

# Hydritic Stress Tolerance Indices for Four New Varieties of Cotonnier (*Gossypium Hirsutum*)

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## Résumé

Le stress hydrique constitue un facteur limitant majeur pour la production du cotonnier dans la zone cotonnière du Cameroun. Cette étude vise à évaluer les indices de tolérance au stress hydrique et à classer les variétés de coton (*Gossypium hirsutum*) afin d'identifier les plus adaptées aux conditions de sécheresse. L'expérimentation a été menée en serre à l'IRAD de Maroua, dans un climat soudano-sahélien. Cinq variétés de cotonnier ont été étudiées sous deux régimes hydriques : conditions normales (ETM) et stress hydrique (privation totale d'eau pendant six jours). Les indices de tolérance au stress évalués comprennent : l'indice de sensibilité au stress (SSI), l'intensité du stress (SI), l'indice de tolérance au stress (STI), la tolérance au stress (TOL) et l'indice de stabilité du rendement (YSI).

Les résultats montrent une variabilité significative entre les variétés quant à leur tolérance au stress hydrique. IRMA A2188 et IRMA H2062 se distinguent par leur stabilité de rendement et leur résilience face au stress, tandis que IRMA F2181 et IRMA Q302 sont plus sensibles, avec une forte réduction de rendement en conditions de sécheresse. L'analyse des corrélations révèle que STI et YSI sont des indicateurs fiables pour identifier les variétés tolérantes. L'étude propose une classification des variétés en trois groupes : (i) variétés résistantes (IRMA D2139 et IRMA H2062), (ii) variétés sensibles (IRMA F2181 et IRMA Q302) et (iii) variété intermédiaire (IRMA A2188). Ces résultats sont essentiels pour orienter les programmes de sélection variétale afin d'améliorer la résilience du cotonnier face au stress hydrique.

**Mots-clés :** Stress hydrique, tolérance, indices de sensibilité, sélection variétale, cotonnier (*Gossypium hirsutum*).

## ABSTRACT

Water stress is a major limiting factor for cotton production in the Cameroon cotton-growing zone. The aim of this study was to evaluate water stress tolerance indices and classify cotton varieties (*Gossypium hirsutum*) to identify those best adapted to drought conditions. The experiment was conducted in a greenhouse at IRAD Maroua, in a Sudano-Sahelian climate. Five cotton varieties were studied under two water regimes: normal conditions (ETM) and water stress (total deprivation of water for six days). The stress tolerance indices assessed included: stress sensitivity index (SSI), stress intensity (SI), stress tolerance index (STI), stress tolerance (TOL) and yield stability index (YSI). The results show significant variability between varieties in terms of their tolerance to water stress. IRMA A2188 and IRMA H2062 stand out for their yield stability and resilience to stress, while IRMA F2181 and IRMA Q302 are more sensitive, with a sharp reduction in yield under drought conditions. Correlation analysis reveals that STI and YSI are reliable indicators for identifying tolerant varieties. The study proposes a classification of varieties into three groups: (i) resistant varieties (IRMA D2139 and IRMA H2062), (ii) susceptible varieties (IRMA F2181 and IRMA Q302), and (iii) intermediate varieties (IRMA A2188). These results are essential for guiding breeding programs to improve the resilience of cotton to water stress.

**Keywords:** Water stress, tolerance, sensitivity indices, plant breeding, cotton (*Gossypium hirsutum*).

## 1. Introduction

Water stress is a major factor limiting crop production, particularly in the cotton-growing zone of Cameroon. It affects plant growth by inducing morphological, physiological and biochemical changes linked to the expression of genes associated with drought tolerance [8].

To survive, plants develop adaptation mechanisms, such as the accumulation of osmotic substances (proline, betaine, soluble sugars) and morphological changes in roots (formation of water-storing tubers) [14].

However, improving plants to withstand drought is complex due to the lack of rapid and reproducible screening techniques.

Several methods have been used to study drought, including measurement of water content, canopy temperature [21], osmoticum accumulation, membrane integrity [7], root parameters (length, number, diameter, architecture), yield components and stress tolerance indices [13][12]. Among these indices are stress tolerance (TOL), stress sensitivity index (SSI), yield index (YI), yield stability index (YSI) and stress tolerance index (STI), which assess the performance of genotypes under stress and non-stress conditions[11][15][1].

The general aim is to contribute to cotton productivity. Specifically, the aim is to assess water stress tolerance indices and to establish a typology of varieties in order to identify those that are best adapted to water stress conditions, with a view to guiding varietal selection programs.

## 2. Materials and Methods

### 2.1. Materials

#### 2.1.1. Study site

This study was carried out in Maroua, in the Far North region of Cameroon, more precisely in the Diamaré Department, Maroua 1st Arrondissement, located between the 10th and 13th degrees of North latitude and between the 13th and 15th degrees of East longitude at an altitude of 412 m. It was carried out in a greenhouse at the Institutes de Recherche Agronomiques pour le Développement (IRAD) in Maroua. The climate in this region is Sudano-Sahelian. The rainy season lasts 5 months, from May to September, with numerous interruptions. Average annual rainfall is between 730 and 850 mm. The average annual temperature is 28.7°C [20].

#### 2.1.2. Plant material

Five varieties of *Gossypium hirsutum* were evaluated:

- IRMA Q302 (control variety),
- IRMA A2188 (intermediate variety),
- IRMA D2139, IRMA F2181 and IRMA H2062 (new varieties from the breeding programmer).

### 2.2 Methods

The study was conducted using a split-plot experimental design with two factors and two replications. The first factor, 'varieties', consisted of five varieties of cotton (*Gossypium hirsutum*), including four new varieties and a control. The second factor, 'water regime', comprised two levels: normal amount of water for plant growth (ETM) and total absence of water (STRESS).

So, 60 pots were divided into 2 large plots (sub-blocks). Each large plot was then divided into 5 small plots, with 3 pots for each of the varieties evaluated. Hydric stress is induced by total water deprivation between the 45th and 75th day after emergence (DAE). The stress applied corresponds to a drying rate of 80% of the useful reserve (UR). The plants were therefore irrigated as soon as the 80% depletion rate threshold was reached. This measurement was taken using a TDR-100 soil moisture meter.

Several indices that describe drought tolerance have been defined by [9][1][2]. and were used in this study:

- **Stress sensitivity index (SSI):**  $SSI = [1 - (Y_s / Y_p)] / SI$
- **Stress Intensity (SI):**  $SI = [1 - (Y_s / Y_p)]$
- **Stress tolerance index (STI):**  $STI = [(Y_p \times Y_s) / \bar{Y}_p^2]$
- **Stress tolerance (TOL):**  $TOL = (Y_p - Y_s)$
- **Yield stability index (YSI):**  $YSI = Y_s / Y_p$

Where  $Y_s$  and  $Y_p$  are the yields of genotypes evaluated under stress and non-stress conditions and  $\bar{Y}_s$  and  $\bar{Y}_p$  are the averages of all genotypes evaluated under stress and favorable conditions.

### 3. Static analysis

The statistical analysis was performed with Excel 2016 and XLSTAT 2019, including:

- Correlations between indices and returns,
- Hierarchical ascending classification (HAC),
- Principal Component Analysis (PCA).

## 4. Results and Discussion

### 4.1 Water stress tolerance indices

The results obtained show that drought has a significant impact on the yield of the varieties studied, with significant differences depending on their tolerance to water stress. Analysis of yields under normal conditions ( $Y_p$ ) and under stress ( $Y_s$ ) reveals that some varieties maintain a relatively stable yield, while others suffer a sharp reduction. For example, IRMA D2139 has the highest yield under normal conditions ( $19.5 \pm 7.64$ ) but suffers a significant drop under stress ( $9.6 \pm 7.64$ ), indicating moderate sensitivity. In contrast, IRMA F2181 showed the greatest difference between  $Y_p$  and  $Y_s$ , with a TOL of  $13.2 \pm 7.44$ , indicating high sensitivity to drought. Conversely, IRMA A2188 maintained a more stable yield with a TOL of  $3.9 \pm 4.70$ , suggesting better tolerance to water stress. These observations are in line with the work of [9]. and [15], who showed that varieties with a low TOL are more tolerant because they suffer fewer losses under stress.

The Stress Susceptibility Index (SSI) confirms these trends by making it possible to assess the susceptibility of varieties. IRMA F2181 has the highest SSI value ( $1.4 \pm 7.44$ ), indicating a high vulnerability to drought. On the other hand, IRMA A2188 and IRMA H2062, with SSI values of  $0.6 \pm 4.70$  and  $0.8 \pm 6.96$  respectively, appear to be the most resistant varieties. These results are consistent with the work of [5], who demonstrated that varieties with an SSI of less than 1 are more tolerant to water stress.

Analysis of stress tolerance and stability indices reinforces these observations. The stress tolerance index (STI) can be used to identify the varieties that perform best under stress and non-stress conditions. IRMA D2139 and IRMA H2062 have the highest STI values ( $0.7 \pm 7.64$  and  $0.6 \pm 6.96$ , respectively), suggesting that they can maintain relatively stable yields under drought conditions. On the other hand, IRMA F2181, with an STI of  $0.2 \pm 7.44$ , is the variety most affected by drought. The yield stability index (YSI) confirms these observations, with IRMA A2188 showing the highest value ( $0.6 \pm 4.70$ ), indicating its resilience, while IRMA F2181 has the lowest YSI ( $0.2 \pm 7.44$ ), indicating greater sensitivity. These results are in line with studies by [4]., who showed that genotypes with high STI and YSI values are better adapted to arid environments.

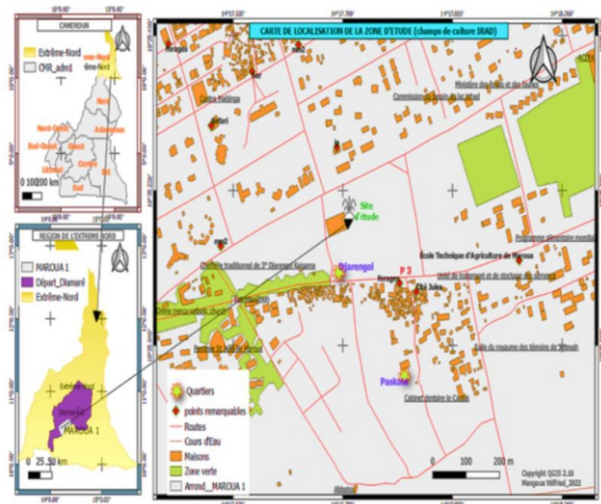


Figure 1: Location of the study site

**Table 1: Stress tolerance indices of the varieties tested**

| Variety    | Yp          | Ys         | TOL         | SSI        | STI        | YSI        |
|------------|-------------|------------|-------------|------------|------------|------------|
| IRMA A2188 | 11.7 ± 4.70 | 7.8 ± 4.70 | 3.9 ± 4.70  | 0.6 ± 4.70 | 0.3 ± 4.70 | 0.6 ± 4.70 |
| IRMA D2139 | 19.5 ± 7.64 | 9.6 ± 7.64 | 9.9 ± 7.64  | 0.9 ± 7.64 | 0.7 ± 7.64 | 0.4 ± 7.64 |
| IRMA F2181 | 17.6 ± 7.44 | 4.3 ± 7.44 | 13.2 ± 7.44 | 1.4 ± 7.44 | 0.2 ± 7.44 | 0.2 ± 7.44 |
| IRMA H2062 | 17.8 ± 6.96 | 9.8 ± 6.96 | 7.9 ± 6.96  | 0.8 ± 6.96 | 0.6 ± 6.96 | 0.5 ± 6.96 |
| IRMA Q302  | 15.2 ± 5.98 | 6.2 ± 5.98 | 9 ± 5.98    | 1.0 ± 5.98 | 0.3 ± 5.98 | 0.4 ± 5.98 |

#### 4.2 Correlations between indices and yields

The results presented in the table show correlations between several variables related to water stress tolerance in cotton genotypes. The correlation between yield under favorable conditions (Yp) and under stress conditions (Ys) was positive but not significant ( $p = 0.22$ ), indicating that genotypes that perform well under optimal conditions do not necessarily do so under water stress. This result is in line with the work of [5], and recent studies such as [18], which have shown that performance under favorable conditions does not always predict stress tolerance.

Furthermore, the correlation between Yp and TOL is high but not significant ( $p = 0.09$ ), suggesting that high-yielding genotypes under optimal conditions tend to suffer greater yield loss under stress. This confirms the observations of [17], and is reinforced by the results of [10], according to which high-yielding genotypes are often more sensitive to water stress.

On the other hand, the correlation between Ys and STI is strongly positive and significant ( $0.95^*$ ), which confirms that the STI index is a good indicator for identifying genotypes that perform well under water stress, as pointed out by [4], and the recent research by [16]. Similarly, the negative and significant correlation between SSI and YSI ( $-0.93^*$ ) shows that stress-sensitive genotypes have low yield stability, in line with the conclusions of [6], and more recent studies by [18]. Finally, the positive and significant correlation between Ys and YSI ( $0.91^*$ ) indicates that genotypes that perform well under stress also have good yield stability, which is consistent with the work of [3], and recent research by [22].

**Table 2: Correlation matrix between the different stress tolerance indices and yields under favorable (Yp) and stress (Ys) conditions**

| Variety | Yp      | Ys     | TOL     | SSI    | STI    | YSI |
|---------|---------|--------|---------|--------|--------|-----|
| Yp      | 1       |        |         |        |        |     |
| Ys      | 0.67ns  | 1      |         |        |        |     |
| TOL     | 0.82ns  | 0.22ns | 1       |        |        |     |
| SSI     | 0.85ns  | 0.37ns | 0.95*   | 1      |        |     |
| STI     | 0.87ns  | 0.95*  | 0.54ns  | 0.64ns | 1      |     |
| YSI     | -0.56ns | 0.91*  | -0.82ns | -0.93* | 0.67ns | 1   |

#### 4.3. Genotype typology

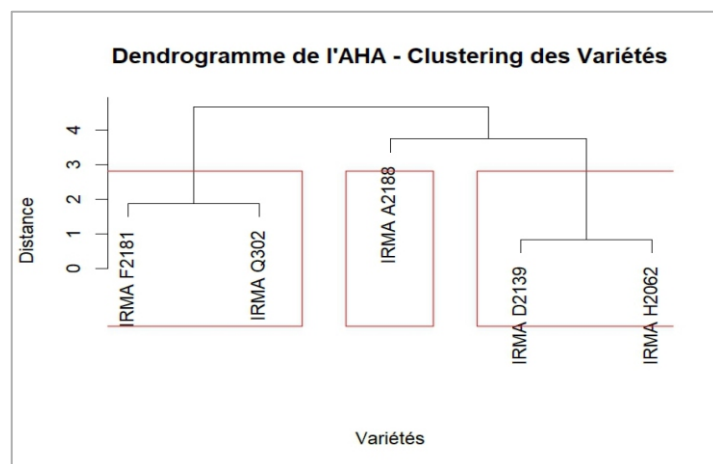
Analysis of the groups of varieties based on stress tolerance indices (SSI, STI and YSI) reveals marked differences in their response to water stress, making it possible to classify them into three distinct groups.

Group 1, made up of the varieties IRMA D2139 and IRMA H2062, is characterized by high resistance to stress, with a moderate stress sensitivity index (SSI) (0.88), a good stress tolerance index (STI) (0.67) and a relatively stable yield under stress index (YSI) (0.52). These varieties are well adapted to stressful environments, as they combine good stress tolerance with acceptable yield performance, in line with the observations of [4], and [6], who showed that varieties with a high STI and stable YSI are able to maintain acceptable yields under stress.

Group 2, on the other hand, which includes the varieties IRMA F2181 and IRMA Q302, is highly vulnerable to stress, with a high SSI (1.24), a low STI (0.31) and an average YSI (0.32), indicating a sharp drop in yield under stress conditions. These varieties, which are poorly adapted to difficult environments, confirm the

conclusions of [17], and [9], according to which varieties with a high SSI and a low STI are very sensitive to stress.

Finally, Group 3, represented by the variety IRMA A2188, has intermediate or resistant characteristics, with a low SSI (0.62), a moderate STI (0.34) and a high YSI (0.66). This variety shows a low sensitivity to stress and a good capacity to maintain its yield despite stress, which makes it an interesting option for stressful environments, as highlighted by [4], and [3].

**Figure 2: Graphic presentation of the groups resulting from the hierarchical ascending classification according to the stress tolerance indices of the varieties tested**

#### Conclusion

The results of this study show that drought has a significant impact on the yield of the varieties studied, with notable differences depending on their tolerance to water stress. Some varieties, such as IRMA A2188, maintained stable yields under stress, while others, such as IRMA F2181, experienced a sharp reduction. The stress sensitivity index (SSI) confirmed these trends, distinguishing vulnerable varieties from the most resistant. In addition, the stress tolerance and stability indices (STI and YSI) were used to identify the varieties that perform best under stress, in particular IRMA D2139 and IRMA H2062, which maintain good yields despite difficult conditions. Correlation analysis revealed that STI is a good indicator of performance under stress, while the negative correlation between SSI and YSI indicates that the most sensitive varieties have lower yield stability. By grouping the varieties into three categories, it appears that IRMA D2139 and IRMA H2062 are the most tolerant, IRMA F2181 and IRMA Q302 are the most susceptible, and IRMA A2188 presents an intermediate profile with good resilience.

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