Characterization of agricultural drought in semi-arid zones II. Assessment of agricultural drought forms in Senegal by simulation of the crop's water balance

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INTRODUCTION

Before embarking on a programme to improve adaptation to drought, 2 questions need to be answered :

1) How long is the useful rainy season for the species being studied.

2) For a zone with a given useful rainy season length, what are the risks of drought occurring depending on the stage of development reached by the plant.

The answer to the first question makes it possible to fix the cycle length to be sought for each zone considered, bearing in mind the known probability of the crop succeeding. Once the different levels of susceptibility to drought, depending on the stage of development reached by the plant, have been placed in order of importance, the answer to the second question makes it possible to put forward initial hypotheses as to the types of adaptation mechanisms it would be best to seek in this species.

The interest of such an approach can be illustrated by the groundnut growing situation in Senegal since the end of the 1960s. This country, located in the Sahel zone, has been experiencing a prolonged period of drought which justifies the introduction of a programme aimed at improving drought adaptation in groundnut. Drought characterization is the essential first step in defining the research to be undertaken in this type of programme (Khalfaoui and Annerose, 1987 ; Annerose, 1988). This study is generally based on a multiple year analysis of rainfall (Khalfaoui and Annerose, 1987). Nonetheless, this approach is not enough to acquire a satisfactory picture of agricultural drought. The latter notion is particularly important in semi arid zones where substantial annual variations in climatic drought and in the differences in crop susceptibility to drought depending on the stage of development reached complicate assessment of drought effects on productivity.

As we have already illustrated (Annerose and Diagne, 1990), integration of simple physiological data on plant functioning when modelling a crop's water balance can provide significant additional precision in agricultural drought assessment. We shall therefore now proceed with a new assessment of drought forms in groundnut in Senegal, attempting to be more specific in the objectives defined prior to improving this species' adaptation to drought.

Determining the length of the useful growing cycle.

The useful length of the rainy season is determined as the period between the date of the first rainfall at which sowing can take place (first sowing rain) and the date on which the easily available water reserve along the root profile no longer meets some or all of the crop's water requirements.

Determining the first sowing rainfall will depend on :

a — the type of crop ; for example, millet is often sown dry in the Sahel zone, since it can germinate with small amounts of rain and survive until more substantial rain falls. Groundnut's greater water requirements for germination and the higher cost of seeds mean that this crop has to be sown under humid conditions with rainfall amounting to at least 15 mm (Dancette *et al.*, 1976) ;

b — the date the rain falls, its intensity and the probability that it will be followed by further rainfall enabling the crop to continue its development without serious risk of drought early on in the cycle. Hence, after rainfall of a given intensity it will be easier to decide to sow the later the rain occurs ;

c — the type of soil and crop techniques, which will determine the soil's hydrodynamics, especially humidification depth. For example the very sandy soils of dune origin in northern Senegal have much lower water-holding capacities than the clayey soils in central and southern Senegal and will limit the amount of water available to the crops. Likewise, Chopart and Nicou (1976) showed that ploughing at the beginning of the cycle reduces water evaporation from the soil and favours root development ;

d — the root characteristics and rooting dynamics of the variety used, which will determine the volume of soil occupied and the quantity of water available to the plant.

By integrating the principles primarily described in the first two points, Dancette (1978) developed a method for determining the probability of crop success depending on the day the first sowing rain falls and its intensity. Knowledge of the average water requirements for crops to survive, combined with multiple-year statistical analysis of rainfall distribution provides a reliable tool on a regional scale for deciding when to sow.

Determining the date on which the rainy season ends and identifying drought periods is a much more complex matter. This requires dynamic utilization of available information on root characteristics, the quantity of water available in the soil and the crop's water consumption. To this end, use was made of a groundnut water balance simulation model, using both the available bioclimatological data and a few simple physiological concepts relative to the plant's reaction to drought (Annerose and Diagne, 1990).

The development and rate at which a groundnut crop's water requirements are met were simulated daily over the period 1961-1987 in 27 Senegalese locations to the north of Gambia.

Three variety types were considered for each of these locations :

— short cycle varieties (90 days), called early, which correspond to the earliest varieties currently available on a wide scale.

— intermediate cycle varieties (105 days), called semi early

— long cycle varieties (120 days) called late.

The useful length of the rainy season (ULRS), which determines the cycle length of the varieties to be used, is calculated as being :

ULRS = PLRS − NDHPN + A   Eq. 1

where PLRS = the potential length of the rainy season, i.e. (harvest date - sowing date).

NDHPN = the number of days from harvest that crop photosynthesis has been nil, i.e. 5 days after the start of stress

and A = the period during which the plant can use its carbohydrate reserves to finish off its cycle when photosynthesis is nil, within the following limits :

A_{max} is fixed at 5 days. Beyond this limit, even if reserves are still available, the decision to harvest is taken because drying out of the surface layers of the soil is assumed to significantly increase the risks of losing pods in the ground when the plants are lifted.

If NDHPN is under 5 days, A is equal to NDHPN

The frequency distribution of ULRS simulated over the period for the different locations then undergoes zoning of satisfied cycles for the country as a whole.

Examination of the regional variety distribution map (Fig. 1) and of the ULRS zoning map (Fig 2) shows that the length of the development cycle of the earliest varieties extended (90 days) was too long during the period considered to ensure a satisfactory probability of procuring a successful groundnut crop (> 7 out of 10 years) in the northern half of Senegal. In the adjacent central zone bordering onto Gambia in the south, the extended varieties proved to be well adapted to the estimated ULRS.

The agronomical performance of the earliest variety in the collection, Chico (Spanish, 75-day cycle in Senegal) is negligible and means that its extension is not possible.

One of the main objectives is therefore to combine Chico's precocity characters with the agronomic potential of the 90 day varieties currently extended. By directing the improvement

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NJRP0 = nombre de jours à la récolte depuis lesquels la photosynthèse de la culture est nulle, soit 5 jours après le début du stress,

et A = période durant laquelle la plante peut utiliser ses réserves glucidiques pour boucler son cycle lorsque la photosynthèse est nulle avec les conditions limites suivantes :

– A max est fixé à 5 jours. Au-delà de cette limite même si des réserves sont encore disponibles la décision de récolter est prise car on considère que l'assèchement des couches superficielles du sol augmente significativement les risques de pertes en terre des gousses lors de l'arrachage ;

– si NJRP0 est inférieur à 5 jours alors A est égal à NJRP0.

La distribution fréquentielle des DUSP simulées sur la période pour les différentes localités est ensuite reprise pour effectuer un zonage des durées de cycles satisfaits sur l'ensemble du pays.

A l'examen de la carte de répartition variétale de la région (Fig. 1) et de la carte du zonage des DUSP (Fig. 2) on constate que durant la période considérée la durée du cycle de développement des variétés vulgarisées les plus précoces (90 jours) a été trop longue pour assurer une probabilité satisfaisante de réussite d'une culture d'arachide (> 7 années sur 10) dans la moitié Nord du Sénégal. Dans la zone Centre adjacente et bordée au Sud par la Gambie les variétés vulgarisées se sont révélées bien adaptées aux DUSP estimées.

La variété la plus précoce existant en collection, Chico (Spanish, cycle de 75 jours au Sénégal) a un niveau de performance agronomique négligeable qui ne permet pas sa vulgarisation.

Un des principaux objectifs est donc d'associer les caractères de précocité de Chico avec les potentialités agronomiques des variétés de 90 jours actuellement vulgarisées. En engageant le programme d'amélioration dans cette voie on peut affiner la caractérisation de la région en ce qui concerne les DUSP et faire la distinction entre 3 grandes zones :

1 — une zone Centre, comprise entre la Gambie et un axe passant au Nord d'une ligne Dakar-Bambey, pour laquelle la longueur de cycle idéale (120 à 90 jours) existe déjà parmi les variétés vulgarisées ;

2 — une zone Nord, comprise entre la zone Centre et une ligne passant par Louga; qui pourra être colonisée par les variétés très précoces (90 à 75 jours) nouvellement créées. Bien que la localité de Louga soit située sur une ligne de DUSP égale à 65 jours (Fig. 2) elle a été incluse dans cette zone. Cette décision est dictée par le fait que la DUSP a été déterminée, pour cette localité, en simulant le développement d'une variété de 90 jours dont les besoins en eau à toutes les phases de son cycle doivent être supérieurs à ceux

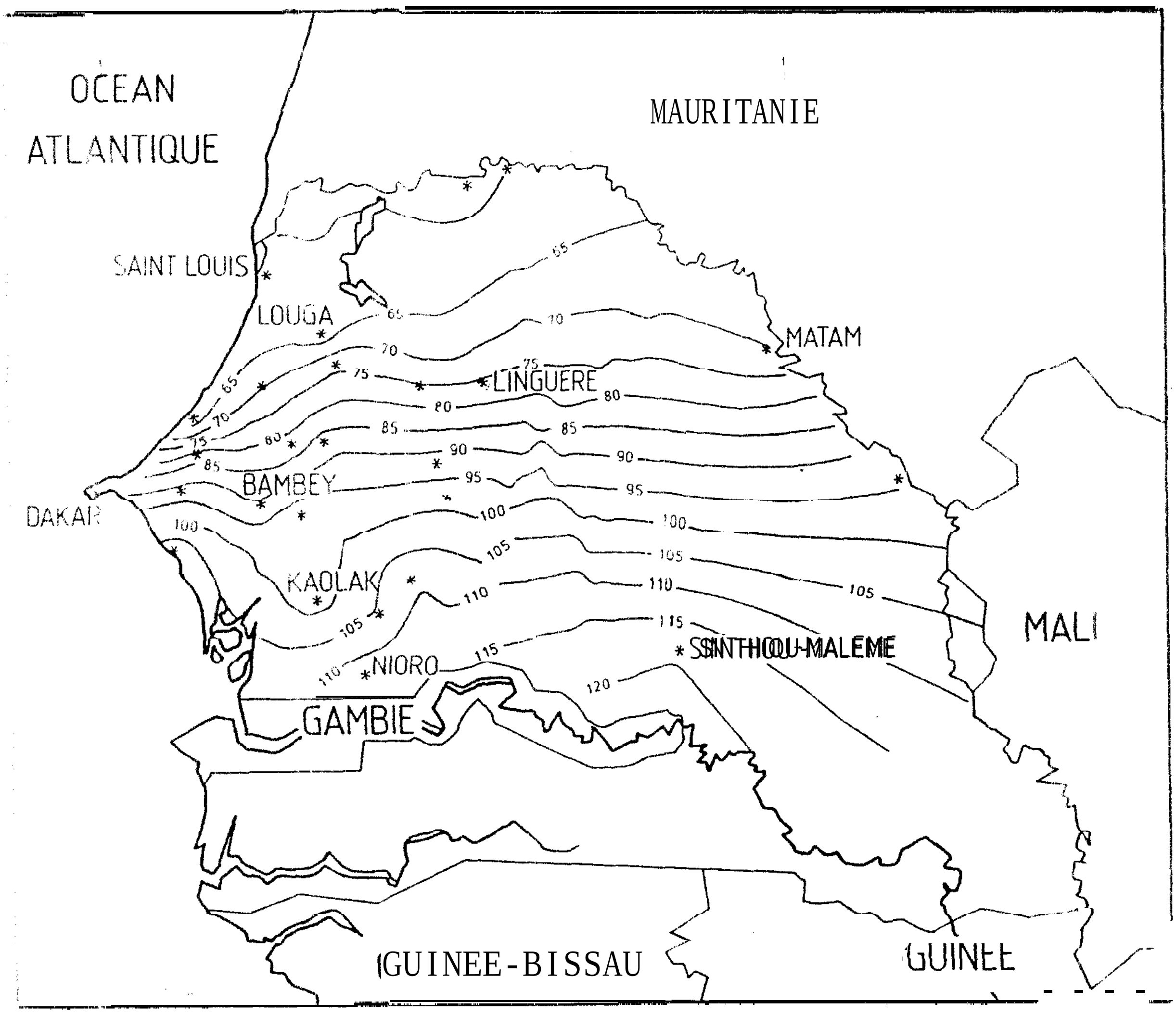

FIG. 2. — Durée des cycles satisfaits (DUSP) au moins 7 années sur 10 durant la période 1968-1987 pour les variétés d'arachide actuellement vulgarisées au Sénégal. — *Cycle lengths (CLRS) satisfied at least 7 out of 10 years during the 1969-1987 period for the groundnut varieties currently widely available in Senegal.*

présentant une bonne plasticité, à travers l'amélioration simultanée des caractères agronomiques et physiologiques d'évitement et de tolérance à la sécheresse, afin de privilégier la stabilité des rendements. Puisque les longueurs de cycle idéales sont déjà disponibles parmi les variétés vulgarisées l'objectif sera d'associer dans un même matériel les performances agronomiques des variétés hâtives à tardives déjà vulgarisées à des caractères physiologiques leur permettant d'élargir leur capacité de réaction à la sécheresse.

CONCLUSION

L'intégration des acquis agro-bioclimatologiques et de quelques concepts physiologiques, dans cette étude, a permis de mettre un certain ordre dans la perception que l'on peut avoir de la sécheresse en se basant uniquement sur les observations pluviométriques.

Cette analyse a mis en évidence l'existence d'une grande variation des formes de manifestation de la sécheresse au niveau du bassin arachidier sénégalais qui concerne à la fois la durée utile de la saison de culture et la fréquence de manifestation de périodes de sécheresse en cours de cycle. Elle a permis de formuler les premiers objectifs de sélection à atteindre pour tenter d'améliorer la productivité de cette espèce. Cependant l'hétérogénéité annuelle et spatiale des formes de sécheresse rencontrées indique que ces objectifs doivent être précisés en complétant l'analyse par une description des effets de la sécheresse en fonction du stade de développement auquel elles se manifestent, sur la production finale de la culture. La connaissance des niveaux de sensibilité au manque d'eau en fonction du stade de développement devrait ainsi permettre de hiérarchiser l'importance des différentes formes de sécheresse observées et des formes d'adaptation à rechercher.

Ces deux niveaux d'analyse constituent, pour l'amélioration des espèces cultivées en zone sahélienne des étapes indispensables dans la mise en place de programmes d'amélioration de l'adaptation à la sécheresse. Ils ont l'avantage avec les méthodes décrites ici, d'associer dans des outils de diagnostic cohérents des données souvent éparses dont l'intégration facilite la formulation des bonnes questions préalables et des objectifs à atteindre d'un tel programme.

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SUMMARY

Characterization of agricultural drought in semi-arid zones. II. Assessment of agricultural drought forms in Senegal by simulation of the crop's water balance.

D. J. M. ANNEROSE, *Oléagineux*, 1991, 46, N° 2, p. 61-67.

The agricultural drought forms affecting groundnut in Senegal were analyzed using crop development and water requirement simulation. With the current widely available varieties (90 to 120 days), three major zones were defined in the Senegalese groundnut basin depending on the useful length of the growing season and the risks of stress during the growing cycle. For each of the zones, these data were used to determine the initial objectives of an improvement programme for adaptation to drought. The need to improve the precocity of planting material intended for the northern region and to improve physiological drought adaptation characters for the central northern and central southern regions was thus made clear.

RESUMEN

Caracterizacion de la sequia agronómica en áreas semiáridas. II. Evaluación de las formas de sequia agronómica del maní en Senegal, por simulación del balance hídrico del cultivo.

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Se ha realizado un análisis de las formas de sequia agronómica del maní encontrado en Senegal, basándose en una simulación del desarrollo y de las necesidades de agua del cultivo. Las variedades ahora divulgadas (de 90 a 120 días) se hallan distribuídas dentro de tres grandes áreas en la cuenca manisera de Senegal, en la base de la duración útil del periodo de cultivo y del riesgo de producirse « stress » durante el ciclo. A partir de estos datos se ha logrado especificar para cada una los primeros objetivos de un programa de mejora de la adaptación a la sequia. Así se logró evidenciar la necesidad de incrementar la precocidad para el material vegetal destinado a la región Norte, y de mejorar los caracteres fisiológicos de adaptación a la sequia para las regiones centronorte y centrosur.

programme along these lines, the region can be characterized in greater detail as regards the ULRS and a distinction can be made between 3 major zones :

1 - A central zone, between Gambia and an axis passing North of line Dakar-Bambey, for which the ideal cycle length (120 to 90 days) already exists among the extended varieties.

2 - A northern zone, between the central zone and a line passing through Louga, which could be occupied by newly created very early varieties (90 to 75 days). Although Louga is located on a line with a ULRS equal to 65 days (Fig. 2), it was included in this zone. This decision was governed by the fact that the ULRS was determined for this location by simulating the development of a [illegible]-day variety whose water requirements in all the phases of its cycle must be higher than for a shorter cycle variety. We therefore assumed that with this 65-day ULRS limit for a 90-day variety, a hypothetical 75-day variety could finish off its cycle.

3 - An extreme northern region located to the North of Louga for which the desirable precocity does not exist in the collection. In this region, groundnut cultivation under rainfed conditions can only be considered, as now, if a high risk of nil pod production is accepted, thereby [illegible] production characteristics for this crop.

Assessment of drought risks during the cycle.

For each [illegible] varietal types studied (early, semi-late and late), the risks of drought occurring were assessed in accordance with the stage of development reached by the crop. For this analysis, a drought indicator is [illegible] during each development phase 5 days [illegible] the start of stress (TSAT [illegible] 0.7), i.e. at the moment gas [illegible] to be nil.

In view of the [illegible] ULRS in the extreme northern region, the analysis was mainly carried out for locations within the Northern and Central zones defined above (Table I).

In the northern zone, agricultural drought cannot be explained by the varieties' unadapted cycle length alone ; there is also a high probability of drought risk during the cycle. Nonetheless, it should be noted that drought risk characterization in this region was carried out by simulating the development of extended varieties, whose cycle length proved to be too long. As can be seen for Bambey, Kaolack [illegible], where development of the different varietal types was simulated, increased precocity should not only [illegible] to better groundnut [illegible] the region's ULRS, but also [illegible] drought risks [illegible] the cycle.

[illegible] this region, the improvement programme will have to be [illegible] 2 phases :

1 - A selection phase intended to increase precocity combined with [illegible] productivity potential.

2 - A [illegible] phase for the material obtained, [illegible] to [illegible] its ability to adapt to the region with tools such as the simulation model used. The results of this analysis will be used to determine whether reducing cycle length will be sufficient to adapt the crop to the drought conditions in the region, or whether it will be necessary to continue the search for early varieties also having physiological drought adaptation characters.

The analysis is different for the Central Zone, since the varieties available are well adapted to the estimated ULRS. This means a general reduction in the risks of drought occurring during the cycle compared to those observed in the Northern Zone.

In this zone, the probability of [illegible] drought in two of the crop's development phases the same year was 12 % for the period considered and with the varieties currently extended, as opposed to 58 % in the northern region. This result means that the drought periods in the Central region are briefer during the crop's development cycle. A comparison of this result with drought risk distribution depending on the stage of development reached by the plant also reveals high variability between the dates on which drought occurs in this region from one year to the next.

However, the situation is different for the southern part of this region represented by Nioro and Sinthiou-Malème, since this zone, located at the limit of the Sudanese climatic zone is primarily characterized by end-of-cycle drought for the extended varieties, with low risk for the cycle as a whole.

The heterogeneity of the data obtained in the northern part of this zone also reveals the difficulty of accurate drought risk zoning depending on the stage of development reached by the crop in this region. This is well illustrated by the results obtained at Bambey and Diourbel, two sites located 25 km apart on the same latitude. Although these two sites are in a zone where drought risks for the cycle as a whole are the same, risk distribution at Bambey also involved the different phases of crop development, whereas at Diourbel, drought risks were high during flowering and nil during fruiting.

In this region, the high variability of the drought periods will therefore make it necessary to develop highly versatile material, through simultaneous improvement of agronomical and physiological drought avoidance and tolerance characters, so as to favour yield stability. Given that the ideal cycle lengths are already found in available varieties, the aim will be to combine in the same material the agricultural performance of the early to late varieties already extended with the physiological characters that enable them to enhance their ability to react to drought.

CONCLUSION

The integration of agro-bioclimatological progress with a few physiological concepts in this study provided a clearer picture of drought based solely on rainfall observations.

This analysis revealed the existence of substantial variation in the way drought occurs in the Senegalese groundnut basin, both as regards the useful length of the growing season and the frequency with which drought periods occur during the growing cycle. It was subsequently possible to determine the primary selection objectives to be met in an attempt to improve productivity in this species. Nonetheless, annual and spatial heterogeneity in the different types of drought encountered indicated that these objectives need to be more clearly specified, by completing the analysis with a detailed description of drought effects on the crop's final production according to the stage of development reached by the plant when drought occurs. Knowledge of the plant's susceptibility to water shortage depending on the stage of development it has reached should also make it possible to classify the different forms of drought observed and the different forms of adaptation to be sought in order of importance.

These two levels of analysis are essential steps in setting up improvement programmes to adapt the species grown in the Sahel zone to drought. Along with the methods described above, they offer the advantage of incorporating into coherent diagnostic tools certain data which are often scarce and whose integration make it easier to ask the right questions and determine the objectives to be reached in this type of programme.