Performance of Maize-Soybean Intercropping under Various N Application Rates and Soil Moisture Conditions in Northern Mozambique

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Abstract: Soybean has attracted increasing attention as a cash crop while subsistent maize production is the first priority for smallholder farmers in southern Africa. Our study examined the performance of maize-soybean intercropping system at three sites across northern Mozambique. Both monocropped and intercropped maize received three levels of N application, while soybean was grown without additional fertilization. The grain yield of monocropped maize applied N at three rates and that of monocropped soybean ranged 1.6 – 2.1 t ha⁻¹ and 0.57 t ha⁻¹, respectively, in Nampula; 1.7 – 3.9 t ha⁻¹ and 1.87 t ha⁻¹, respectively, in Gurue; and 2.8 – 4.5 t ha⁻¹ and 2.01 t ha⁻¹, respectively, in Lichinga. Relative to these values, maize-soybean intercropping demonstrated advantageous productivity over monocropping in terms of the land equivalent ratio (LER) at 1.15 – 1.49 across the experimental sites. LER above 1 was mainly attributed to the consistently superior growth of intercropped maize than the monocropped maize. Under moist field conditions, the LER values were particularly high in the non-fertilized plots because maize plants became more competitive and depressed the intercropped soybean yields to greater degrees with increasing N application rates. When exposed to a dry spell, intercropped soybean showed an apparent benefit in drought avoidance, as shown by the slow depletion of the soil water potential and leaf stomatal conductance and by the retention of the aboveground biomass relative to the monocropped soybean. These results indicate that maize-soybean intercropping can be beneficial to introduce soybean while ensuring subsistent maize production in the low-N-input and drought-prone environment that prevails in the region.

Key words: Land equivalent ratio (LER), Maize-soybean intercropping, Nitrogen application, Northern Mozambique, Rainfed farming.
Table 1. Soil physical and chemical properties (0 – 15-cm depth) at the three experimental sites.

|          | Bulk density (g cm⁻³) | Texture (%) | pH1:2.5 (H₂O) | Total C content (g kg⁻¹) | Total N content (g kg⁻¹) | Available P (mg kg⁻¹) | CEC (cmol kg⁻¹) |
|----------|----------------------|-------------|----------------|--------------------------|--------------------------|-----------------------|-----------------|
| Nampula  | 1.50                 | Clay 5.0    | Silt 7.0       | Sand 88.0                | 5.48                     | 5.0                   | 0.4             | 7.87            | 1.65 |
| Gurue    | 1.43                 | Clay 9.3    | Silt 11.0      | Sand 79.7                | 5.74                     | 5.3                   | 0.4             | 39.26           | 4.15 |
| Lichinga | 1.26                 | Clay 28.1   | Silt 22.3      | Sand 49.5                | 4.80                     | 13.2                  | 1.0             | 39.05           | 6.73 |

a: sieving and pipetting method  
b: NC analyzer, Sunigraph NC-220F (SCAS, Japan)  
c: Bray No.2 method (Bray and Kurtz, 1945)  
d: Ammonium acetate extract method at pH 7.0

and is commonly used to assess the performance of intercropping (Willey, 1979). It is generally accepted that LER values above 1 indicate that an intercropping system offers a land-use advantage over a monocropping system. Muoneke et al. (2007) showed yield advantage of maize-soybean intercropping with the LER values of 1.08 – 1.49 by testing various planting densities for two seasons in the savanna agro-ecological zone of Nigeria. However, the empirical data of this emerging cropping system is lacking in the region.

The advantages of maize-legume intercropping systems have been reported particularly under conditions of low N availability because the dominant maize plants become so competitive with increasing N availability that they substantially depress the productivity of the legume component and reduce the total land-use efficiency of the system (Searle et al. 1981; Ahmed and Rao, 1982; Chang and Shibles, 1985). Morris and Garrity (1993) noted that cereal-legume intercropping could be more advantageous in water-deficit environments due to the greater water-use efficiency of intercropping systems compared with the corresponding monocropping systems. However, they also noted that few empirical and quantitative data were available in examining the mechanisms and magnitudes of the advantageous effect of intercropping systems in various growing environments. This lack is partly related to an adherent difficulty in conducting intercropping trials at multiple sites. The experimental designs of intercropping systems within a single site are usually complex because many aspects of cultural practices affect the growth and competition of the component crops (Fukai and Trenbath, 1993). The fact that intercropping is primarily practiced in developing countries where research equipment and field infrastructure (e.g., weather stations and irrigation) are limited may also restrict an analysis of the interactive effect between growing environments and intercropping systems.

In the current study, an extensive research team was established to cover the field experiments at different locations under a trilateral partnership project (Pro-Savanna) among Japan, Brazil, and Mozambique for the agricultural development in northern Mozambique. In northern Mozambique, rainfed and extensive farming practices are dominant, and soybean production has gradually increased as a new cash crop for smallholder farmers (N2Africa, 2013). This region covers large variances in the pedoclimatic conditions, from sandy soils in the semi-arid east to relatively clayey soils in the sub-humid highland in the west (Tsujimoto et al., 2011).

This study examined the performance of a maize-soybean intercropping system compared to the corresponding monocropping systems at three experimental sites across northern Mozambique. At each site, three levels of N application rates to maize were established to assess how the competitiveness of maize affects the subordinate soybean growth under various field conditions. The aboveground growth and physiological responses of soybean as well as the field moisture conditions were monitored in the monocropping and intercropping systems throughout the growing periods. Then, we discuss the applicability of the maize-soybean intercropping system in the rainfed fields of this region.

Materials and Methods

1. Experimental design

Field experiments were conducted at three locations in Nampula (15º17’ S, 39º19’ E, 372 m alt.), Gurue (15º19’ S, 36º42’ E, 691 m alt.), and Lichinga (13º20’ S, 35º15’ E, 1397 m alt.), ranging from the northeastern plain to northwestern highland of Mozambique during the rainy season of 2012 – 2013. The pedoclimatic conditions varied greatly with the experimental site, i.e., the Nampula site was represented by a hot and semi-arid climate with sandy soils, while the Lichinga site had clayey soils with a cool and humid climate in the tropical highland. The pedoclimatic conditions of Gurue were intermediate between those of the two other sites. The soil physical and chemical properties of each experimental site are summarized in Table 1.

Seven treatments were laid out in a randomized complete block design with four replicates at every site. The treatments included soybean monocropping and a factorial arrangement of two cropping systems (maize monocropping and maize–soybean intercropping) with three levels of N application to maize rows. The treatments
are summarized as follows:

- **S**: Soybean monocropping
- **M (0N)**: Maize monocropping with no additional N
- **M (+N)**: Maize monocropping with 0.48 g per plant (equivalent to 3 g m\(^{-2}\)) of additional N
- **M (++N)**: Maize monocropping with 1.28 g per plant (equivalent to 8 g m\(^{-2}\)) of additional N
- **M/S (0N)**: Intercropping with no additional N
- **M/S (+N)**: Intercropping with 0.48 g per plant of additional N
- **M/S (++N)**: Intercropping with 1.28 g per plant of additional N

Each replicate plot was 6.4 × 5.6 m in size.

Locally recommended cultivars of maize (Matuba) and soybean (TGX-1937-1F) were used at all three sites. The Matuba is early-maturing and open pollinated cultivar of soybean, has relatively long growth duration among those that were recently released in Mozambique with 110 – 120 days to maturity (Sperling et al., 1994). The TGX-1937-1F, an indeterminate cultivar of soybean, has relatively long growth duration among those that were recently released in Mozambique with 110 – 120 days to maturity (Boahen, S., personal communication, November 7, 2014). The maize and soybean seeds were simultaneously planted in the north-to-south row direction on 19 Dec, 11 Dec, and 6 Dec, 2012, in Nampula, Gurue, and Lichinga, respectively. The plants were thinned three weeks later, leaving one plant per hill. The plantings densities in the monocropping plots were 6.25 hills m\(^{-2}\) (80 × 20 cm) for maize and 12.5 hills m\(^{-2}\) (40 × 20 cm) for soybean. The row arrangements of each cropping system are summarized in Fig. 1. In the intercropping plots, a maize row was replaced by three soybean rows every other two rows, which corresponds to the planting density of maize at 4.67 hills m\(^{-2}\) with soybean at 6.25 hills m\(^{-2}\). The relative planting densities of maize and soybean in intercropping were two-thirds (= 0.67) and a half (= 0.50) of those in the monocropping, respectively. A regionally available type of NPK complex fertilizer was uniformly incorporated into the soil at a rate of 3:6:3 g m\(^{-2}\) of N:P:K\(_2\)O one day prior to sowing at every site. Three weeks after sowing, urea was side-dressed along the maize rows at the designated application rates for the M (+N), M (++N), M/S (+N), and M/S (++N) plots. No additional fertilizer was applied to any soybean rows or maize rows in the M (0N) and M/S (0N) plots. The fields were rained throughout the growing periods. Manual weeding was frequently conducted. Pests were controlled by spraying chemicals.

2. Measurements

The daily mean temperature, rainfall, and solar radiation were recorded by Watchdog 1525 micro stations (Spectrum Technologies Inc., Plainfield, IL, USA) at each site. Changes in the soil water potential were recorded daily throughout the growing periods using watermark soil moisture sensors that were connected to Watchdog 1400 data loggers (Spectrum Technologies Inc., Plainfield, IL, USA). Moisture sensors were installed at a depth of 20 cm in the middle of the monocropped soybean rows (S) and intercropped soybean rows (M/S (0N)) at each replicate. The mean values of four replicates were calculated to represent the soil hydrological dynamics beneath the monocropped soybean canopy and intercropped soybean canopy at each site.

A portable Ap4-Porometer (Delta-T devices LTD., Burwell, Cambridge, UK) was used to examine the responses of stomatal leaf conductance of the soybean leaves (g\(_s\)) to the soil hydrological dynamics between the cropping systems at each site. The g\(_s\), on the abaxial side was measured for the central leaflet of the open-top leaf and then averaged for six plants in each plot. The g\(_s\) measurements were conducted between 1100 and 1400 h on clear sunny days at 48, 73, and 84 days after sowing (DAS hereafter) in Nampula, 70 and 84 DAS in Gurue, and 79 and 95 DAS in Lichinga.

The grain yields were determined by harvesting all four maize rows (4 rows × 5.6 m) and 36 soybean plants (6 rows × 6 plants) in the middle of the plots on 4 Apr and 3 May, respectively, in Nampula; on 22 Mar and 20 Apr, respectively, in Gurue; and on 18 Apr and 10 May, respectively, in Lichinga. Both maize and soybean were harvested approximately two weeks after the plants reached physiological maturity at each site. The grain yields were expressed in t ha\(^{-1}\) at a 0% moisture basis. The aboveground biomass was recorded by sampling four maize plants and six soybean plants from each replicate periodically and at harvest. The dry weights of the plant samples were determined after oven drying at 80 °C to a.
constant weight. The soybean plants were separated into leaves and other tissues to determine the changes in the leaf dry mass from the 2nd to 4th sampling points at each site.

3. Data analysis

The land equivalent ratio (LER) was calculated as the sum of the relative yields of maize and soybean in the intercropping plots to the monocropping plots using the following equation:

\[ LER = LER_{soy} + LER_{maize} = \frac{Y_{int-soy}}{Y_{mono-soy}} + \frac{Y_{int-maize}}{Y_{mono-maize}} \]

where \( Y_{int-soy} \), \( Y_{mono-soy} \), \( Y_{int-maize} \), and \( Y_{mono-maize} \) are the grain yields (t ha\(^{-1}\)) of intercropped soybean, monocropped soybean, intercropped maize, and monocropped maize, respectively. In the equation, the \( LER_{soy} \) and \( LER_{maize} \) are defined as the partial land equivalent ratios of soybean and maize, respectively, according to Ofori and Stern (1987). \( LER_{maize} \) was calculated as the relative yield of intercropped maize to monocropped maize at the same N application rates, i.e., \( M(0N) \) vs. \( M/S(0N) \), \( M(+N) \) vs. \( M/S(+N) \), and \( M(++)N \) vs. \( M/S(++)N \). The values of LER, \( LER_{soy} \) and \( LER_{maize} \) were calculated for each replicate (n = 4) to perform statistical analysis. A one-sample t-test was conducted to determine whether the LER values were significantly different from 1 (n = 4).

A three-way analysis of variance (ANOVA) was performed to determine the individual and interaction effects of the location (Nampula, Lichinga, Gurue; df = 2), cropping system (monocropping vs. intercropping; df = 1) and N application rate (0N, +N, ++N; df = 2) on the measured variables for maize. Because the soybean plants received no nutrient treatments, a two-way ANOVA was conducted to determine the single effects of the cropping system (monocropping vs. intercropping; df = 1) or treatment (S, M/S (0N), M/S (+N), and M/S (++N); df = 3) and the interaction of these factors with location on the measured variables for soybean. Student’s t-test and Tukey’s honestly significant difference (HSD) test were conducted to compare the mean values at the 5% level of probability. The JMP 8 software (SAS Institute Inc.) was used to perform the statistical analysis.

Results

1. Weather and soil hydrological conditions

Fig. 2 shows the daily rainfall and changes in the soil water potential beneath the monocropped soybean (S) and intercropped soybean (M/S (0N)) canopies during the trials at the experimental sites. The Nampula site had a severe dry spell from 66 to 88 DAS that corresponded to the seed-filling stage of soybean (R5) and the maturing stage of maize (Fig. 2A). The soil water potential at a 20 cm depth decreased sharply during this long dry spell, while the rate of decrease was significantly lower beneath the intercropped soybean canopy than beneath the monocropped soybean canopy. There was a nine-day lag in the soil water potential reaching below -50 kPa between the monocropped soybean canopy (at 70 DAS) and the intercropped soybean canopy (at 79 DAS). A slower soil water depletion beneath the intercropped soybean canopy was also observed during the periodic short dips in the water potential at approximately 35 and 55 DAS in Nampula, 85 DAS in Gurue, and 85 DAS in Lichinga. The Lichinga site had relatively constant rainfall and maintained a soil water potential above -50 kPa throughout the growing periods. The soil water potential gradually decreased after the maize harvest and at the maturing period of soybean at the end of the rainy season at every site. The mean
temperature and solar radiation were both greater in the order of Nampula, Gurue and Lichinga (Table 2).

### Table 2. Monthly averages of the daily mean temperature and daily solar radiation at the three experimental sites.

| Site     | Mean temperature (°C) | Solar radiation (MJ m⁻² day⁻¹) |
|----------|-----------------------|---------------------------------|
|          | Dec  | Jan  | Feb  | Mar  | Apr | Dec  | Jan  | Feb  | Mar  | Apr |
| Nampula  | 27.5 | 26.8 | 25.9 | 25.9 | 24.5| 24.2 | 23.1 | 22.7 | 24.1 | 23.2|
| Gurue    | 25.9 | 24.8 | 24.4 | 25.1 | 23.4| 20.6 | 18.8 | 20.7 | 22.2 | 19.0|
| Lichinga | 20.5 | 20.3 | 19.9 | 19.7 | 18.6| 17.1 | 15.3 | 16.0 | 16.9 | 17.7|

### 2. Grain yields of maize and soybean and the land equivalent ratio (LER)

Fig. 3 shows the grain yields of maize and soybean in each treatment (N application rate) and in the means of the yield in the three treatments (0N, +N, ++N). The grain yields of monocropped maize increased with increasing N application rates ($M(0N) < M(+N) < M(++N)$) in the range of 1.6 - 2.1 t ha⁻¹, 1.7 - 3.9 t ha⁻¹, and 2.8 - 4.5 t ha⁻¹ in Nampula, Gurue, and Lichinga, respectively (Fig. 3A). The mean yields and responses to N application were both small in the drought-stressed Nampula site relative to the other two sites. The intercropped maize yields were consistently lower than the monocropped maize yields at all of the N application rates. The relative grain yields of maize ($LER_{maize}$) were 0.75 - 0.86, 0.76 - 0.82, and 0.81 - 0.82 in Nampula, Gurue, and Lichinga, respectively (Table 3). However, these $LER_{maize}$ values were consistently higher than the relative planting density (= 0.67) of intercropping

### Table 3. Land equivalent ratio (LER) of the maize-soybean intercropping system and the partial LER ($LER_{soy}$ and $LER_{maize}$) as affected by different N application rates to maize.

| Location   | N application | $LER_{maize}$ | $LER_{soy}$ | LER  |
|------------|---------------|---------------|-------------|------|
| Nampula    | $M/S(0N)$    | 0.75          | 0.62        | 1.37 |
|            | $M/S(+N)$    | 0.82          | 0.60        | 1.41 |
|            | $M/S(++N)$   | 0.86          | 0.63        | 1.49 |
| Gurue      | $M/S(0N)$    | 0.81          | 0.48        | 1.29 |
|            | $M/S(+N)$    | 0.76          | 0.39        | 1.16 |
|            | $M/S(++N)$   | 0.82          | 0.33        | 1.15 |
| Lichinga   | $M/S(0N)$    | 0.81          | 0.46        | 1.27 |
|            | $M/S(+N)$    | 0.82          | 0.45        | 1.27 |
|            | $M/S(++N)$   | 0.82          | 0.33        | 1.15 |
| ANOVA      | Location (L) | ns.           | ***         | **  |
|            | N application (N) | ns.          | $P = 0.07$  | ns. |
|            | L x N         | ns.           | ns.         | ns. |

**P<1% and ***P<0.1%. ns. not significant.

The LER values with underbars are significantly different from 1 at $P < 5\%$ with one-sample t-test ($n = 4$). $\dagger P = 0.061$, ns. $P = 0.11$. 

Fig. 3. Grain yields of (A) maize and (B) soybean using different cropping systems (monocropping vs. intercropping) and N application rates to maize rows (0N, +N, and ++N) in Nampula, Gurue, and Lichinga. Within each location, values followed by the same letters do not significantly differ at 5% by Tukey’s HSD test. Error bars indicate the standard error of the replicates (n = 4).
The grain yields of monocropped soybean (S) vs. intercropped soybean (M/S (0N), M/S (+N), and M/S (++N)) were 0.57 t ha⁻¹ vs. 0.33 – 0.36 t ha⁻¹, 1.87 t ha⁻¹ vs. 0.61 – 0.88 t ha⁻¹, and 2.01 t ha⁻¹ vs. 0.66 – 0.93 t ha⁻¹ in Nampula, Gurue, and Lichinga, respectively (Fig. 3B). The general productivity and the yield difference between monocropping and intercropping were relatively small in Nampula. In the other two sites, the intercropped soybean yields tended to be suppressed to greater degrees as the

| Location  | Treatment | Individual yield g plant⁻¹ | Harvest Index (HI) | Individual yield g plant⁻¹ | Harvest Index (HI) |
|-----------|-----------|-----------------------------|--------------------|-----------------------------|--------------------|
| Nampula   | S         | 0                           | 0.30               | 4.5                         | 0.28               |
|           | M (0N)    | 25.7                        | 0.30               | 0                           | 0                  |
|           | M (+N)    | 28.5                        | 0.29               | 0                           | 0                  |
|           | M (++N)   | 34.1                        | 0.30               | 0                           | 0                  |
|           | M/S (0N)  | 27.7                        | 0.30               | 5.4                         | 0.35               |
|           | M/S (+N)  | 34.5                        | 0.30               | 5.3                         | 0.35               |
|           | M/S (++N) | 43.3                        | 0.30               | 5.7                         | 0.38               |
| Monocrop mean | 29.4       | 0.30                       |                    | 4.5                         | 0.28               |
| Intercrop mean | 35.2       | 0.31                       |                    | 5.3                         | 0.36               |
| Gurue     | S         | 0                           | 0.30               | 15.0                        | 0.37               |
|           | M (0N)    | 27.9                        | 0.25               | 0                           | 0                  |
|           | M (+N)    | 44.9                        | 0.30               | 0                           | 0                  |
|           | M (++N)   | 62.8                        | 0.34               | 0                           | 0                  |
|           | M/S (0N)  | 30.5                        | 0.26               | 14.0                        | 0.45               |
|           | M/S (+N)  | 50.6                        | 0.30               | 11.2                        | 0.48               |
|           | M/S (++N) | 76.6                        | 0.34               | 9.7                         | 0.47               |
| Monocrop mean | 45.2       | 0.30                       |                    | 15.0                        | 0.37               |
| Intercrop mean | 52.6       | 0.31                       |                    | 11.7                        | 0.46               |
| Lichinga  | S         | 0                           | 0.30               | 16.1                        | 0.48               |
|           | M (0N)    | 44.9                        | 0.35               | 0                           | 0                  |
|           | M (+N)    | 57.0                        | 0.34               | 0                           | 0                  |
|           | M (++N)   | 71.3                        | 0.37               | 0                           | 0                  |
|           | M/S (0N)  | 54.4                        | 0.33               | 14.9                        | 0.50               |
|           | M/S (+N)  | 69.8                        | 0.35               | 14.3                        | 0.51               |
|           | M/S (++N) | 86.6                        | 0.36               | 10.6                        | 0.48               |
| Monocrop mean | 57.8       | 0.36                       |                    | 16.1                        | 0.48               |
| Intercrop mean | 70.3       | 0.35                       |                    | 13.3                        | 0.50               |

ANOVA

| Source of Variation | Location (L) | Cropping Syst. (C) | N application (N) | L x C | L x N | C x N |
|---------------------|--------------|--------------------|-------------------|-------|-------|-------|
|                     | ***          | ***                | ***               | ns    | **    | ns    |
|                     | ***          | ns.                | ***               | ***   | ***   | ns.   |
|                     | ***          | ***                | ***               | ns.   | ns.   | ns.   |
|                     | ns.          | ns.                | ns.               | **    | *     | ns.   |
|                     | ***          | *                  | ns.               | ns.   | ns.   | ns.   |
|                     | P = 0.081    | ns.                | ns.               | ns.   | ns.   | ns.   |

Within each column, values with the same letter do not significantly differ at 5%.
*P < 5%, **P < 1%, and ***P < 0.1%. ns. not significant.
adjacent maize plants received higher N application rates (Fg. 3B). The yield suppression of intercropped soybean shown by relative grain yields of soybean (LER_{soy}) was 0.48, 0.39, and 0.33 in the \( M / S (0N) \), \( M / S (+N) \), and \( M / S (++N) \) treatments, respectively, in Gurue; and 0.46, 0.45, and 0.33, respectively, in Lichinga (Table 3). The sum of LER_{maize} and LER_{soy}, i.e., LER value, was 1.37 – 1.49, 1.15 – 1.29, and 1.15 – 1.27 in Nampula, Gurue, and Lichinga, respectively (Table 3). The LER values were consistently and significantly above 1, except at \( M / S (++N) \) in Lichinga (\( P=0.061 \)) and \( M / S (0N) \) in Gurue. The LER values were particularly high in Nampula due to the large LER_{soy} values of 0.60 – 0.63. The ANOVA indicated a significant effect of location on both LER and LER_{soy} values.

3. Individual grain yields and harvest index (HI) of maize and soybean

Table 4 summarizes the per-plant grain yield (hereinafter referred to as the individual yield) and harvest index (HI) of maize and soybean. The results of the ANOVA indicate that both the cropping system and N application rate significantly affected the individual yield of maize. The individual yield of intercropped maize was consistently greater than that of the monocropped maize with a mean rate of increase over N application treatment of 19%, 15%, and 22% in Nampula, Gurue, and Lichinga, respectively. These superior individual yields compensated to some extent for the reduced planting density in the intercropping system and provided LER_{maize} values above the relative planting density of 0.67 (Table 3). The HI of
maize in monocropping was not different from that in intercropping at any site (Table 4).

The individual yield of soybean did not significantly vary with the cropping system (monocropping or intercropping) and also with the N application rates (the degree of competitiveness) in the intercropped maize plants \((M/S (0N))\) vs. \(M/S (+N)\) vs. \(M/S (++N)\) in Nampula (Table 4). In the other two sites, the individual yields of soybean were significantly suppressed by intercropping compared with monocropping. The yield suppression rates were greater, as the intercropped maize plants received more N, at 6%, 25%, and 35% in the \(M/S (0N)\), \(M/S (+N)\), and \(M/S (++N)\) treatments, respectively, in Gurue; and at 7%, 11%, and 34% for the \(M/S (0N)\), \(M/S (+N)\), and \(M/S (++N)\) treatments, respectively, in Lichinga. The HI of soybean was significantly lower in monocropping than the intercropping in Nampula and Gurue (Table 4).

4. Changes in the aboveground biomass of soybean

Fig. 4 depicted changes in the aboveground biomass of soybean on a per-plant basis in the monocropping system (S) and intercropping system with various N application rates \((M/S (0N), M/S (+N),\) and \(M/S (++N)\)) in Nampula, (B) Gurue, and (C) Lichinga. Error bars indicate the standard error of the replicates \((n = 4)\).
Thereafter, the occurrence of a long dry spell significantly reduced the aboveground biomass of the monocropped soybean from the peak at 73 DAS to maturity (P < 5%), whereas the aboveground biomass of the intercropped soybean was not significantly changed during this period (Fig. 4A). As a result, the per-plant aboveground biomass of soybean at maturity was not different between the monocropping and intercropping systems in Nampula.

On the other hand, the aboveground biomass was gradually and consistently suppressed by intercropping compared with monocropping from the flowering stage to maturity in Gurue and in Lichinga (Fig. 4BC). The growth suppression of soybean was particularly severe when the adjacent maize plants received more N application. The per-plant aboveground biomass of soybean at maturity was reduced by 23%, 41%, and 49% in the M/S (0N), M/S (+N), and M/S (++N) treatments, respectively, in Gurue; and by 10%, 16%, and 33% in the M/S (0N), M/S (+N), and M/S (++N) treatments, respectively, in Lichinga. The trends of growth suppression were reflected in the differences in individual yields and LERsoy values among the treatments at each site (Table 3; Table 4).

5. Physiological responses of soybean leaves to the field moisture conditions in monocropping and intercropping

Fig. 5 shows the changes in the dry weight of soybean leaves around the flowering and seed-filling periods at
each site. Corresponding to the changes in the aboveground dry matter, the soybean leaf dry weight was significantly greater in monocropping than intercropping throughout the growing periods in Gurue and in Lichinga and prior to the dry spell in Nampula (Fig. 5A). However, substantial leaf abscission occurred during the dry spell in the monocropped soybean (S) plots in Nampula, which negated the differences in leaf dry weight between the cropping systems (Fig. 5A).

The leaf stomatal conductance (gs) around noon was significantly greater in the monocropped soybean than in the averages of intercropped soybean by 9 – 42% under moist soil conditions at the pre-flowering stage in Nampula, at the beginning of seed-filling stage in Gurue, and throughout the measurements in Lichinga (Fig. 6). As the soil water potential decreased, the gs of soybean gradually decreased with greater inclination in monocropping than in intercropping in Nampula. The difference in the gs between monocropping and intercropping was insignificant due to large standard errors among the replicates at the beginning of the dry spell. Thereafter, the gs of monocropped soybean became significantly lower than the intercropped soybean, with severely restricted values of 0.063 – 0.166 mol m\(^{-2}\) s\(^{-1}\) (Fig. 6A). The stop of rainfall at the end of the growing season in Gurue also decreased the soil water potential and resulted in a sharper decline in the gs of monocropped soybean than intercropped soybean (Fig. 6B). The gs values at the first measurement (79 DAS) in Lichinga were relatively low despite the moist soil conditions (Fig. 6C). This is most likely because the measurements were delayed until approximately 1400 h while the other measurements were conducted between 1100 and 1300 h.

Discussion

1. Performance of the maize-soybean intercropping system in Northern Mozambique

This study demonstrated the consistent yield advantage of the maize-soybean intercropping system over the corresponding monocropping systems as indicated by LER values of 1.15 – 1.49 across three different field conditions in northern Mozambique (Table 3). The high LER values were mainly attributed to the superior individual yields of maize in intercropping than in monocropping at any N application rate across the three sites (Table 4). The vigorous growth of individual maize plants is commonly observed in replacement intercropping systems with subordinate legume crops, which compensated to some extent for the reduced planting densities (Sivakumar and Virmani, 1980; Mao et al., 2012). This compensation effect can be generally explained by the superior capture of available resources on a per-plant basis with a reduced planting density for maize.

Previously, experiments that were conducted under rainfed conditions in West Africa showed positive results of maize-soybean intercropping systems with LER values of 1.20 – 1.70 or 1.08 – 1.49 (Raji, 2007; Muoneke et al., 2007). The moncropped grain yields in these studies, including the current study, were relatively low, i.e., approximately 0.6 – 2.0 t ha\(^{-1}\) for soybean and 1.3 – 4.5 t ha\(^{-1}\) for maize. In contrast, some irrigated experiments of maize-soybean intercropping have resulted in low LER values of approximately 0.99 – 1.05 when the monocropped grain yields were 1.7 – 3.9 t ha\(^{-1}\) for soybean and 9.2 – 14.5 t ha\(^{-1}\) for maize (Lesoing and Francis, 1999; Coll et al., 2012). These high-yielding experiments also exhibited superior individual yields of maize in intercropping relative to monocropping. However, the LER values were restricted because the intercropped maize plants were so competitive that they severely decreased the yields of the understory soybean.

These studies corresponded to the current results, in which the LER values tended to be high at the water-stressed Nampula site and under the non-fertilized treatment (M/S (0N)) in Gurue and Lichinga (Table 3), where maize productivity or competitiveness was relatively low (Fig. 3). Given the current low-input and low-output farming status in the region, the maize-soybean intercropping system can be regarded as a beneficial approach for smallholder farmers to introduce soybean while ensuring subsistent maize production. A combination of maize and soybean cultivars differing in growth duration, as tested in the current study, might be also an important component to improve the performance of maize-soybean intercropping system. Fukai and Trenbath (1993) reviewed that intercropping is most productive when component crops differ greatly in growth duration so that they can reduce competition for resources during the respective growing periods. Further studies are necessary to identify the optimum combination of maize and soybean cultivars for intercropping in various field environments in the region.

2. Soybean growth as affected by maize competition and field moisture conditions

In cereal-legume intercropping systems, subordinate legume crops are typically suppressed in their growth and grain yields due to resource competition or the shading effect of dominant cereal crops (Keating and Carberry, 1993). For instance, Tsubo and Walker (2004) showed that a maize canopy shaded an intercropped bean canopy from incident radiation by 77 – 86% during the reproductive stage and caused a 90% reduction in bean yields. The current study also demonstrated the growth suppression of the intercropped soybean to greater degrees with the increasing competitiveness of adjacent maize plants as they grew in later growth stages and received higher N application rates (Fig. 4BC). As a result, the intercropped...
soybean yields and LER_{soy} values decreased under the higher N application rates to maize plants in Gurue and Lichinga (Table 3).

In contrast, the individual grain yields of intercropped soybean were not different from that of the monocropped soybean (Table 4), which resulted in particularly high LER_{soy} and LER values in the water-deficit condition in Nampula (Table 3). The growth suppression of intercropped soybean occurred prior to the dry spell in Nampula, whereas the substantial biomass loss of the monocropped soybean negated the growth differences between the cropping systems irrespective of the N application rates to the intercropped maize during the dry spell (Fig. 4A).

The difference in growth response to the dry spell between monocropping and intercropping might be attributable to the slow soil water depletion under the intercropped soybean canopy relative to the monocropped soybean canopy (Fig. 2A). The significantly greater harvest index (HI) of the intercropped soybean might also be derived from this drought mitigation effect of intercropping because the dry spell corresponded to the seed-filling period when soybean is most sensitive to drought stress in determining grain yields (e.g., Eck et al., 1987). Although more repeated observations are required to confirm the drought-mitigation effect of the intercropping system, our experiment demonstrates the pronounced advantage of maize-soybean intercropping over monocropping in soil-water dynamics and soybean growth when exposed to water-deficit conditions.

3. Relationship between the leaf stomatal conductance of soybean and the field moisture conditions in monocropping and intercropping

The transpiration rate per unit leaf area is the product of stomatal conductance (g_s) and the gradient in the concentration of water vapor from the inside to the outside of the leaf, i.e., vapor pressure deficit (VPD). The significantly greater g_s and leaf mass must have contributed to the higher carbon assimilation rates in monocropped soybean under adequate soil moisture conditions at every site (Fig. 5; Fig. 6). However, the vigorous growth of the monocropped soybean could have come at a cost of rapid soil water depletion (Fig. 2) and caused severe drought stress, as reflected in the sharp decrease in the g_s and substantial leaf abscission during the long dry spell in Nampula (Fig. 5A; Fig. 6A). On the other hand, the low transpiration and slow growth rates under the limited light intensity might have contributed to the retention of the soil water potential and led to drought mitigation for the intercropped soybean during the dry spell. Although no measurements were conducted, g_s of intercropped soybean could have been particularly low relative to the monocropped soybean in the morning when most of the sunlight was expected to be cut by the adjacent maize canopy.

Harris and Natarajan (1987) noted that the reduction in the water potential of groundnut leaves was mediated when groundnut was intercropped with sorghum, which resulted in a productivity advantage of intercropping over monocropping to a greater extent under dry field conditions than wet field conditions. The retention of the leaf water potential was also reported for understory cowpea when intercropped with sorghum under water-deficit field conditions (Shackel and Hall, 1984). As Morris and Garrity (1993) noted, the effect of windbreak and reduced air temperature by shading from the maize canopy might have moderated the VPD of the intercropped soybean canopy. Although no measurements were conducted in the current study, this microclimate change in VPD might have also contributed to water conservation in the intercropped soybean canopy.

Using climatic data and a crop model simulation, Sinclair et al. (2014) recently reported that the beneficial effects of introducing genetic traits of limited transpiration and drought-tolerant N2 fixation would be particularly high in northern Mozambique among the areas in East and West Africa, suggesting that drought risk management is important for stable soybean production in the region. The maize-soybean intercropping system, in which the maize canopy shades the understory soybean, may offer an agronomic approach to cope with drought risks for soybean production under the drought-prone environment that prevails in the study region.

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