Toward Sustainable Cocoa (*Theobroma Cacao* L) Production: The Role of Potassium Fertilizer in Cocoa Seedlings Drought Recovery and Survival

James S. Kaba, Albert Y. Asare, Henrietta Andoh, Godswill K.S Kwashie, and Akwasi A. Abunyewa

Department of Agroforestry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

**ABSTRACT**

Cocoa (*Theobroma cacao* L) is an understorey plant that is highly sensitive to drought, especially at the seedling stage. In Ghana, only 20% cocoa seedlings survive the dry spells within 24 months after transplanting. Potassium (K) is known to enhance the growth of plants root to increase water uptake under drought conditions. This study assessed the effect of different levels of K fertilizer in enhancing the drought recovery and survival of four cocoa genotypes grown in Ghana. A 3 × 3 factorial experiment in Randomized Complete Block Design was carried out at the FRNR farm, Kwame Nkrumah University of Science and Technology, Ghana in 2019/2020 and 2020/2021 cropping seasons. The treatments consisted of 0 g, 4 g and 6 g plant⁻¹ of muriate of potash (60% K₂O) and three cocoa varieties: Amaz15-15XEq78 (V1); CRGB914XA150 (V2) and PA7/808XPound10 (V3). The result showed that cocoa varieties applied with 4 g or 6 g plant⁻¹ produced higher (p < .05) belowground and aboveground biomass than the control. The K treated seedlings had about 77% survival rate than the control (43%) seedlings. Among the varieties, V2 had better drought recovery and survival rate (81%), followed by V3 (78%) and V1 (71%). In addition to the morphological characteristics, K enhanced the nitrogen content in cocoa seedlings during drought recovery and this correlated positively (R = 0.863) with survival rate. In conclusion, when farmers grow V2 and apply 4 gK plant⁻¹ during drought, over 80% of the seedling will recover and survive. This has implications for K fertilty management, yield and the livelihood of smallholder (70%) cocoa farmers.

**KEYWORDS**

Water stress; cocoa varieties; climate change; biomass

**Introduction**

Cocoa (*Theobroma cacao* L) is an understorey tree and highly sensitive to climate variability. Unfortunately, the percentage of drought affected areas in the world has doubled since 1970s and developing countries are the most affected, especially the Sahel region of Africa where the majority (70%) of the world cocoa is produced (Abarchi et al., 2018; Läderach et al., 2013).

An analysis of the impact of climate change on cocoa production suggests a relatively drastic decrease of climatic suitability (rainfall and temperatures) in current growing regions by 2050 (Asante and Amuakwa-Mensah, 2015; Läderach et al., 2013; USAID, 2011). The consequences are increase evapotranspiration, high seedling mortality and decline in cocoa yield (Kaba et al., 2021; USAID, 2011). In Ghana, anecdotal estimates of in-field survival of cocoa seedlings implied that only 20% survive the dry spells within the first 24 months after transplanting. Even though the Cocoa Research Institute of Ghana (CRIG) has developed cocoa varieties for better seedlings...
establishment and growth, it has not yielded the required impact for farmers due to high cocoa seedling mortality as a result of prolonged dry seasons and low soil fertility (Padi et al., 2013; Djan et al., 2018).

Fortunately, Baligar et al. (2017), Djan et al. (2018) and Adenuga and Ariyo (2020) demonstrated that cocoa genotypes show varying degrees for early growth, physiology, and nutrients use efficiency and survival under drought conditions. Previous studies have focused more on clonal propagation, shading effect, the use of agroforestry systems and improving nutrients efficiency to enhance cocoa seedling survival (Famuwagun et al., 2018; Henao-Ramírez et al., 2021; Kaba et al., 2020; Lahive et al., 2019; Osorio et al., 2022). Unfortunately, cocoa seedling mortality on farmers field is still high and recent evidence (Baligar et al., 2017; Djan et al., 2018; Kaba et al., 2021; Läderach et al., 2013; USAID, 2011) show that higher atmospheric temperatures associated with climate change will lead to longer, more severe drought events and this will continue to have a negative impact on cocoa seedling establishment and survival. For instance, Padi et al. (2013) reported that the CRIG effort targeted at minimizing the effect of drought have mostly concentrated on choosing cocoa hybrids with high percentage survival under low shade conditions and on soil with low organic matter content.

 Fortunately, the application of potassium-based mineral fertilizers has been shown to increase the growth and surface area of plants root with corresponding increase in water uptake under drought conditions (Marschner, 2011; Zain and Ismail, 2016). For instance, Nguyen et al. (2002) and Römheld and Kirkby (2010) reported that appropriate potassium supply substantially increased the root growth, activate a wide range of enzyme systems, which regulate photosynthesis, water use efficiency and nitrogen uptake under water deficit conditions.

Our approach is novel, as no study has attempted to use potassium fertilizer to enhance cocoa seedling potential to recover and survival under drought stress. The closest attempt was by Djan et al. (2018) who used potassium fertilizer to enhance the resilience of cocoa seedling at nursery, but the approach was different and the result was at preliminary stage. In addition, we used morphological changes in cocoa seedlings induced by water deficits as indicators of drought recovery, establishment, and survival, since such indicators are considered better when selecting drought resilient crops (Kul et al., 2020; Shao et al., 2008).

Therefore, our objective was to assess the effect of different levels of K fertilizer in enhancing the drought recovery, establishment and survival of four cocoa genotypes commonly grown by farmers in Ghana. This we believe would reduce seedling replanting on farmers field and improve yield to enhance the livelihood of the majority (70%) of smallholder farmers who depend on cocoa farming.

**Materials and Method**

**Description of Study Site**

The experiment was carried out at the experimental farm of the Faculty of Renewable Natural Resource, Kwame Nkrumah University of Science and Technology (KNUST), Ghana (Figure 1). The site is located at Lat. 6° 40’ N; Long. 1° 34’ W. The area falls within the semi-deciduous forest zone of Ghana and is characterized by bimodal rainfall pattern (Badu et al., 2019). The major rainy season starts from March to July while the minor season starts from late August to November. The annual rainfall of the area ranges between 1250 mm–1500 mm and the mean annual temperature is 26.6°C.

The soil type in the study area is classified as Ferric Acrisol (Motsara, 2015). The initial soil (0–20 cm) analysis showed that the textural class of the soil is sandy-loam while the total N is 0.5 g/kg (Table 1).
Experimental Design

A 3 × 3 factorial experiment in Randomized Complete Block Design (RCBD) was used. The experiment consisted of three levels of potassium (0, 4, and 6 g/plant) and three varieties of cocoa (Amaz 15–15 X Eqx78; CRG8914 X PA150 and PA7/808 X Pound 10).

Thirty (30) seedlings of each variety were used per treatment with three replications. The potassium treatments were applied as dry granules of muriate of potash (MOP, 60% K₂O) at 4 g/plant and 6 g/plant and a control of no K application (0 g/plant).

Table 1. Initial physicochemical properties of the topsoil (0–20 cm) of the experimental site at the faculty of renewable natural resources research farm, Ghana.

| Parameter                        | Value       |
|----------------------------------|-------------|
| pH (H₂O) 1:1                     | 5.83 (0.3)  |
| Organic carbon (g/kg)            | 1.2 (0.1)   |
| Total Nitrogen (g/kg)            | 0.5 (0.0)   |
| Organic matter (g/kg)            | 2.07 (0.3)  |
| Available P (mg/kg)              | 7.81 (0.2)  |
| Exchangeable K (mg/kg)           | 82.87 (3.5) |
| Texture (%)                      |             |
| Sand                             | 62 (4.3)    |
| Clay                             | 15 (8.1)    |
| Silt                             | 23 (7.9)    |
| Textural class                   | Sandy-loam  |

Values are the means of five replicates. Values in parentheses are standard error of means.

Figure 1. Map of Ghana showing the experimental (FRNR Farm) site.
**Experimental Procedure**

The experiment was conducted in two cropping seasons; the 2019/2020 and 2020/2021 cocoa cropping seasons. In the two separate experiments, three cocoa varieties (hereafter called V) namely: Amaz 15–15 X Eqx78 (V1); CRG8914 X PA150 (V2) and PA7/808 X Pound 10 (V3) were evaluated. The cocoa varieties were obtained from the Cocoa Research Institute of Ghana (CRIG). The cocoa beans were raised in a nursery under a shade net (to protect the seedlings from direct sunlight) using 127 mm by 178 mm polyethylene bags filled with soil (850 g) at 0–20 cm depth. The soil was obtained from the Department of Agroforestry Research Farm, KNUST. Holes were created at the bottom of the polyethylene bags to allow excess water to drain and also prevent water logging.

Three beans of the cocoa were sown in each of the polyethylene bag and later thinned to two after 3 weeks of germination. The seedlings were irrigated with water for a period of three (3) months. After three (3) months, the initial physical parameters, such as number of leaves, stem height and stem diameter (5 cm above the ground surface with the aid of electronic calipers), belowground and aboveground biomass and the root: shoot ratio were taken and the seedlings were then subjected to drought stress (without watering or rainfall) for two weeks. After the two weeks, the physical growth parameters were measured again before muriate of potash was applied at 4 g and 6 g plant\(^{-1}\) with subsequent supply of water to field capacity at regular interval to monitor their recovery rate.

During the recovery process, the growth parameters were measured at 3, 6, and 9-weeks interval. At 3 months, the number of seedlings for each variety and treatment was recorded as number of survived seedling and were destructively sampled and analyzed for the belowground and aboveground biomass, root: shoot ratio, total biomass (DW), total nitrogen (%), and the amount of N estimated.

**Statistical Analyses**

Experimental data on cocoa seedlings were subjected to two-way Analysis of Variance (ANOVA) using GenStat Statistical software ninth edition and significant differences among the means at \(p < .05\) were compared by the least significant difference (LSD).

In addition, Person’s correlation analyses were carried out to detect functional relationships among cocoa seedling parameters.

**Result**

**Effect of Different Rates of Potassium on Early Growth Characteristics, Aboveground and Belowground Biomass of Cocoa Varieties during Drought Recovery**

The different levels of potassium (K) fertilizer had varied (\(p < .05\)) effect on the early growth characteristics of the cocoa varieties during the period of drought recovery. The stem diameter and plant height showed similar pattern of growth in response to the K rates (Table 2). For stem diameter, K fertilizer at the rate of 4 g and 6 g plant\(^{-1}\) did not differ for V1 and V2 while V2 and V3 were also similar in height but all were significantly (\(p < .05\)) higher than the control. The average stem diameter and height for the control was 2.04 mm and 18.37 cm compared to 3.41 mm and 21.01 cm for the K treatment, respectively (Table 2).

The aboveground and belowground biomass was higher (\(p < .05\)) in the K treatments than the control (Figure 2). The K treatments recorded more aboveground biomass (3.79 g/plant) compared to the control (2.37 g/plant). The belowground biomass showed different pattern among the cocoa varieties with the K treatments (Figure 2). V2 had higher (\(p < .05\)) belowground biomass while V1 and V3 were similar in their belowground biomass irrespective of the rate of K applied. But generally, any cocoa variety applied with either 4 g or 6 gK plant\(^{-1}\) produced higher belowground biomass than the control (Figure 2).
Table 2. Effect of different rates of potassium on the stem diameter and height of cocoa varieties during drought recovery at the FRNR Farms, Ghana (Values are averages of both cropping seasons and 3 months after the 2-week drought stress).

| K Rate (g/plant) | V1          | V2          | V3          | V1          | V2          | V3          |
|------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 0 MOP            | 2.03 ± 0.04b| 1.97 ± 0.08b| 2.12 ± 0.13c| 17.88 ± 1.18b| 18.24 ± 0.99b| 19.02 ± 1.15b|
| 4 MOP            | 3.48 ± 0.09a| 3.34 ± 0.06a| 3.47 ± 0.10a| 20.20 ± 1.11a| 20.41 ± 1.08a| 22.91 ± 1.26a|
| 6 MOP            | 3.54 ± 0.11a| 3.40 ± 0.12a| 3.22 ± 0.09b| 18.60 ± 0.98b| 20.85 ± 1.14b| 22.36 ± 1.49a|

Means with different letters within the same column are significantly different at P < 0.05. (± standard error of means)
V1 = Variety 1 (Amaz 15–15 X Eqx78)
V2 = Variety 2 (CRG8914 X PA150)
V3 = Variety 3 (PA7/808 X Pound 10)
MOP = Muriate of potash

Figure 2. Influence of different rates of potassium fertilizer on the amount of aboveground and belowground biomass produced by cocoa varieties during drought recovery process (values are averages of both cropping seasons). Means with different letters on bars are significantly different at P < .05. V1 = Variety 1 (Amaz 15–15 X Eqx78) V2 = Variety 2 (CRG8914 X PA150) V3 = Variety 3 (PA7/808 X Pound 10) MOP = Muriate of potash

Total Biomass (G), Total N (%) and the Amount of N (G) Produced by the Cocoa Varieties after 3 Months of Drought Recovery in Both Seasons

Even though the two seasons had similar pattern, they varied (p < .05) in the total biomass, %N and the amount of N produced by the cocoa varieties (Table 3). In both seasons, all varieties applied with K at both 4 g and 6 g plant⁻¹ had higher (p < .05) total biomass, %N and the amount of N than the control. The total biomass for the K treatment and control seedling was 4.57 g and 2.32 g plant⁻¹ (DW), respectively. Among the varieties, V2 had the highest total biomass, %N and amount of N in both seasons when K was applied either at 4 g or 6 g plant⁻¹, but both levels were similar (Table 3).

Cocoa Seedling Establishment and Survival after Three Months of Drought Recovery

The cocoa seedlings survival rate varied significantly (p < .05) among the varieties and the different K treatments. Generally, cocoa seedlings treated with any rate of K fertilizer had higher recovery and survival rate (77%) than the control (43%) seedlings (Figure 3). Among the varieties, V2 had higher (p < .05) establishment and survival (81%) either at 4 g or 6 g K plant⁻¹, followed by V3 (78%) with V1 showing the least survival rate of 71%. However, increasing the K rate from 4 g to 6 g plant⁻¹ gave similar response in all the varieties (Figure 3).
Table 3. Total biomass (DW), Total N (%) and the amount of N (g) of three cocoa varieties with different K treatments at three months after drought recovery in two cropping seasons.

|                      | 2019/2020 Season |                      |                      |                      |
|----------------------|------------------|----------------------|----------------------|----------------------|
|                      | Total biomass (g)| Concentration of N (%)| Amount of N (g)      |
|                      | V1               | V2                   | V3                   | V1                   | V2                   | V3                   |
| 0g MOP               | 2.04b            | 2.52b                | 2.40b                | 0.30b                | 0.50c                | 0.35c                |
| 4 g MOP              | 4.35a            | 5.24a                | 4.06a                | 0.66a                | 0.93a                | 0.62a                |
| 6g MOP               | 4.32a            | 5.31a                | 4.16a                | 0.71a                | 0.88b                | 0.82a                |

|                      | 2020/2021 season |                      |                      |                      |
|----------------------|------------------|----------------------|----------------------|----------------------|
|                      | Total biomass (g)| Concentration of N (%)| Amount of N (g)      |
|                      | V1               | V2                   | V3                   | V1                   | V2                   | V3                   |
| 0g MOP               | 1.87c            | 3.02b                | 1.49c                | 0.42b                | 0.37b                | 0.40b                |
| 4g MOP               | 3.66b            | 4.96a                | 4.81a                | 0.55b                | 0.82a                | 0.66a                |
| 6g MOP               | 4.04a            | 4.71a                | 3.85b                | 0.80a                | 0.77a                | 0.59a                |

Figure 3. Effect of different rate of potassium fertilizer on the rate of survival of different cocoa varieties during drought recovery (average of the two cocoa cropping seasons). Means with different letters on bars are significantly different at P < .05. V1 = Variety 1 (Amaz 15–15 X Eq78)V2 = Variety 2 (CRG8914 X PA150)V3 = Variety 3 (PA7/808 X Pound 10) MOP = Muriate of potas

The correlation matrix of the morphological growth characteristics, total N and survival rate of the cocoa seedlings showed that nitrogen content positively correlated (R = 0.863, P < .05) with the survival rate of the cocoa seedlings (Table 4). The morphological parameters that also positively correlated with the seedlings survival rate were the belowground (R = 0.226, P < .05) and belowground (R = 0.326, P < .05) biomass and the root: shoot ratio (R = 0.382, P < .05) (Table 4).

Discussion

Water-deficit stress, permanent or temporary, pose serious constraint to cocoa seedling establishment and survival than any other environmental factor. Morphological changes induced by water deficits in cocoa and other higher plants have been shown to be better indicators when selecting drought resilient crops (Kul et al., 2020; Shao et al., 2008). Therefore, this study examined the role different rates of potassium could play in enhancing the drought recovery, establishment and survival of different varieties of cocoa seedlings.
Our result (Table 2) showed that all the varieties treated with K increased in stem diameter and height compared to the control. This gives an indication of the impact of K in promoting these morphological characteristics of the cocoa seedlings which are sensitive to water stress and usually decrease in growth in response to drought conditions.

In line with an earlier study, Aboelill et al. (2012) and Aslam et al. (2013) found that plants treated with K fertilizer gave higher morphological growth parameters, including height, leaf number, and stem diameter, in two experimental seasons under water stress conditions. In addition, we found that increasing the K level from 4 g to 6 g per plant produced similar morphological growth characteristics in all the three varieties in both cropping seasons. This shows that cocoa seedlings respond to a favorable level of K and genetic variations among cocoa seedling does not influence stem diameter and height growth, contrary to previous findings (Hasanuzzaman et al., 2018; Khan et al., 2018). For instance, Djan et al. (2018) reported that under wider genetic variations of cocoa, the seedling showed different morphological characteristics including stem diameter and height. In addition, the observation (Table 2) in the control seedlings is similar to previous report on decreased stem diameter and height of Albizia, Erythrina, and Eucalyptus seedlings under drought stress (Patel and Golakiya, 1988; Shao et al., 2008), with Panneerselvam et al. (2007) reporting up to 25% decreased in height of citrus seedlings.

The varieties also showed varied responses to K in their aboveground and belowground biomass production (Figure 2). Wang et al. (2013) earlier indicated that when plants are treated with K, it has the potential to increase their belowground (root) biomass, leaves, and total dry matter. This validates our findings of higher amount of biomass in the K-treated seedlings compared to the control, and the fact that the number of leaves and height positively correlated with aboveground biomass (Table 4).

Among the Varieties, V2 had the highest amount of both aboveground and belowground biomass while V1 had the lowest (Figure 2). This gives an indication of varied rate of drought recovery potential among the cocoa varieties since belowground biomass (roots) production is a mechanism that plants adapt to access water at deeper soil zones under drought conditions.

Recent studies by Kul et al. (2020) and Kaba Seutra et al. (2021) reported that different plant varieties exhibit varied roots growth characteristics in response to drought since roots are the first part of the plant that detects drought, maintain growth, and distributes biomass to adjust to water deficit during plants development. This finding supports the result of Djan et al. (2018) who indicated that it was not strange to observe different root growth and other morphological characteristics in different varieties of cocoa seedlings.

We also observed that increasing the potassium from 4 g to 6 g per plant did not affect the amount of aboveground biomass produced in all the three varieties. This implies cocoa seedlings recovery from drought do not respond to K beyond a favorable amount (4 g per plant).

Similarly, Djan et al. (2018) found that under water stress conditions, cocoa seedlings treated with muriate of potash from 1 g to 3 g/plant had increased root and shoot biomass leading to improved vigor compared to cocoa seedlings without K application. However, some authors (Römheld and

### Table 4. Correlation matrix for growth characteristics, nitrogen content and survival rate of cocoa seedlings (averages of both cropping seasons).

|          | AGB | GBB | NL  | PH | RTS | SD  | NC  |
|----------|-----|-----|-----|----|-----|-----|-----|
| AGB      | 1.00|     |     |    |     |     |     |
| GBB      | 0.595| 1.00|     |    |     |     |     |
| NL       | 0.138| 0.162| 1.00|    |     |     |     |
| PH       | −0.002| 0.217| −0.104| 1.00|     |     |     |
| RTS      | 0.695| −0.076| 0.026| 0.36| 1.00|     |     |
| SD       | −0.032| −0.133| 0.191| 0.542| 0.27| 1.00|
| NC       | −0.189| −0.091| 0.283| −0.154| −0.28| −0.129| 1.00|
| SR       | 0.326| 0.226| −0.257| −0.164| 0.382| −0.122| 0.863|

AGB = Aboveground biomass, GBB = Belowground biomass, NL = Number of leaves, PH = Plant Height, RTS = Root-to-Shoot ratio, SD = Stem diameter, NC = Nitrogen content, SR = Survival rate
Kirkby, 2010; Xu et al., 2020) observed inhibition of growth when excess K was applied while others (Bahrami-Rad and Hajiboland, 2017; Lindhauer, 1985) reported increased shoot growth and dry matter production under higher concentrations of potassium.

The highest amount of both aboveground and belowground biomass of V2 translated into the best survival percentage (82%) among cocoa varieties (Figure 3). The observation in V2 confirms the assertion that the application of potassium could enhance root growth (Aslam et al., 2013) and consequently influence cocoa seedling drought recovery, establishment, and survival. The above observation is further confirmed by the fact that the control had the lowest (43%) survival rate among the treatments. Our result further revealed that the application of K influences the concentration of N in cocoa seedlings and this further impact on their survival rate under drought stress. For instance, V2 had the highest survival rate of 82%, similarly, it had the highest concentration of N and amount of N. Similar pattern can be seen in V3 and V1 in both seasons (Tables 3 and 4).

This is further affirmed when N content had a positive correlation (R = 0.863, P < .05) with survival rate (Table 4). Literature (Kaba Seutra et al., 2021; Mandi et al., 2018; Nguyen et al., 2002) established that potassium is responsible for activating nitrate reductase; an enzyme critical for the production of protein in plants, regulating photosynthesis, water use efficiency, nitrogen uptake and protein building. Therefore, we can deduce that in addition to the morphological characteristics, the major role played by potassium in enhancing cocoa seedlings recovery from drought and subsequent survival is biochemical (activating the activities of nitrate reductase).

Conclusion

The study established that different cocoa varieties have varied responses to K fertilizer application during drought recovery. V2 (CRG8914 X PA150) had the best mechanism of recovering from drought and subsequent survival. Increasing K to 4 g per plant elicited a better recovery potential among the cocoa varieties compared to 6 g K per plant. The main effect of K was the adjustment of belowground (roots) biomass and this influenced the distribution of aboveground biomass, height, and stem diameter thus, helping the seedlings to recover from the impact of drought. In addition to the morphological characteristics, we speculate that the application of K enhances cocoa seedling shoot N during drought stress and this impact on drought recovery and survival.

Our findings have implications for sustainable cocoa production under climate change variability, K fertility management in cocoa soils and the long-term livelihood of the majority (70%) of smallholder cocoa farmers in Ghana and other cocoa producing countries.

Disclosure Statement

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ORCID

James S. Kaba [http://orcid.org/0000-0001-6432-3464]
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