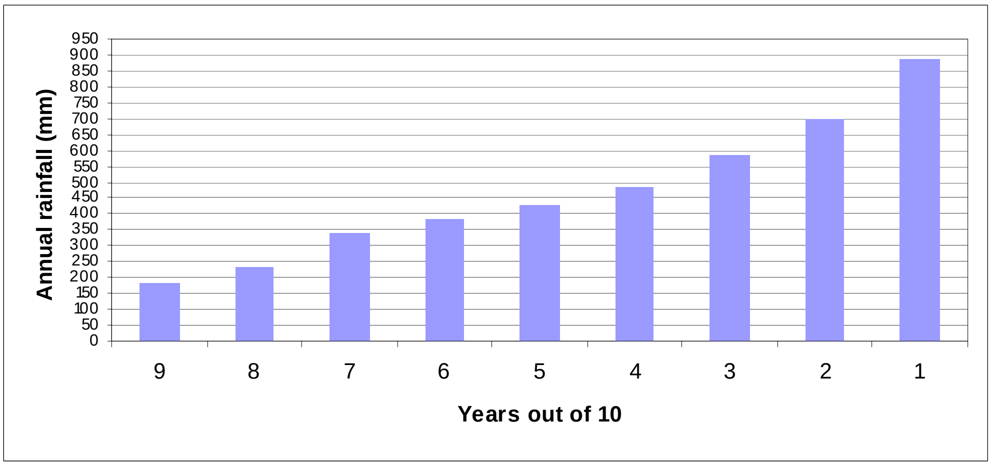

Figure 3: Annual Rain Probabilities in years out of 10

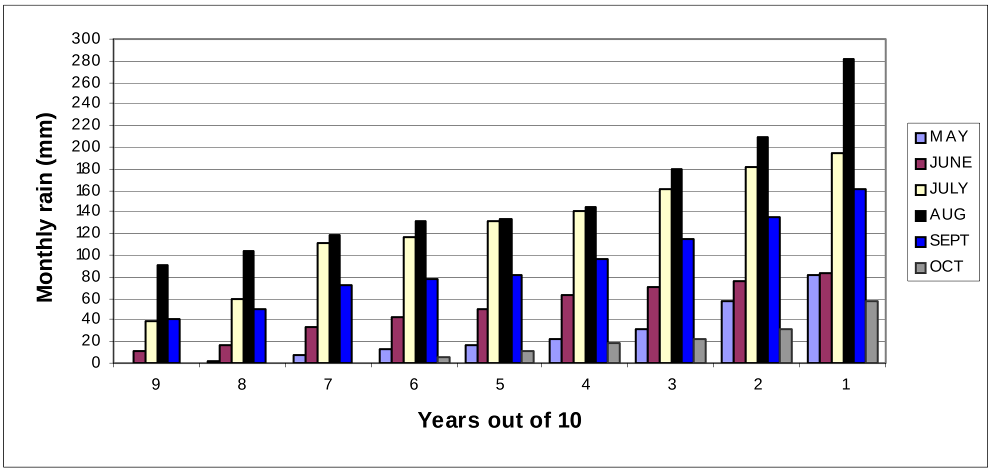

Figure 4: Monthly Rain Probabilities in years out of 10

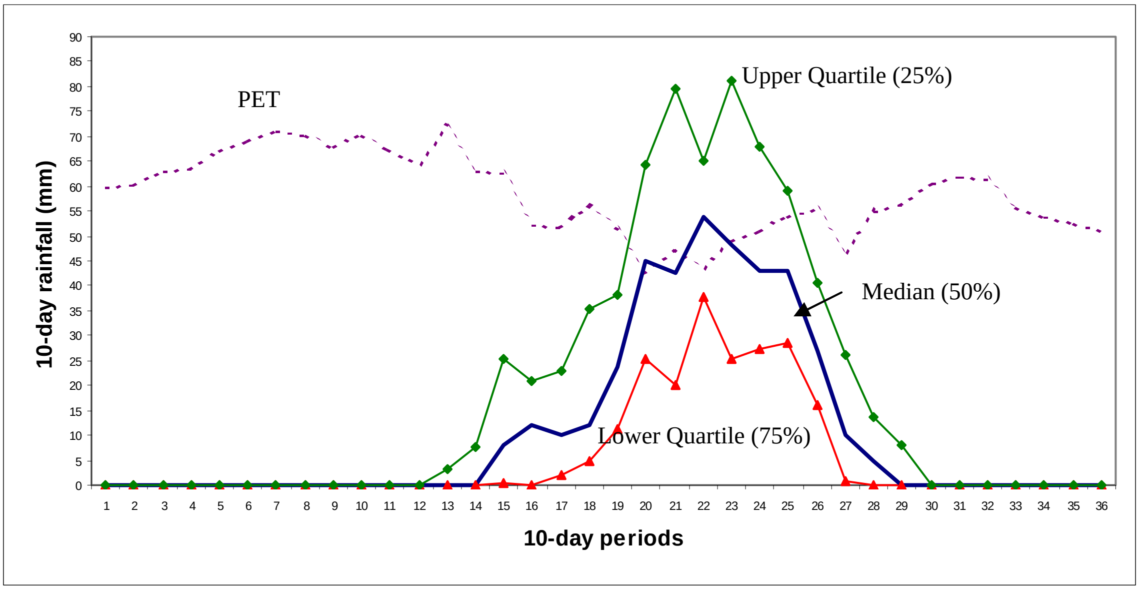

Figure 5: Confidence Interval for 10-day total rainfall and Potential Evapotranspiration (PET)

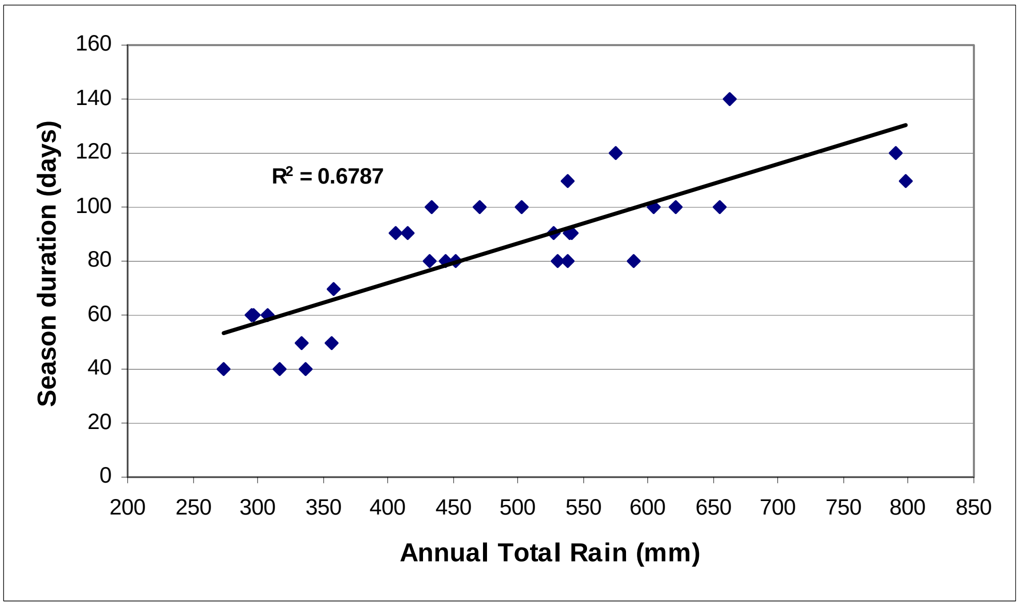

Figure 6. Length of Growing Season vs. Annual Total Rain

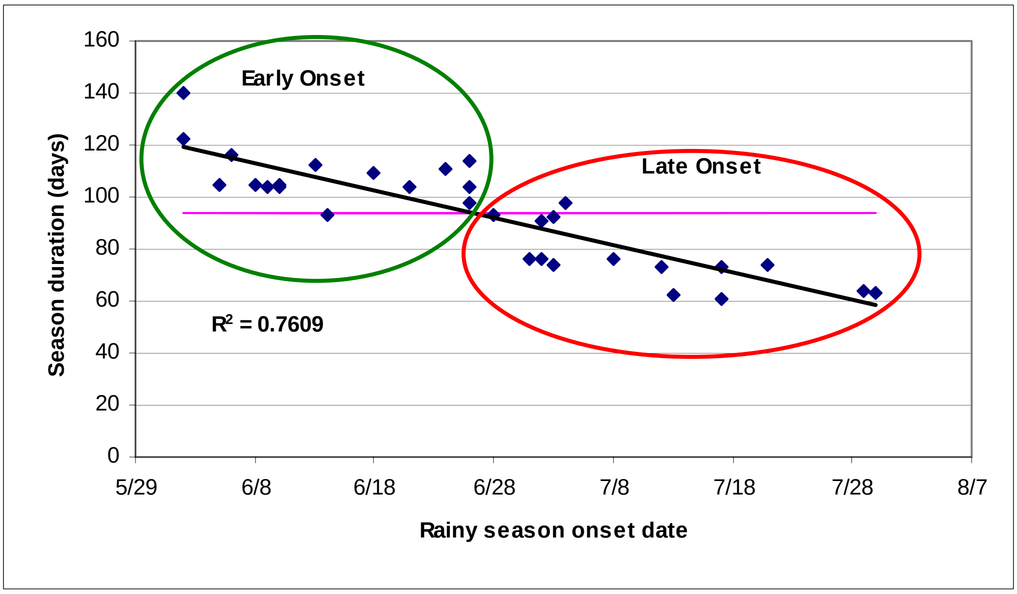

Figure 7: Rainy Season onset date vs. Season duration

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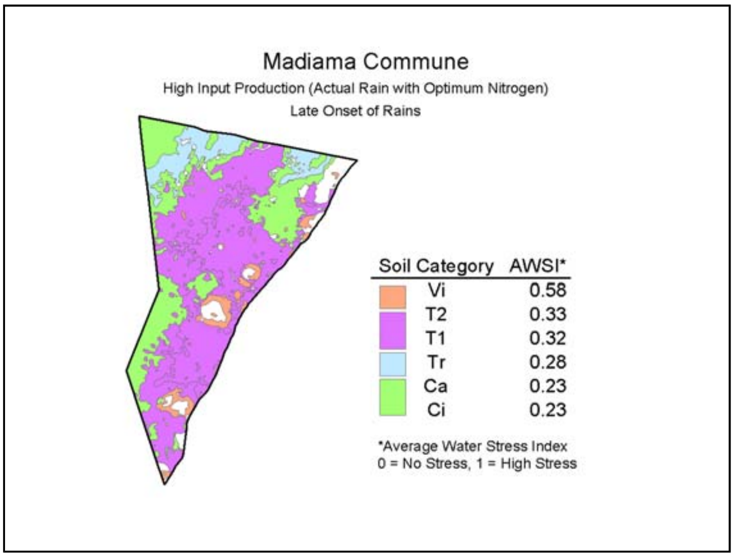
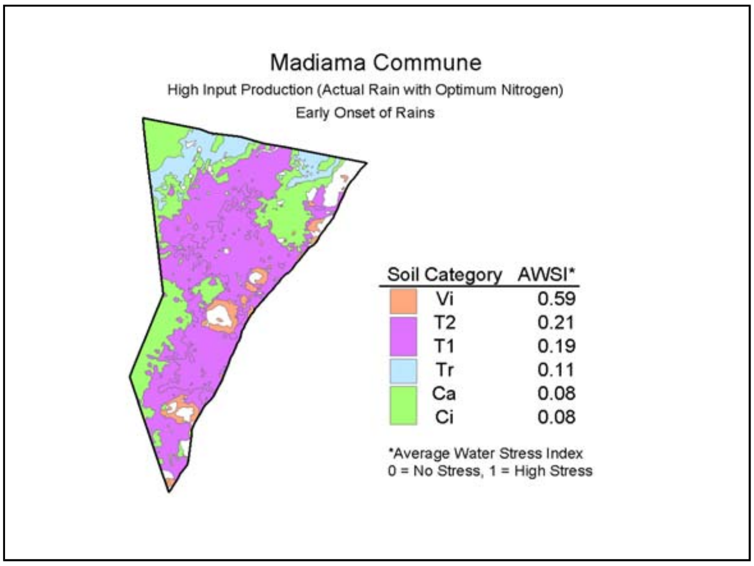


(a)



(b)

Figure 8: Average Water Stress Index vs. Onset dates

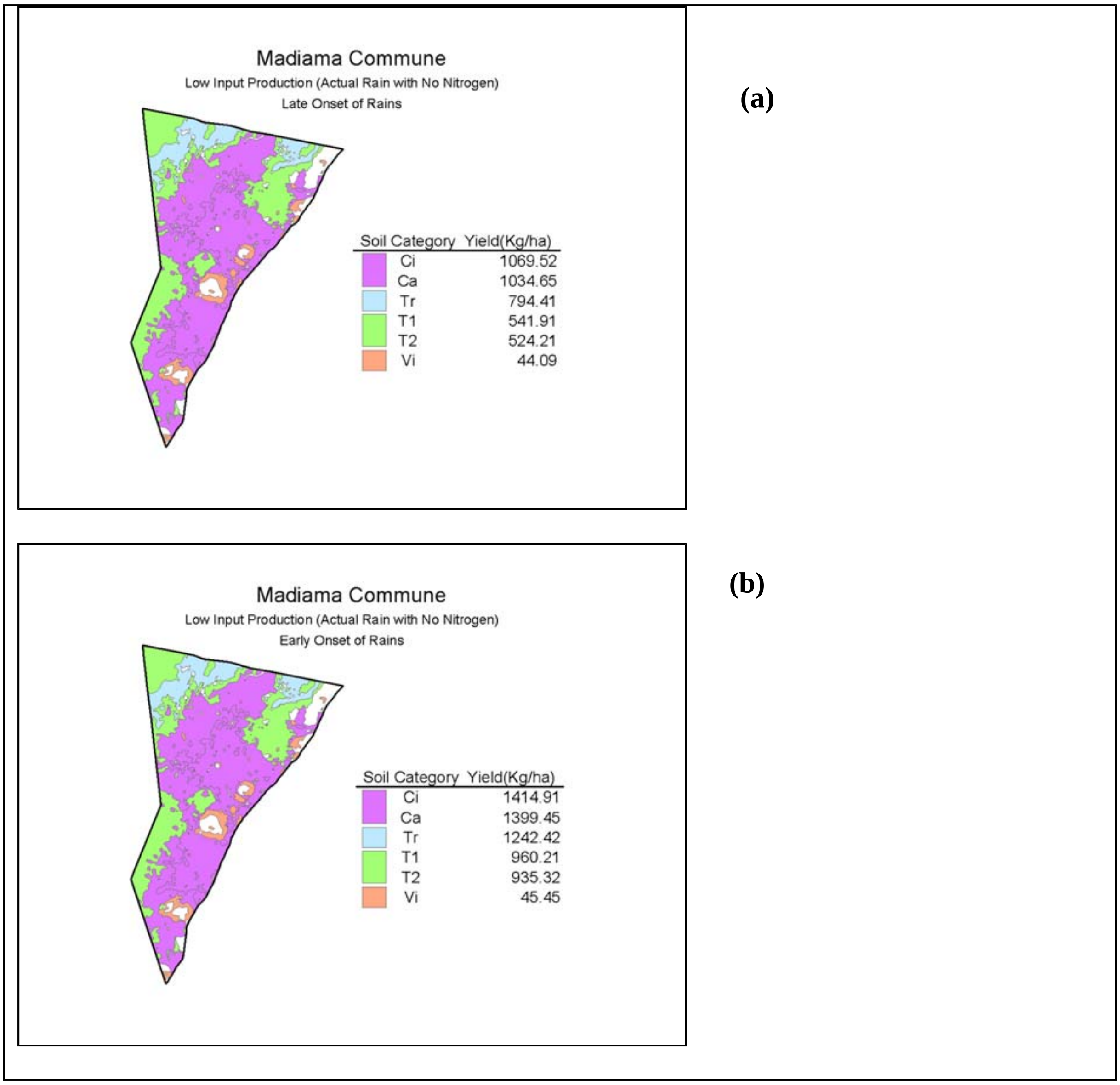


Figure 9: Simulated Yields vs. Onset date

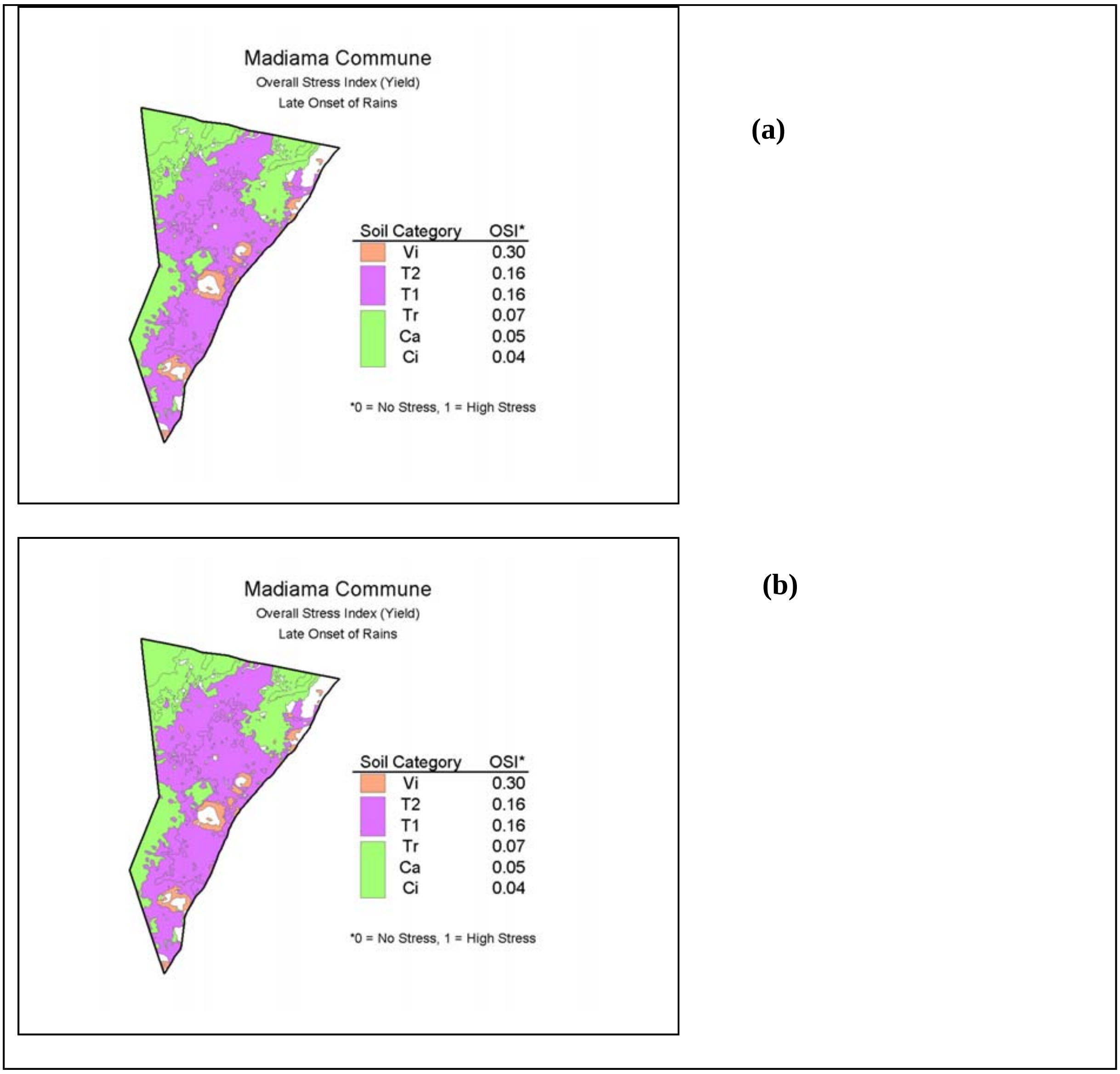


Figure 10: Overall Stress Index (OSI) vs. Onset date