

# Selection of Cowpea Genotypes in Hydroponics, Pots, and Field for Drought Tolerance

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## ABSTRACT

The evaluation of cowpea (*Vigna unguiculata* [L.] Walp.) for drought tolerance in the field is slow, laborious, and provides variable results. The objectives of the study were to assess the differences in the growth of cowpea genotypes in hydroponics, and to determine whether such differences could be associated with drought tolerance in pots and field. Four cowpea genotypes varying in drought tolerance were evaluated for differences in height, collar diameter, leaf area, shoot and root biomass, root-shoot ratio, and root volume in hydroponics. On the basis of these results, selection of cowpea for vigorous growth under well-watered conditions could be conducted by means of hydroponics; however, rapid selection of cowpea for drought tolerance could not be made by this technique.

COWPEA is one of the ancient grain legume crops cultivated in semiarid West Africa where rainfall resources are characteristically low (300–600 mm), variable in time and space, and undependable (Fussell et al., 1991). This region produces about 80% of the world production. The principal producers of cowpea in the West African region are Nigeria, Niger, and Senegal. The average cowpea cultivated area in Senegal is about 70 000 ha with a grain production of about 30 000 Mg. In this part of sub-Saharan Africa, cowpea is the second most important grain legume crop after peanut (*Arachis hypogaea* L.) and plays an important role in the economy and diet of urban and rural poor. The grain is valued for its high protein content (about 25%), flavor, and short cooking time. The plant is also favored by farmers because of its ability to maintain soil fertility through its capacity to fix nitrogen and because of the haulms that are used to maintain livestock during the dry season (Blade et al., 1997). The crop, therefore, forms an integral part of a sustainable agriculture and land-use system.

However, the yield obtained in the sahelian zone of West Africa is lower than that in the USA and in Australia (Quin, 1997). This low productivity has been attributed to water deficit, the persistent traditional cropping system, pests, and diseases. Under adequate soil moisture conditions, the indeterminate cowpea flowers over a long period. As a consequence it produces more seed, and yield loss is limited. On the contrary, under water deficit conditions as is often the case in the semi-arid zone, the flowering period is cut short while the seed

mature earlier. Moreover, the formation of new floral nodes and flowers are delayed (Turk et al., 1980) and/or aborted, thus leading to low productivity.

Progress in cowpea breeding for dry environments has been achieved by yield testing large collections over several locations and years (Hall et al., 1997). Robertson et al. (1985) have used herbicidal band screening techniques to screen cowpea lines for improved rooting. Watanabe (1998) evaluated 900 accessions of cowpea offered by the Genotypic Resources Unit of IITA in the field. These empirical approaches are slow, laborious, and expensive because of the need to assess the yield of large number of lines across several locations and years, and the substantial variation from the effects of environment, error, and genotype–environment interactions (Blum, 1988). Shackel et al. (1982) have argued that when selecting genotypes with increased drought resistance, it is reasonable to propose that the evaluation be made under water limited conditions; but, because of the inconsistencies they observed under water deficit conditions, they concluded that an irrigated condition might be a more reliable indicator of genotypic differences than measurements with plants under drought.

Grantz (1979) has further observed that the problem with selecting in an environment that causes water stress is that the time of anthesis, partitioning of carbohydrates, and time of maturity are influenced by drought. These environmentally induced variations under stress conditions therefore make it difficult to detect genotypic differences. The approach of Blum (1983), which combines selection for yield potential in favorable conditions with selection under controlled, repeatable stress environment for the expression of traits thought to be associated with drought tolerance is most effective (Fussell et al., 1991). This requires, therefore, the identification of specific traits under adequate moisture that are easy to measure and are associated with drought tolerance (Fischer and Wood, 1979).

Hydroponic screening has been reported as a rapid and valuable method for screening cultivars with improved drought tolerance in a number of crops, rice (*Oryza sativa* L.) (Chang et al., 1972; Ekanayake et al., 1985; Price et al., 1997), sorghum [*Sorghum bicolor* (L.) Moench] (Jordan et al., 1979), and peanut (Pandey and Pendleton, 1986). The objectives of the present study were to assess the differences in the growth of cowpea genotypes in hydroponic conditions and to determine whether such differences in growth could be associated with drought tolerance of plants grown under water deficit conditions in pots and subsequently in the field.

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**Abbreviations:**  $\Psi_m$ , osmotic potential; LRWC, leaf relative water content; AET, Actual evapotranspiration; MET, maximum evapotranspiration; WUE, water use efficiency; I, stress index; G<sub>s</sub>, stomatal conductance; RS, root-shoot ratio; LAI, leaf area index.

## MATERIALS AND METHODS

In this study, two concurrent trials were conducted during the period of May to June 1999 in the greenhouse at CERAAS, Thies, Senegal (Latitude 14° 81' North and Longitude 16° 28' West). It consisted of a hydroponic and pot evaluation of four cowpea cultivars. In the greenhouse, the plants experienced maximum day/night temperatures of 37.0/32.3°C. A third trial in the field was conducted between March and April, 1999 at the National Centre for Agronomic Research, Bambey (14° 42' N, 16° 28' W), Senegal. During the course of the experiment, the maximum and minimum temperatures recorded at the meteorological station located at the site were  $37.6 \pm 3^\circ\text{C}$  and  $19.2 \pm 1.7^\circ\text{C}$  respectively. The intensity of photosynthetically active radiation between 1200 and 1300 h was  $2060 \pm 286 \mu\text{mol m}^{-2} \text{s}^{-1}$ . Four cowpea cultivars (Bambey-21, Mouride, Melakh, and TN 88-63) representing the principal cultivars grown in the Sahelian zones of Senegal were used for the study.

### Hydroponic Culture

Four cowpea genotypes were grown in hydroponics in the greenhouse. The hydroponic system consisted of nine tanks of 25-L capacity, each connected to four 4-L plastic tubs. Nutrient solution was pumped into the tubs by multicellular pumps. The pumps were linked to a timing system, which allowed the supply of solution in tides. At high tides of 10-min duration, the tubs were filled to capacity, while at low tides of 7-min duration, the pumps stopped functioning while the nutrient solution slowly descended into the tanks. This allowed the roots to be reoxygenated.

The nutrient solution used was that described by Perez (1997). Macronutrients were added as  $\text{PO}_4^{2-}$  ( $\text{KH}_2\text{PO}_4$ ), 3.38  $\text{cmol}_c \text{kg}^{-1}$ ;  $\text{K}^+$  ( $\text{KNO}_3$ ), 9.00  $\text{cmol}_c \text{kg}^{-1}$ ;  $\text{Ca}^{2+}$  [ $\text{Ca}(\text{NO}_3)_2 \cdot \text{H}_2\text{O}$ ], 10.13  $\text{cmol}_c \text{kg}^{-1}$ ;  $\text{Mg}^{2+}$  ( $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ ), 3.38  $\text{cmol}_c \text{kg}^{-1}$ ; while the micronutrients were added as  $\text{Fe}^{2+}$  ( $\text{FeCl}_2 \cdot 6\text{H}_2\text{O}$ ), 1.6  $\text{mg L}^{-1}$ ;  $\text{Na}^+$  ( $\text{Na}_2\text{EDTA} \cdot \text{H}_2\text{O}$ ), 1.43  $\text{mg L}^{-1}$ ;  $\text{Mn}^{3+}$  ( $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$ ), 0.25  $\text{mg L}^{-1}$ ;  $\text{MoO}_4$  [ $(\text{NH}_4)_6 \text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$ ], 0.006  $\text{mg L}^{-1}$ ; B ( $\text{H}_3\text{BO}_3$ ), 0.37  $\text{mg L}^{-1}$ ;  $\text{Zn}^{2+}$  ( $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ ), 0.12  $\text{mg L}^{-1}$ , and  $\text{Cu}^{2+}$  ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ), 0.03  $\text{mg L}^{-1}$ .

The seeds were germinated on Petri dishes and then transferred to the hydroponic system. A packing material was placed on each tub to hold the plants at the root collar with the roots immersed in the culture solution. During the first and second week, the plants were grown in a 10 and 30% strength nutrient solutions, respectively, after which the strength was increased to 80%. The pH was adjusted to 5.8 every other day with  $\text{H}_3\text{PO}_4$ . Nutrient solution was replaced every week. Each tank held a complete set of cultivars, and constituted one replication of a randomized complete-block design. Three such units were replicated in three blocks to give a total of nine units. The experiment lasted for 4 wk.

Plant height and leaf area were measured at harvest. A leaf area meter (Model MK2  $\Delta\text{T}$  Area Meter Devices, Ltd, England) was used to measure leaf area. Collar diameter was measured at the collar with a calliper gauge. The length of the longest extended root (maximum root length) of each plant was measured from stem base to the tip. Root and shoot biomass were obtained after oven-drying fresh materials at 80°C to constant weight. Root-shoot ratio (RSR) was obtained as the ratio of root dry weight to shoot dry weight. Root volume was determined by measuring the volume of water displaced by the root system.

### Pot Culture

The four genotypes were also grown in pots in the greenhouse. Six-liter plastic pots with drainage holes at the bottom

were used. Each pot contained approximately 5 kg of sandy soil to obtain a bulk density of 1.58  $\text{g/cm}^3$ . Before filling the containers with soil, 5 g of a compound  $\text{N}_6\text{P}_{20}\text{K}_{10}$  fertilizer was thoroughly mixed with the growth medium in each container to remove nutrient deficiency as a limiting factor (Cissé et al., 1996).

The soil in each pot was watered to field capacity 2 d before planting. After sowing the plants were maintained at near field capacity for 2 wk. The daily water requirements of the plants were determined as the difference between the weight of a fully irrigated pot and the weight of the pot 24 h later, after the day's evapotranspiration. This determination was done weekly to take care of changing water demands of the plants with age. The plants were then subjected to two soil moisture regimes, water-stressed and a well-watered control. The water-stressed regime simulated field conditions in the semi-arid zones where the plants are relieved of their stress for only 2 to 3 d by the characteristic sparse rainfall pattern. In the water-stressed pots, plants were rewatered when they showed initial permanent wilting, that is, the permanent wilting of the basal leaves, the point at which the soil must be irrigated if growth of a crop is to continue. At each watering session, each container was supplied with 0.5 L of water, an amount sufficient to relieve drought symptoms for 1 to 2 d but inadequate to bring the pot to field capacity.

The experimental design incorporated a randomized complete block with four genotypes and two watering regimes for a total of eight treatment combinations. The treatments were arranged in three blocks, and in each block a treatment was replicated three times for a total of 24 experimental units. Each experimental unit was made up of six pots. The experiment lasted for 6 wk.

At harvest, the same agro-morphological measurements as in the hydroponic study were made. In addition, nodule number and biomass were determined. Physiological measurements were made weekly on the third fully developed leaf from the top of the plant. Stomatal conductance ( $G_s$ ) was measured using a steady state porometer (Model LI-1600, LICOR, Ltd, Lincoln, NE). Osmotic potential ( $\Psi_\pi$ ) was determined with a calibrated vapor pressure osmometer (Model C-52, Wescor Inc., Logan, UT) and read with a psychrometer microvoltmeter. Leaf relative water content (LRWC) was determined gravimetrically on a leaf disc and calculated from the relationship:  $[(W_{\text{fresh}} - W_{\text{dry}})/(W_{\text{turgid}} - W_{\text{dry}})] \times 100$ , where  $W_{\text{fresh}}$  was the weight of fresh sample,  $W_{\text{dry}}$  was the oven dry weight, and  $W_{\text{turgid}}$  was the turgid weight after floating the sample in water for 4 h (Jensen, 1989).

### Field Trial

Only three genotypes, Bambey-21, Mouride, and TN 88-63, were studied in the field trial because of problems encountered with the establishment of Melakh. They were sown on 19 March at planting distances of 0.25 m within rows and 0.50 m between rows. The plants were fertilized with compound  $\text{N}_6\text{P}_{20}\text{K}_{10}$  at the rate of 150 kg/ha. The experiment lasted for 8 wk.

The plant cultivars were subjected to two watering regimes: well watered (maximal evapotranspiration, Met), and water stressed at the vegetative phase until the beginning of flowering (Str). The two watering regimes and genotypes constituted the two factors studied in a split-plot, randomized complete block design with four replicates. The watering regimes at two levels were the main plot and the three cultivars were the subplot to give a total of 24 plots. The plots were 6.5 by 6.5 m with a yield area of 3 by 3 m at the center. Water stress was applied by withholding irrigation. Soil water content was

monitored with the aid of a neutron probe. Actual evapotranspiration (AET, mm d<sup>-1</sup>) was obtained from the following relationship (Allen et al., 1998):

$$\text{AET} = \text{Irr} + \Delta \text{ stock} \pm R \pm D,$$

where Irr. corresponds to the quantity of water given by irrigation,  $\Delta$  stock is defined as the difference in soil moisture content measured at two different dates such that  $S_1$  is the soil moisture content measured at date  $T_1$  and  $S_2$ , the soil moisture content at date  $T_2$  ( $\Delta \text{ stock} = S_1 - S_2$ );  $R$  and  $D$  correspond to water loss by runoff and percolation drainage, respectively. Irrigation of the plots was however performed in such a manner as to avoid runoff and percolation drainage, and by consequence,  $R$  and  $D$  were negligible. Each week, leaf area index was measured with the aid of a leaf surface area analyzer (Model LAI 2000, Li-Cor, Inc.) by measuring the difference between the flux quantity measured above the canopy and below the same canopy.

At harvest, pod weight, seed yield, and total aboveground biomass (shoot and pod) were determined. The weight of 100 seeds was measured with the aid of a numerical counter followed by their weighing. Water use efficiencies (WUE, kg ha<sup>-1</sup> mm<sup>-1</sup>) were determined for the pods (WUE<sub>p</sub>), the seed (WUE<sub>g</sub>), and the total aboveground biomass (WUE<sub>bt</sub>) as the ratio of each yield component to the amount of water consumed (Stanhill, 1986).

Stress index was also obtained from the relationship (Fischer and Maurer, 1978):

$$I_s = 1 - (Y_{\text{Str}}/Y_{\text{Met}}),$$

where  $Y_{\text{Met}}$  is the mean total yield (seed, pod, total biomass) at harvest under well-watered conditions and  $Y_{\text{Str}}$  the mean total yield under water-stress conditions. Stress index is important in translating the effect of water stress on plant yield. The more it approaches unity (1), the more depressive the effect of stress on the yield component (Ndunguru et al., 1995). On the other hand, as  $I_s$  approaches zero, the higher the resistance capacity of a plant to drought.

Statistical analysis of the results was performed with SAS (SAS Statistical Institute, Cary, NC). The data were subjected to analysis of variance (ANOVA) and the partitioning of the means were made with Duncan's Multiple range Test at 5% probability level.

### Holistic Performance Analysis

Holistic assessments were conducted only on the traits that showed genotypic differences to determine whether the performances of the genotypes under the three growth conditions in hydroponics, in pots, and in the field were comparable. For each trait, scores were assigned to each genotype according to its relative performance. The scores ranged from 1 (for a cultivar with the least performance) to 4 (for a cultivar with the best performance). The total score for each cultivar was

obtained on the basis of which comparisons were made and conclusions drawn (Ogbonnaya et al., 1997).

## RESULTS AND DISCUSSION

Analysis of variance conducted on the growth attributes of the four cowpea cultivars in hydroponics showed there were significant genotypic differences in plant height, collar diameter, leaf area, shoot, and root biomass, root volume, and RSR. No significant genotypic differences were obtained for maximum root length, which could be due to the restricted volume of the tubs. TN 88-63 attained the highest plant height, but was not significantly different from those of Melakh and Mouride, while Bambe-21 attained the least. The least collar diameter, leaf area, and shoot biomass were recorded for Melakh. Bambe-21 had significantly more root growth (in biomass and volume) than the other cultivars. Melakh had a significantly higher RSR compared to the other cultivars, whereas Mouride had the lowest (Table 1).

Variations due to the watering regimes were found highly significant for all the traits measured in the greenhouse. Water stress adversely affected all the growth, yield, and physiological traits that were measured. In general, increases in soil water deficit causes a decline in leaf water potential, CO<sub>2</sub> uptake, limitations in photosynthetic activities, wilting, and dramatic impairment of metabolic functions (Kramar, 1983). Prolonged drought leads to retarded growth, reduced yield, and may cause death.

Significant variations due to genotypes were observed for all the morphological traits. Significant interactions between watering regimes and genotypes were also observed for collar diameter, root biomass, RSR, and root volume. Combined with other factors, these later traits could be considered sensitive enough to soil moisture differences as to be used in screening tests (Clavel and Diouf, unpublished data, 1999). Further analysis of variance on the morphological traits that showed genotypic variations revealed that water stress was responsible for the variations observed in collar diameter, shoot biomass, and RSR. On the other hand, well-watered control conditions were only responsible for the variations in root volume, while both watering regime treatments caused variations in plant height, leaf area, root biomass, and nodule biomass (Table 2).

It is important to note that no significant genotypic variations and interactions were observed for the physiological traits, LRWC,  $\Psi_{\pi}$ , and  $G_s$ . This result confirms

**Table 1. Growth responses of four cowpea genotypes grown in hydroponics in the greenhouse.**

| Genotypes                      | Bambe-21 | Melakh  | Mouride | TN 88-63 |
|--------------------------------|----------|---------|---------|----------|
| Plant height (m)               | 0.636 b† | 1.032 a | 1.238 a | 1.163 a  |
| Collar diameter (mm)           | 8.22 a   | 6.28 b  | 7.09 ab | 7.39 ab  |
| Leaf area (m <sup>2</sup> )    | 0.198 a  | 0.138 b | 0.171 a | 0.189 a  |
| Shoot biomass (g)              | 10.35 a  | 7.11 b  | 8.23 ab | 8.53 ab  |
| Root biomass (g)               | 1.81 a   | 1.31 b  | 1.27 b  | 1.29 b   |
| RSR‡                           | 0.178 b  | 0.192 a | 0.153 c | 0.155 c  |
| Max. root length (m)           | 0.563 a  | 0.459 a | 0.498 a | 0.442 a  |
| Root volume (mm <sup>3</sup> ) | 2333 a   | 1133 c  | 1533 c  | 1833 b   |

† Within rows, means followed by the same letter are not significantly different ( $P = 0.05$ ) according to Duncan's multiple range test.

‡ RSR = root-shoot ratio.

**Table 2. Morphological and physiological traits of cowpea genotypes grown in pots in the greenhouse under well-watered and water-stressed conditions.**

| Traits                                | Well-watered |         |          |          | Water-stressed |         |         |          |
|---------------------------------------|--------------|---------|----------|----------|----------------|---------|---------|----------|
|                                       | Bambey-21    | Melakh  | Mouride  | TN 88-63 | Bambey-21      | Melakh  | Mouride | TN 88-63 |
| <b>Morphological</b>                  |              |         |          |          |                |         |         |          |
| Collar diam. (mm)                     | 8.05 a†      | 7.33 a  | 8.36 a   | 7.62 a   | 7.33 a         | 6.02 b  | 6.67 b  | 5.72 c   |
| Plant height (m)                      | 0.616 b      | 0.560 c | 0.535 c  | 1.016 a  | 0.226 b        | 0.204 b | 0.216 b | 0.585 a  |
| Leaf area (m <sup>2</sup> )           | 0.112 b      | 0.090 b | 0.157 ab | 0.264 a  | 0.050 b        | 0.035 c | 0.057 b | 0.077 a  |
| Shoot biomass (g)                     | 14.02 a      | 12.59 a | 18.07 a  | 15.65 a  | 5.28 a         | 4.42 ab | 4.45 ab | 3.67 b   |
| Root biomass (g)                      | 5.58 a       | 6.72 a  | 3.50 b   | 7.89 a   | 1.93 b         | 2.03 b  | 3.02 a  | 2.89 a   |
| RSR‡                                  | 0.40 a       | 0.37 a  | 0.37 a   | 0.51 a   | 0.37 b         | 0.47 b  | 0.67 a  | 0.79 a   |
| Max. root length (m)                  | 0.509 a      | 0.546 a | 0.463 a  | 0.537 a  | 0.449 a        | 0.445 a | 0.351 b | 0.474 a  |
| Root vol. (mm <sup>3</sup> )          | 3183 a       | 2433 b  | 2433 b   | 3444 a   | 867 a          |         | 1178 a  | 1178 a   |
| N° of Nodules                         | 238 a        | 188 b   | 236 a    | 244 a    | 38 c           |         | 77 a    | 56 b     |
| Nodule biomass (g)                    | 0.67 ab      | 0.58 b  | 0.74 ab  | 1.27 a   | 0.05 b         | 0.10 b  | 0.22 a  | 0.27 a   |
| <b>Physiological</b>                  |              |         |          |          |                |         |         |          |
| LRWC (%)#                             | 78.10 a      | 60.67 a | 70.04 a  | 66.06 a  | 62.9 a         | 49.20 a | 57.72 a | 50.09 a  |
| Ψ <sub>π</sub> (MPa) ¶                | -1.31 a      | -1.30 a | -1.31 a  | -1.46 a  | -1.79 a        | -1.53 a | -1.75 a | -1.65 a  |
| G <sub>s</sub> (cm s <sup>-1</sup> )§ | 0.42 a       | 0.38 a  | 0.54 a   | 0.43 a   | 0.126 a        | 0.170 a | 0.090 a | 0.110 a  |

† For each treatment, along the rows, means followed by the same are not significantly different (*P* = 0.05) according to Duncan's multiple range test.

‡ RSR = root-shoot ratio.

# LRWC = leaf relative water content.

¶ Ψ<sub>π</sub> = osmotic potential.

§ G<sub>s</sub> = stomatal conductance.

those reported earlier by Hall and Patel (1985), who observed little osmotic adjustment in the leaves of cowpea and little differences in leaf osmotic potential among 100 cowpea genotypes. Shackel and Hall (1983) did not observe genotypic differences in leaf water potential (Ψ<sub>w</sub>) among cowpea cultivars. Similarly, Pimentel et al. (1999) did not observe any significant differences in water potential between the Senegalese Mouride and the Brazilian Epace 10 cultivars. This absence of strong genetic differences in these traits may be explained by the narrow genetic base available to breeders when these lines were developed (Jordan et al., 1979), or their selection in similar environments (Sene, 1974; Cissé et al., 1995; 1997). Furthermore, Fussell et al. (1991) have argued that at the whole plant level, agromorphological responses to water deficit are easier to measure, and are more reliable criteria for selection of cowpea cultivars than physiological and biochemical responses.

Water regimes, genotypes, and interactions were significant for most of the traits measured in the field test (Table 3). Water stress had the highest depressive effect on the yields of Bambey-21, while Mouride was the least

affected. Water stress increased the seed weight of the three cultivars compared with the well-watered control. Increase in seed weight under water stress has also been observed in other legumes (Nautiyal et al., 1991). This may be due to the reduction in the number of seeds per pod and the partitioning of the available photosynthate to fewer seeds.

Under well-watered conditions at full vegetative growth, TN 88-63 and Mouride had more leaf development than Bambey-21 (Table 3). The higher LAI values recorded for TN 88-63, and Mouride could be attributed to their creeping and semierect habits, respectively. Under water stress, the cultivars did not show any significant differences in leaf development and the LAI values recorded for the three cultivars were below 2 under water stress.

Actual evapotranspiration (AET) of plants under well-watered conditions was 305 mm. This value was statistically different from 232 mm observed for plants under stress. High WUE<sub>bt</sub> were recorded for TN 88-63 under water-stressed and well-watered conditions, respectively. This water use economy is of interest for

**Table 3. Yield, yield components, and WUE of three cowpea genotypes grown in the field under well-watered and water-stressed conditions.**

| Traits  | Well-watered |         |          | Water-stressed |               |               |
|---|--------------|---------|----------|----------------|---------------|---------------|
|   | Bambey-21    | Mouride | TN 88-63 | Bambey-21      | Mouride       | TN 88-63      |
| <b>Yield and yield components (g)</b>           |              |         |          |                |               |               |
| Aboveground biomass                             | 2083 b†      | 2349 b  | 3182 a   | 1299 c (38)    | 2079 b (11.5) | 3031 a (4.8)‡ |
| Pod yield                                       | 2377 a       | 1729 b  | 1827 b   | 1110 a (47)    | 1449 a (16.2) | 1205 a (34)   |
| Seed yield                                      | 1838 a       | 1387 b  | 1520 ab  | 733 b (60)     | 1055 a (24)   | 912 ab (40)   |
| Biomass of 100 seeds                            | 19.13 a      | 14.03 b | 11.20 c  | 20.15 a        | 17.82 b       | 12.94 c       |
| LAI#  | 3.49 b       | 5.15 a  | 6.11 a   | 1.18 a         | 1.40 a        | 1.64 a        |
| <b>WUE (kg ha<sup>-1</sup> mm<sup>-1</sup>)</b> |              |         |          |                |               |               |
| Aboveground (WUE <sub>bt</sub> )#               | 7.27 b       | 7.35 b  | 10.04 a  | 6.36 c         | 9.25 b        | 12.8 a        |
| Seed yield (WUE <sub>s</sub> ) §                | 6.42 a       | 4.34 b  | 4.60 b   | 3.28 a         | 4.74 a        | 3.88 a        |
| Pod yield (WUE <sub>p</sub> ) ††                | 7.53 a       | 4.87 b  | 4.93 b   | 4.45 a         | 5.91 a        | 4.61 a        |

† For each treatment, along the rows, means followed by the same are not significantly different (*P* = 0.05) according to Duncan's multiple range test.

‡ () = percentage loss in yield.

# LAI = leaf area index.

¶ WUE<sub>bt</sub> = total biomass water use efficiency.

§ WUE<sub>s</sub> = seed water use efficiency.

†† WUE<sub>p</sub> = pod water use efficiency.

Table 4. Holistic performance analysis of traits that showed significant genotypic differences in hydroponics, in pots, and in the field under well-watered and water-stressed conditions.

| Treatments          | Pot culture        |      |      |     |      |     |              |      |      |     |      |      | Field trial    |      |      |     |  |  |
|---------------------|--------------------|------|------|-----|------|-----|--------------|------|------|-----|------|------|----------------|------|------|-----|--|--|
|                     | Hydroponic culture |      |      |     |      |     | Well-watered |      |      |     |      |      | Water-stressed |      |      |     |  |  |
|                     | B-21†              | Mel. | Mour | TN  | B-21 | TN  | B-21         | Mel. | Mour | TN  | B-21 | Mour | TN             | B-21 | Mour | TN  |  |  |
| Collar diam.        | 4.0                | 3.0  | 3.5  | 3.5 | —    | —   | 4.0          | 3.0  | 3.0  | 2.0 | —    | —    | —              | —    | —    | —   |  |  |
| Plant height        | 3.0                | 4.0  | 4.0  | 4.0 | 3.0  | 4.0 | 3.0          | 3.0  | 3.0  | 4.0 | —    | —    | —              | —    | —    | —   |  |  |
| Leaf area           | 4.0                | 3.0  | 4.0  | 4.0 | 3.0  | 4.0 | 3.0          | 2.0  | 3.0  | 4.0 | —    | —    | —              | —    | —    | —   |  |  |
| Shoot biomass       | 4.0                | 3.0  | 3.5  | 3.5 | —    | —   | 4.0          | 3.5  | 3.5  | 3.0 | —    | —    | —              | —    | —    | —   |  |  |
| Root biomass        | 4.0                | 3.0  | 3.0  | 3.0 | 4.0  | 4.0 | 3.0          | 3.0  | 4.0  | 4.0 | —    | —    | —              | —    | —    | —   |  |  |
| RSR‡                | 3.0                | 4.0  | 2.0  | 2.0 | —    | —   | 3.0          | 3.0  | 4.0  | 4.0 | —    | —    | —              | —    | —    | —   |  |  |
| Root volume         | 4.0                | 2.0  | 2.0  | 3.0 | 4.0  | 4.0 | —            | —    | —    | —   | —    | —    | —              | —    | —    | —   |  |  |
| Max. root length    | —                  | —    | —    | —   | —    | —   | 4.0          | 4.0  | 3.0  | 4.0 | —    | —    | —              | —    | —    | —   |  |  |
| N° of Nodule        | —                  | —    | —    | —   | 3.5  | 4.0 | 2.0          | 4.0  | 3.0  | 3.0 | —    | —    | —              | —    | —    | —   |  |  |
| Nodule biomass      | —                  | —    | —    | —   | 3.5  | 4.0 | 2.0          | 3.0  | 4.0  | 4.0 | —    | —    | —              | —    | —    | —   |  |  |
| Aboveground biomass | —                  | —    | —    | —   | —    | —   | —            | —    | —    | —   | —    | —    | —              | —    | —    | —   |  |  |
| Pod yield           | —                  | —    | —    | —   | —    | —   | —            | —    | —    | —   | —    | —    | —              | —    | —    | —   |  |  |
| Seed yield          | —                  | —    | —    | —   | —    | —   | —            | —    | —    | —   | —    | —    | —              | —    | —    | —   |  |  |
| Wt 100 seeds        | —                  | —    | —    | —   | —    | —   | —            | —    | —    | —   | —    | —    | —              | —    | —    | —   |  |  |
| LAI#                | —                  | —    | —    | —   | —    | —   | —            | —    | —    | —   | —    | —    | —              | —    | —    | —   |  |  |
| WUE <sub>m</sub> ¶  | —                  | —    | —    | —   | —    | —   | —            | —    | —    | —   | —    | —    | —              | —    | —    | —   |  |  |
| Total Score         | 26                 | 22   | 22   | 23  | 21   | 24  | 28           | 28.5 | 30.5 | 32  | 15   | 13   | 14.5           | 9.0  | 2.5  | 3.0 |  |  |
| % performance§      | 93                 | 79   | 79   | 82  | 88   | 100 | 78           | 79   | 85   | 89  | 83   | 72   | 81             | 60   | 83   | 80  |  |  |

† B-21 = Bambeey-21, Mel. = Melakh, Mour = Mouride, TN = TN 88-63.

‡ RSR = root-shoot ratio.

# LAI = leaf area index.

¶ WUE<sub>m</sub> = total biomass water use efficiency.

§ Obtained as the total score for each variety expressed as a percentage of its possible maximum score (28 being maximum score in hydroponics, 24 for well watered and 36 for water stressed in pots, and 18 for well watered and 15 for water stressed in the field).

**Table 5. Correlation between growth traits of cowpea in hydroponics with those under well-watered and water-stressed conditions in the field ( $n = 3$ ).**

|                    | Field trial   |                     |            |                    |               |                   |            |                  |
|--------------------|---------------|---------------------|------------|--------------------|---------------|-------------------|------------|------------------|
|                    | Well-watered  |                     |            | Water-stressed     |               |                   |            |                  |
|                    | Total biomass | WUE <sub>bt</sub> † | Seed yield | WUE <sub>g</sub> ‡ | Total biomass | WUE <sub>bt</sub> | Seed yield | WUE <sub>g</sub> |
| <b>Hydroponics</b> |               |                     |            |                    |               |                   |            |                  |
| Root biomass       | -0.538 ns     | -0.587 ns           | 0.884 ns   | 0.996**            | -0.848 ns     | -0.824 ns         | -0.838 ns  | -0.705 ns        |
| Root volume        | -0.230 ns     | -0.287 ns           | 0.989**    | 0.912*             | -0.626 ns     | -0.591 ns         | -0.971 ns  | -0.899 ns        |
| Shoot biomass      | -0.460 ns     | -0.512 ns           | 0.923*     | 0.985**            | -0.797 ns     | -0.770 ns         | -0.884 ns  | -0.766 ns        |

\* significant at  $P = 0.10$

\*\* significant at  $P = 0.02$ .

ns = not significant.

† WUE<sub>bt</sub> = total biomass water use efficiency.

‡ WUE<sub>g</sub> = seed production water use efficiency.

a plant that is grown essentially for its forage value. Whereas Mouride recorded higher WUE under water-stressed conditions, Bambey-21 on the contrary, obtained higher WUE under well-watered conditions in the field (Table 3). Water stress indices ( $I_s$ ) for Bambey-21 were rather high for all the yield components used in its assessment. On the basis of this result, it is therefore more sensitive to drought than the other cultivars.

A holistic analysis of the traits that showed genotypic differences is shown in Table 4. In hydroponics, Bambey-21 ranked the highest, followed by TN 88-63, while Mouride and Melakh performed the least. Similarly, in pots, under well-watered conditions, TN 88-63 and Bambey-21 were better cultivars than were Mouride and Melakh. The same trend was observed under well-watered conditions in the field. On the contrary, under water-stressed conditions in pots, the best growth was observed for TN 88-63 and Mouride, followed by Melakh, while Bambey-21 showed the least growth. Similarly, under soil moisture stress in the field, Mouride showed the best growth, followed by TN 88-63 and the least was by Bambey-21.

The relatively poor performances shown by Melakh and Bambey-21 under water stress could be explained by the fact that they are early maturing varieties. Hall et al. (1997) and Singh et al. (1997) have argued that early maturing varieties depend more on drought escape mechanisms, which enable them to complete their life cycle before the occurrence of terminal drought. If, however, they are exposed to intermittent moisture stress during the vegetative or reproductive stages, they perform very poorly. Hall et al. (1979) and Fischer (1980) have proposed that an intermediate level of earliness may be desirable since an extremely precocious plant may be as poorly adapted as a late one. As the rainy seasons are often marked by periods of severe water deficit, this would constitute a handicap in the productivity of these early maturing cultivars.

The utility of traits in a plant breeding program is strongly enhanced by the consistency in its performance (Hall et al., 1992) under different growth conditions. Correlation analysis performed between traits in hydroponics with those in pots were found not significant, except between root volume in hydroponics and under well-watered condition in pots ( $r = 0.76$ ). However, root volume and shoot biomass in hydroponics were positively correlated with seed yield under well-watered

conditions. Root biomass, root volume, and shoot biomass were significantly correlated with WUE<sub>g</sub> under well-watered conditions in the field (Table 5). On the contrary, no evidence of significant correlation between hydroponic traits and yield under water-stressed conditions in the field were found. These traits in hydroponics therefore, could only be used for selecting cowpea cultivars for growth under adequate soil moisture conditions and not under water deficit conditions in the field. A similar result was obtained by Mian et al. (1993) with wheat (*Triticum aestivum* L. em Thell.), where hydroponic culture selected for vigorous seedlings in soil with adequate moisture, but not under severe drought conditions.

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