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Effect of Nitrogen Fertilizer Application and Soil Moisture Regimes on Growth, Biomass Partitioning and Water Use Efficiency of Two Plantain Genotypes at the Nursery Stage

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Abstract — **Crop WUE is of important consideration where irrigation water resources are limited or diminishing and where rainfall is a limiting factor. One of the components of a management system that affects WUE is soil fertility. A complete and balanced fertility program helps to produce a healthier crop that can more easily withstand seasonal stresses. The study was conducted to evaluate the effects of two Nitrogen (N) levels (0 and 10gN/ plant) and three soil moisture regimes (40, 60, and 90% Field Capacity, FC) on the growth, biomass production and water use efficiency of two plantain genotypes Brodewuio (landrace, AAB) and PITA 24 (plantain hybrid, AABB). Plant height, girth and total leaf area were significantly increased by N application for the two genotypes. However these increments were higher in PITA 24 than Brodeyuo. The highest increments were obtained at 60% FC with N application for both genotypes. The specific leaf area of PITA 24 was significantly higher than that of Brodeyuo with or without N application. N application significantly increased shoot and total biomass for both genotypes. The highest shoot and total biomass were observed in PITA 24 at 60% and 90% FC respectively. The below-ground: above-ground ratio was mainly influenced by N application (Table 3). More biomass was partitioned to above-ground tissues when N was applied in both genotypes across the three soil moisture regimes. The highest relative growth rate for Brodeyuo was observed between 2nd and 3rd sampling when N was applied at 90% FC. The highest (water use efficiency) WUE was recorded when N was applied at 60% FC for the two genotypes. WUE of PITA 24 was higher than Brodeyuo. It is concluded that application of N fertilizer could increase growth and WUE of plantain.**

Keywords – **Nitrogen fertilizer, Soil moisture regimes, Plantain genotypes, Growth, Water use efficiency.**

I. Introduction

Water deficiency is a major factor limiting agricultural production worldwide. The increasing demand for food and water calls for a more efficient water use in agriculture. A better understanding of how water deficiency affects plant growth and yield production and of how water use efficiency in agriculture can be optimized is of great importance [1], [2].

Generally, plants adapt to dry conditions by developing a strong below-ground system for gathering limited soil resources, showing higher resource-use efficiencies and greater biomass allocation to root [3],[4]. An appropriate N supply could stimulate plant growth, improve water-use efficiency (WUE), and alleviate the effects of drought stress [5] [6]. Reference [7] also reported that adequate N supply could enhance plant drought tolerance. However, excess N applications can reduce biomass allocation to root [3] increase leaf sensitivity to stress [8] and lead to depressed plant growth [9] under drought conditions.

There is abundant evidence that drought stress reduces nutrient uptake and their availability for growth [10] - [12]. Likewise, increased levels of soil water positively affect nutrients input, decomposition, mineralization, and physical transport, all of which can increase their availability to the plant [13], [14]. Therefore, it is important to understand how soil water and nutrients act together to regulate plant growth in adverse environments. Such knowledge will help to improve resource-use efficiency, increase biomass accumulation, and alleviate drought-induced effects.

Genotypic differences exist in nutrient uptake, growth and water use. Different genotypes of Malus rootstocks show various responses to drought stress, as manifested by their biomass accumulations, allocations, and water use efficiency, WUE [15]. However, it is unclear whether there is a correlation between soil water and N supply for those parameters. Commercial production of plantain has increased demand for planting materials but there is little information on water use and nutrient requirement for plantain at the nursery stage. In the present study, we examined the effects of N supply on growth, biomass production, and WUE of two plantain genotypes, PITA 24 (plantain hybrid, AABB) and Brodeyuo (landrace, AAB) under different soil moisture regimes. Information on the effects of different moisture levels and N fertilizer application on growth, dry matter production and WUE of different plantain genotypes will offer a very good insight about the agronomic performance of these genotypes. It will increase the interest in the adequate use of water which is vital for its efficient management and use in crop production especially in urban and per urban areas of developing countries. Our objective was to obtain information that can be used to improve plantain sucker production and alleviate drought-induced effects when plantain suckers are grown under water stressed conditions.

II. Materials and Methods

A pot experiment was conducted at University of Ghana Forest and Horticultural Crops Research Centre, Kade in the Eastern region of Ghana. Maiden suckers of two plantain genotypes Brodeyuo (landrace, AAB) and PITA 24 (plantain hybrid, AABB) were obtained from mother plants and corms were pared and split into mini-setts of 300 g.

The mini-setts were treated with Bendazim (carbendazim fungicide) at the rate of 2g per litre of water to prevent fungal infection and rot. The mini-setts were then planted in sterilized sawdust in nursery boxes to sprout. Watering was done immediately the mini-setts were planted in the sawdust and afterwards whenever necessary.

One month after nursing the split corms, the sprouted mini-setts were transplanted into polybags filled with 10 kg soil after crushing and screening through 2mm sieve at three moisture levels 90% Field Capacity (FC), 60% FC and 40% FC with two Nitrogen levels (control, no N fertilizer (N0) and 10gN as Ammonium sulphate (N1). The N fertilizer was applied one week after transplanting. Each treatment consisted of 10 plants and arranged in a completely randomized block design with 3 replications. The plants were watered whenever necessary.

Three months after transplanting, plant height and plant girth were recorded. Afterward, six plants were harvested from each treatment and divided into leaf, stem, and root portions to determine values for above-ground biomass, root biomass, total biomass, and the root/shoot ratio (R/S, root biomass divided by shoot biomass). Materials were oven-dried at 70°C to a constant weight before measuring total dry weight for each tissue type. Total leaf area was obtained by multiplying the length and breadth of individual leaves and multiplying it by a factor 0.8 summing the individual leaf area of the plants. Specific leaf area was calculated as Leaf area ⁄ leaf dry weight.

WUE was defined as the ratio of dry biomass production to total water transpired during the experimental period. The initial average dry mass of plants was subtracted from their final biomass for WUE calculation. While calculating the amount of water transpired over time, evaporative loss from the pot was taken into account by subtracting the average amount of water loss from the control pots.

Crop water use is the water used by the crop for growth and cooling purposes and was determined by summing up the water stored in the plant and the amount of water transpired. The water stored in the plant was determined by finding the difference between the fresh and the dry weight of the harvested maize plant. Crop water use per day was calculated as the ratio of the Cumulative water used up to the sampling period to number of days within the period. Crop water consumption rate was calculated according to [16] as the ratio of cumulative water used or consumed to total leaf area at specific time periods.

Crop water use/day was calculated= (Cumulative water used up to the sampling period) / (number of days within the period).

Data were analyzed using analysis of variance procedure with GenStat 5.0 Release 4.23DE, Discovery Edition 1 [17] Duncan Multiple Range Test was employed for means separation.

III. Results

Plant height, girth and total leaf area were significantly increased by N application for the two genotypes as shown in Table 1. However these increments were higher in PITA 24 than Brodeyuo. The highest increments were obtained at 60% FC with N application for both genotypes. The specific leaf area of PITA 24 was significantly higher than that of Brodeyuo with or without N application. It was observed that N application did not significantly affect specific leaf area in both genotypes at the different soil moisture regimes. The highest specific leaf area was obtained in PITA 24 when N was applied at 60% FC.

Table 1. Influence of N supply on plant height (cm), total leaf area (cm^2), plant girth (cm), specific leaf area (cm^2/g) for two plantain genotypes (PITA 24 and Brodeyuo) under different soil moisture condition at the nursery stage.

Plantain genotype	Nitrogen level	Field capacity (%)	Plant height (cm)	Plant girth (cm)	Total leaf area (cm^2)	Specific leaf areacm2
Brodeyuo	N0	40	35.6h	10.8h	4343.7g	1.13e
		60	39.0f	12.6f	4436.7g	1.13e
		90	37.5g	11.3g	3504.1h	1.12e
	N1	40	55.9d	15.0d	10859.6d	1.10e
		60	58.0c	17.2c	10220.7d	1.11e
		90	57.5c	17.0c	11434.4c	1.20d
PITA 24	N0	40	37.0g	11.5g	4503.8g	1.49b
		60	42.0e	13.2e	5803.6e	1.33c
		90	39.0f	12.2f	5398.0f	1.44b
	N1	40	56.0d	15.4d	11009.4c	1.54a
		60	69.0a	19.8a	15057.5a	1.59a
		90	63.0b	18.3b	14003.9b	1.48b

Values with the same letters in the same column are not significantly different (P= 0.05) by DMRT

The application of nitrogen fertilizer significantly increased dry matter production, irrespective of genotype and soil moisture level (Table 2). N application significantly increased shoot and total biomass for both genotypes. The highest shoot and total biomass were observed in PITA 24 at 60% and 90% FC respectively. However in Brodeyuo the highest shoot and total biomass were observed at 90% FC. Brodeyuo produced a higher root biomass than PITA 24 with or without N application. The highest root biomass was observed in Brodeyuo when N was applied at 60% FC. Soil moisture regimes significantly influenced corm biomass production in both genotypes with or without N application. Soil moisture at 60 and 90% FC significantly increased corm biomass over 40% FC in both genotypes. Without N application there was no significant difference in corm biomass production at 60 and 90% FC for Brodeyuo. The highest corm biomass was produced at 90% FC with N application in Brodeyuo (Table 2).

Table 2. Influence of N supply on shoot biomass (g), root biomass (g), corm biomass (g), total biomass (g) for two plantain genotypes (PITA 24 and Brodeyuo) under different soil moisture condition at the nursery stage.

Plantain genotype	Nitrogen level	Field capacity (%)	Shoot biomass (g)	Root biomass (g)	Corm biomass (g)	Total biomass (g)
Brodeyuo	N0	40	28.8j	24.4c	12.6e	65.8h
		60	36.1h	20.2e	18.4d	74.5f
		90	39.4g	26.6ab	18.9d	84.6d
	N1	40	49.5e	10.8g	9.4f	69.8g
		60	70.7c	27.0a	25.9b	122.7b
		90	71.0c	26.3ab	28.4a	126.0b
PITA 24	N0	40	34.1i	18.1f	9.8f	61.9i
		60	48.7e	24.5c	18.8d	91.7c
		90	43.7f	24.9c	21.7c	90.3c
	N1	40	51.7d	12.6	8.1g	73.0e
		60	96.2a	25.8b	25.4b	144.5a
		90	92.5b	23.2d	28.2a	143.2a

Values with the same letters in the same column are not significantly different (P= 0.05) by DMRT

Table 3. Influence of N supply on biomass partitioning for two plantain genotypes (PITA 24 and Brodeyuo) under different soil moisture condition at the nursery stage.

Plantain genotype	Nitrogen level	Field capacity (%)	Below-ground: above-ground	root: above-ground	corm: root	corm: above-ground
Brodeyuo	N0	40	1.29a	0.85a	0.52e	0.44ab
		60	1.06b	0.56c	0.90b	0.50a
		90	1.15ab	0.67b	0.72d	0.48ab
	N1	40	0.40g	0.22f	0.84c	0.17e
		60	0.64e	0.41d	0.96b	0.23d
		90	0.77d	0.37	1.07ab	0.40b
PITA 24	N0	40	0.87c	0.53c	0.54e	0.28d
		60	0.92c	0.51c	0.82c	0.42ab
		90	1.07b	0.57c	0.87c	0.50a
	N1	40	0.34h	0.23ef	0.47f	0.11e
		60	0.43g	0.27e	0.98b	0.15e
		90	0.56f	0.25e	1.22a	0.31c

Values with the same letters in the same column are not significantly different (P= 0.05) by DMRT

The below-ground: above-ground ratio was mainly influenced by N application (Table 3). More biomass was partitioned to above-ground tissues when N was applied in both genotypes across the three soil moisture regimes. On the other hand, below-ground biomass allocation was higher in treatment without N application. These distribution patterns resulted in increased below-ground: above-ground ratio for treatments without N application. Generally the soil moisture regimes did not significantly affect the below-ground: above-ground ratios, the highest were obtained at 90% FC. Brodeyuo produced a higher below-ground: above-ground ratio compared to PITA 24. The highest root: above-ground and corm: root ratios were obtained with Brodeyuo when N was applied at 40% and 90% FC respectively.

Nitrogen fertilizer application significantly influenced relative growth rate of the two genotypes (Table 4). The highest relative growth rate for Brodeyuo was observed between 2nd and 3rd sampling when N was applied at 90% FC. However, for PITA 24, the highest relative growth rate was observed between 3rd and 1st sampling when N was applied at 90% FC. The lowest relative growth rate for the two genotypes was obtained at 40% FC with or without N application.

Table 4. Influence of N supply on relative growth rate for two plantain genotypes (PITA 24 and Brodeyuo) under different soil moisture conditions at the nursery stage.

Plantain genotype	Nitrogen level	Field capacity (%)	RGR btn2nd and 1stsamp	RGR btn 2nd and 3rdsamp	RGR btn3rd and 1stsamp
Brodeyuo	N0	40	3.12d	4.06d	4.14cd
		60	4.04b	4.19c	4.25c
		90	4.00b	4.32b	4.38c
	N1	40	3.70c	4.13	4.18cd
		60	4.25ab	4.75ab	4.62ab
		90	4.44a	4.90a	4.77a
PITA 24	N0	40	3.76c	4.01d	4.07d
		60	3.99b	4.40b	4.46b
		90	4.20ab	4.38b	4.44b
	N1	40	4.08b	4.17c	4.44b
		60	4.46a	4.85a	4.56b
		90	4.49a	4.87a	4.70a

Values with the same letters in the same column are not significantly different (P= 0.05) by DMRT

Table 5. Effect of N supply on water used (Litres), WUE and consumptive water use of two plantain genotypes (PITA 24 and Brodeyuo) under different soil moisture conditions at the nursery stage.

Plantain genotype	Nitrogen level	Field capacity (%)	Water used (Litres)	WUE	Consumptive water use (mls/cm^2)
Brodeyuo	N0	40	14.60h	4.50d	3.40e
		60	22.40e	3.38g	5.42c
		90	37.00a	2.2i	8.56a
	N1	40	14.20h	4.88c	1.31i
		60	21.70f	4.98c	2.12h
		90	34.00c	3.82f	2.89f
PITA 24	N0	40	15.40g	4.00ef	3.30e
		60	20.10ef	4.70cd	4.50d
		90	35.10b	2.60h	6.50b
	N1	40	13.00i	5.60b	1.10j
		60	20.70ef	6.50a	1.40i
		90	33.00d	4.40d	2.40g

Values with the same letters in the same column are not significantly different (P= 0.05) by DMRT

Water used was mainly influenced by soil moisture regimes (Table 5). Water used significantly increased with increasing soil moisture. The highest water used for the two genotypes was obtained at 90% FC with or without N application. N application slightly reduced water used in both genotypes.

Nitrogen fertilization increased water use efficiency for the two genotypes. The WUE increased with N fertilizer application in both genotypes, and was significantly different from that of no N fertilizer application. The highest WUE was recorded when N was applied at 60% FC for the two genotypes. WUE of PITA 24 was higher than Brodeyuo.

Consumptive water use was significantly reduced by N application. The lowest Consumptive water use was recorded in PITA 24 when N was applied at 40% FC whilst the highest was recorded in Brodeyuo without N application at 90% FC.

IV. Discussion

The results of the study indicated that nitrogen supply have great influence on growth and biomass production of the different plantain genotypes at different moisture regimes (Tables 1 and 2). Similar observation was reported with other plant species [12], [18], [19]. N application dramatically increased both growth and the accumulation of biomass at the higher soil moisture regimes. Parameters such as plant height, girth, total leaf area and biomass production showed positive responses to N application with increasing soil moisture content. These findings imply that both N supply and soil moisture level are critical for growth and biomass production of plantain. Similar observations have been reported with plants grown in both relatively wet and relatively dry regions [5], [20]. This demonstrates that an appropriate supply of water and nitrogen may contribute to higher carbon assimilation. As proposed by [21], plants often use N primarily for the production and maintenance of leaves in order to maximize carbon fixation for optimal growth.

The observation that application of N significantly reduced below-ground: above-ground ratio indicates that more assimilates were allocated to the shoot when N was applied. Reference [22] have suggested that such nitrogen-induced responses can be attributed to the balance between absorption and utilization of water and nutrients, that is, plants adjust their developmental patterns to facilitate the acquisition and distribution of growth-limiting resources. The study also showed that Brodeyuo had a higher below-ground: above-ground ratio than PITA 24 indicating that Brodeyuo can withstand water stress more than PITA 24. Biomass allocation may be a key sensitive predictor of functional responses to stress [23]. Partitioning more biomass to roots, thereby maintaining a higher R/S, may be advantageous for drought-adapted plants at the onset of drought stress because greater water absorptive component can sustain more water and nutrient uptake for transpiration and respiration [24], [25].

Crop WUE is of important consideration where irrigation water resources are limited or diminishing and where rainfall is a limiting factor. Additionally, recent increases in energy prices have many irrigated producers asking how to manage inputs to maximize efficiency of their water resources. One of the components of a management system that affects WUE is soil fertility. Inorganic fertilization has been reported to mitigate the adverse effects of water stress by increasing the WUE of crop growth and development [26] - [28]. Increasing evidence suggests that mineral-nutrient status of plants plays a critical role in enhancing water use efficiency by proper nutrition. Nitrogen is important in improving WUE and soil water use. Increased yields and WUE from added N were observed in several dry-land areas where crops were grown on the same land for several years [29].

WUE, the functional indicator strongly related to plant development and health under a moisture deficit, is dependent upon the amount of water used for growth and biomass production [30], [31]

N application improved WUE and reduced Consumptive water use in the two genotypes. The higher WUE obtained with PITA 24 over Brodeyuo may be due to their genetic differences. The same observations have been reported by [5] and [6], and may be related to differences among cultivars in their production of biomass. Leaf area, photosynthesis rate, and stomatal conductance play dominant roles in determining WUE because they are sensitive to biomass production, which is a direct factor that influences WUE [22].

Root biomass also strongly impacts WUE because a larger water-absorptive component (that is, the roots) can improve water uptake and sustain more water supplies for transpiration [32]. Therefore, our results suggest at least two mechanisms by which the N supply affects plants WUE. First, the increased availability of soil nitrogen might lead to higher values for leaf area, photosynthesis rate, and biomass production, and, hence, improved drought tolerance and WUE. Second, an adequate N supply may lead to a greater root biomass, which can enhance water uptake and then result in a higher drought tolerance and WUE. Reference [33] have suggested that a balance exists between the N supply and WUE or drought tolerance. Our results also allow us to conclude that sufficient nitrogen is associated with greater adaptability of plantain suckers to drought conditions, which is manifested by better growth, increased biomass production, and improved WUE. Water, nitrogen, cultivar and their interaction greatly influenced plant development, biomass production, and WUE.

V. Conclusion

Application of sufficient nitrogen is associated with greater adaptability of plantain suckers to drought conditions, which is manifested by better growth, increased biomass production, and improved WUE.. Therefore, we conclude that an appropriately low supply of nitrogen is good for an efficient production of split corm-derived plantain suckers.

VI. Acknowledgment

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I. Current research areas

1. Evaluation of different combinations of soilless potting media on the growth of split corm-derived plantains (*Musa* spp.) suckers.
2. Evaluation of effects of pot size and growing media on the growth of cocoa (*Theobroma cacao*) seedlings.
3. Evaluation of effects of pot size and different mulching types on the growth of transplanted cocoa (*Theobroma cacao*) seedlings.

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