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Effect of fertilizer placement on storage root yield and leaf elemental concentration of 'Whatley/Loretan' sweetpotato variety

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Field studies were conducted to evaluate the effect of various fertilizer placements on nutrient uptake, growth responses, storage root yield and leaf elemental concentration of Whatley/Loretan sweetpotato [*Ipomoea batatas* (L.) Lam.]. The fertilizer placement treatments comprised broadcast (Br), banded at two different widths (Ba), side dressing (Sd) or applied in various combinations of the above, and an untreated check. Fertilizer rates were 135, 35 and 133 kg.ha^{-1} each of N, P and K based on soil test. At nine weeks after planting, the fifth fully expanded leaf from the tip of five plants was collected and analyzed for elemental concentration. The plants were harvested 101 days after transplanting and biomass data were collected. Vine yield for all placement treatments was equal to or exceeded that of the full rate broadcast. Yield of US # 1 roots was increased 78 and 72%, respectively, when 2/3 of the fertilizer was banded and tended to increase total storage root yield compared to the same, full or 2/3 the rate broadcast. Leaf N was highest with 1/3 Ba at planting with two side dressings, while leaf P was reduced by all treatments compared to the check. Leaf K was highest with 2/3 the rate Br at planting. Storage root N was lower than foliar N while root K increased with 1/3 Br combined with 1/3 Ba. Root Ca, Mg, Fe and B were not significantly affected by placement. Root Mn was lower than foliar Mn suggesting that sweetpotato distributes more Mn to foliage relative to storage roots. Generally, these results suggest that placement rather than quantity of fertilizer applied enhanced yield and elemental concentration.

Key words: Broadcast fertilizer, *Ipomoea batatas*, banded fertilizer, side-dressing, elemental concentration, storage roots, plant nutrition.

INTRODUCTION

Crop producers want increased crop yields with increased use of fertilizer inputs, which is applied through broadcasting. This has put a strain on the environment as they sometimes spend more on inputs to produce crops with diminishing returns. They incur an extra cost of fertilizer application that is causing environmental

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pollution due to leaching in Dead Zones (Breitburg et al., 2018; Watson, 2016; Karstensen et al., 2016). This N leaching results in principal loss and often limiting nutrient needed by plant for growth (Plošek et al., 2017). There must be optimization of fertilizer use to achieve high nutrient use efficiency and high crop productivity (Schütz et al., 2018; Paul, 2016; Tilman et al., 2002). High fertilizer costs coupled with the increasing awareness of non-point source pollution run-off of applied fertilizers is putting pressure on farm economics (O'Geen et al., 2010). Banding of fertilizer has been shown to be much more efficient than broadcasting in supplying nutrients to most crops as well as reducing nitrate and phosphate pollution. For example, Alam et al. (2018) showed that banding placement P, produced the highest available, and total P, content in soil at 0-6 cm depth after harvesting of maize, as well as a significant increase in P uptake by maize plants.

N in single bands 15 cm from the plants produced high late season yield of tomatoes and combined placements in wider bands or four bands produced high fruit yield and leaf concentrations of N, P, K, and Mn of fresh market tomatoes (Wyatt et al., 2001). Parish et al. (1997), found inconsistent response of several vegetable crops to fertilizer placement. They found differences in plant size and vigor in spring turnips with broadcast treatments appearing superior but yield at first harvest and total yield was lower, neither cabbage nor turnip responded to placement treatments. Thus, most fertilizer placement studies have been conducted using vegetable crops with economic production above ground.

Although several fertilizer studies have been conducted with sweetpotatoes, very few have been directed towards fertilizer placement effects on yield and /or nutrient uptake. Earlier work suggests that storage root yield was improved with half the fertilizer applied prior to planting, either directly under the ridge or between 10 and 15 cm from the plants on a level with slightly below the depth at which the plants were set; the remainder being applied two to three weeks after planting (Steinbauer and Kushman, 1971). Tsuno and Fujise (1968) found that storage root yields were increased when K was banded 30 or 40 cm deep into the soil layer. The objective of this experiment was to evaluate the impact of fertilizer placement treatments on vine and storage root yield, root dry matter and elemental leaf and root concentration of sweetpotato.

MATERIALS AND METHODS

'Whatley/Loretan' sweetpotato slips were grown on a Norfolk sandy loam soil (fine, silicious, thermic typic Paleudult with a pH of 6.2, organic matter <1%, cation exchange capacity of of 4.94 mm L/kg and total N 0.08%, Mortley and Ntibashirwa, 2012) at the George Washington Carver Agricultural Experiment Station in Tuskegee, AL located at latitude 30° 27' N and 85° 42' W with an elevation of 470.34 m above sea level. Temperature and rainfall during the growing season averaged 32°C and 158 mm, respectively. A randomized complete block design, with 10 treatments and 4 replications in 3-row plots measuring 1.2 m × 6.1 m (of which the center row was used for data collection) was used. Soil analyses results showed a pH level of 6.2, P and K levels medium and Ca, high. The fertilizer sources were ammonium nitrate (34% N), triple superphosphate (34% P) and muriate of potash (60% K) which were applied at rates 135, 35 and 133 kg ha^{-1} respectively. Treatments were a combination of banded (Ba), broadcast (Br), combined broadcast/banded (Br/Ba) two days before planting, combination of banding with one or two side-dressings (Ba/Sdr_1, Ba/Sdr_2) at, wide bands (WBa) and an untreated check. Banded fertilizers were placed 10 cm on each side of the plants except WBa which were placed 15 cm on either side or 10 cm deep.

All broadcast fertilizer were evenly applied over each plot area and incorporated manually. All banded treatments except those in wide bands (WBa) were applied in double bands 10 cm on each side of the plants and 10 cm deep. Plants were side dressed similar to Ba being applied as close to the plants as possible (10 cm) 40 days after planting and a second side dressing was applied at 56 days after planting. The plants were subjected to standard cultural practices and moisture was supplied through drip irrigation.

Sweetpotato slips were planted using 0.30 m in-row spacing. At nine weeks after planting, leaf samples consisting of the fifth fully expanded leaf from the end of the vine of five plants were collected from each plot. The leaves were cleaned by dipping in tap water, followed by three successive deionized water rinses. Leaf samples were dried at 65°C for 48 h and ground to pass a 1 mm screen. At harvest, storage root samples (25 g) were collected from four randomly selected US #1 storage roots from each plot and dried at 65°C for 48 h and ground to pass through 1 mm screen. All samples were analyzed for N, P, K, Ca, Mg, Mn, Cu, and B by the Plant Testing Laboratory at the Auburn University, Alabama (located 32° 35' 36.0852' N and 85° 29' 42.5868' W)

Storage root yield and foliage weight data were obtained from roots and foliage harvested 101 days after transplanting. Storage roots were graded according to the guidelines of the National Sweepotato Collaborators Group (NSCG, 2009) into marketable (US#1, canners and jumbo) and non-marketable (culls and cracks), and root and foliage yields determined. All fields, leaf and storage root analyses data were subjected to analysis of variance and to Waller-Duncan's Bayesian K-ratio t test at K=100 (SAS, 2009).

RESULTS AND DISCUSSION

Growth responses

Sweetpotato vine yield increased under all placement treatments except with 1/3Br compared to the unfertilized control (Table 1). Differences in vine yield among comparable Ba and Br treatments (2-5) were not evident. However, plants receiving 1/3 of the fertilizer Ba combined with 1/3 Br (treatment 7) produced significantly higher vine yield than when a similar rate was Ba with one side-dressing, or 1/3 the full rate Ba with 2/3 applied as two side-dressings (treatments 8 and 9). Thus, vine yields produce by all Ba placement treatments at lower quantities were as great as or greater than that of the full rate Br (treatment 6).

Total storage root yield increased substantially in response to placement treatments except with the 2/3 or full rate Br (treatments 5 and 6), when compared with that of the untreated check. Storage root yield tended to be greater with 2/3 Ba (treatment 4) when compared with either a similar or full rate Br. Most placement treatments

Table 1. Fertilizer placement effects on vine and storage yield and percent dry matter (DM) of 'Whatley/Loretan' Sweetpotato.

Treatments	Vine[z] Yield	Storage root yield Total	Storage root yield Marketable	DM
		(t ha^{-1})		(%)
Check	3.4[d]	10.2[b]	9.7[c]	18.5[abc]
1/3Ba[y]	10.7[bc]	23.7[a]	21.4[abc]	20.5[a]
1/3Br	8.1[cd]	25.5[a]	25.5[ab]	19.9[ab]
2/3Ba	12.3[abc]	31.1[a]	29.0[ab]	17.7[abc]
2/3Br	15.6[ab]	21.7[ab]	19.3[abc]	16.7[c]
1Br	13.0[abc]	22.8[ab]	19.8[abc]	16.2[c]
1/3Br/Ba	17.6[a]	26.0[a]	23.5[ab]	17.1[abc]
1/3Ba/Sd_1	10.5[bc]	27.5[a]	25.2[ab]	18.3[abc]
1/3Ba/2/3Sd_2	11.1[bc]	33.6[a]	31.9[a]	18.2[abc]
2/3WBa	11.8[abc]	32.0[a]	30.0[ab]	17.0[c]

[z]Mean separation in columns by Waller-Duncan's Bayesian K-ratio t-test at K=100. Means not followed by the same letter are significantly different. [y]Banded (Ba) broadcast (Br), combined broadcast/banded (Br/Ba), combination of banding with one or two sidedressings (Ba/Sd_1, Ba/Sd_2), wide bands (WBa). Bands were placed 10 cm on either side of the plants except WBa which were placed 15 cm on either side. All bands were 10 cm deep.

increased marketable yield markedly over that of the untreated check (Table 1). Marketable yield was greater when with 2/3 of NPK Ba compared with either the 2/3 Br or full rate Br; the highest marketable root yield was obtained when Ba was combined with two side-dressings. There was no difference in yield of non-marketable root yield among treatments. However, it should be noted that non-marketable yield made up only 5 and 3.6% of total yield among plants receiving treatments 4 and 9, respectively, compared to 12% for treatment 6. The number of storage roots produced per plant was not significantly lower in treatments involving higher (2/3) rates Br, Br/Ba, or the full rate Br.

Yield of US#1s increased significantly when 2/3 NPK was banded compared to either 2/3 Br, 1/3Ba/Br, or the full rate Br (Table 2). It is worthy of note also that the 2/3 Ba treatment produced similar yields of US#1s as that of 1/3 Ba with 2/3 Sd, or 2/3 Ba in wider bands. All fertilizer placement treatments produced significantly greater yields of US#1 storage roots than the untreated check. The percent of US#1s was significantly higher among plants compared to either the full or 2/3 the quantity Br. Although placement treatments significantly affected the yield of US#1s, they produced very little effect on yield of canners and jumbos.

These data show that neither vine nor total storage root yields were increased by comparable banded or broadcast placements regardless of quantity applied (Table 1). Vine yield was lowered with both side dressing treatments versus 1/3 Ba combined with 1/3 Br. However, vine yield was increased by all placement treatments compared to the check. This was probably due to the increased rate of N and P rather than K in these treatments. For example, Stino (1953) reported increased vine growth with N and P but none with K. Wide banding (WBa) at 15 cm did not reduce yields or have other unfavorable effects when compared to the standard bands (10 cm). This would suggest that fertilizer bands can be placed up to 15 cm on either side of the row for sweetpotatoes. It was also observed that total storage root and US # 1 yields produced by the 2/3 Ba treatment were at least equal to or exceeded those of the same or full rate Br, suggesting that storage root yields were enhanced with fertilizer placement rather than the quantity applied. It appears that higher fertilizer rates in the placement treatments tended to lower the percent dry matter of storage roots.

Leaf and storage root elemental concentration

Leaf N was higher in all treatments except with 1/3 Br or Ba compared to the check (Table 3). When 1/3 of the fertilizer was banded at planting followed by two side dressings, leaf N was significantly higher than with 2/3Ba at planting. Thus, an extra increment of fertilizer was needed to obtain an increase in leaf N and to equal the yield of the 2/3Ba treatment. Leaf P was reduced by all placement treatments compared to the untreated check, probably due to "dilution effects" brought about by the addition of carbohydrates from photosynthesis, resulting in greater vine and storage root yields obtained with these treatments. As with N, leaf K increased with most placement treatments except when only 1/3 of the fertilizer was either Ba or Br. Plants receiving 2/3 NPK Br had higher leaf K than the comparable rate Ba although

Table 2. Fertilizer placement effects on yield and marketable grades of US#1, Canners, Jumbos and Percent US #1 Storage Roots of 'Whatley/Loretan' Sweetpotato.

Treatments	US #1z	Canners	Jumbo	US #1
		($t\ ha^{-1}$)		
Check	4.4e	5.0^{a}	0.2^{a}	44.4^{c}
1/3Ba[y]	13.7^{d}	6.9^{a}	0.6^{a}	60.0^{ab}
1/3Br	14.9^{cd}	7.7^{a}	2.7^{a}	59.4^{abc}
2/3Ba	22.5^{ab}	5.9^{a}	0.5^{a}	73.9^{a}
2/3Br	12.6^{d}	5.1^{a}	1.5^{a}	59.6^{ab}
1Br	13.0^{d}	5.6^{a}	1.1^{a}	55.3^{bc}
1/3Br/Ba	15.6^{bcd}	52.2^{a}	2.6^{a}	60.2^{ab}
1/3Ba/Sd_1	$18.3^{a\text{-}d}$	5.9^{a}	0.9^{a}	64.3^{ab}
1/3Ba/2/3Sd_2	23.9^{a}	6.6^{a}	1.4^{aa}	72.0^{a}
2/3WBa	21.8^{abc}	7.0^{a}	1.1^{a}	69.3^{ab}

[z]Mean separation in columns by Waller-Duncan's Bayesian K-ratio t-test at K=100. Means not followed by the same letter are significantly different. [y]Banded (Ba) broadcast (Br), combined broadcast/banded (Br/Ba), combination of banding with one or two side dressings (Ba/Sd_1, Ba/Sd_2), wide bands (WBa). Bands were placed 10 cm on either side of the plants except WBa which were placed 15 cm on either side. All bands were 10 cm deep.

Table 3. Fertilizer placement effects on elemental leaf concentration of 'Whatley/Loretan' sweetpotato.

Treatments	N[z]	P	K	Ca	Mg	Mn	Fe	B
		(%)					($\mu g\ g^{-1}$)	
Check	3.05^{d}	0.33^{a}	1.53e	0.74^{a}	0.82^{a}	175.8^{a}	90.0^{a}	2.5^{a}
1/3Ba[y]	3.32^{cd}	0.25^{b}	1.91^{cde}	0.63^{a}	0.58^{ab}	188.0^{a}	64.5^{a}	16.8^{b}
1/3Br	3.3^{cd}	0.27^{b}	1.76^{de}	0.69^{a}	0.62^{ab}	213.5^{a}	69.0^{b}	16.8
2/3Ba	3.48^{bc}	0.24^{b}	2.28^{bcd}	0.56^{a}	0.48^{b}	242.3^{a}	63.8^{b}	13.3^{b}
2/3Br	3.58^{ab}	0.26^{b}	3.02^{a}	0.68^{a}	0.54^{b}	280.8^{a}	73.5^{b}	15.8^{b}
1Br	3.73^{abc}	0.25^{b}	2.94^{a}	0.67^{a}	0.51^{b}	274.5^{a}	72.0^{b}	15.0^{b}
1/3Br/Ba	3.85^{ab}	0.26^{b}	2.99^{a}	0.68^{a}	0.54^{b}	291.3^{a}	75.3^{ab}	15.8^{b}
1/3Ba/Sd_1	3.78^{ab}	0.26^{b}	2.26^{bcd}	0.58^{a}	0.52^{b}	211.2^{a}	73.3^{b}	12.5^{b}
1/3Ba/2/3Sd_2	3.88^{a}	0.26^{b}	2.71^{ab}	0.55^{a}	0.46^{b}	185.5^{a}	75.0^{ab}	12.3^{b}
2/3WBa	3.61^{abc}	0.25^{b}	2.39^{bc}	0.73^{a}	0.59^{ab}	194.0^{a}	71.0^{b}	14.8^{b}

[z]Mean separation in columns by Waller-Duncan's Bayesian K-ratio t-test at K=100. Means not followed by the same letter are significantly different.
[y]Banded (Ba) broadcast (Br), combined broadcast/banded (Br/Ba), combination of banding with one or two side dressings (Ba/Sd_1, Ba/Sd_2), wide bands (WBa). Bands were placed 10 cm on either side of the plants except WBa which were placed 15 cm on either side. All bands were 10 cm deep.

this increase was not reflected in improve storage root yields (Constantin et al., 1977). All treatments involving Br or Br/Ba tended to produce higher leaf K than the other treatments. Leaf Ca, Mg, and Cu were not significantly affected by any placement treatments regardless of quantity applied, while leaf Fe and B were reduced by most treatments. Leaf N, P, Ca, and Mg were all within the sufficiency ranges for sweetpotato during the first half of the growing season (Mills and Jones, 1996), while K was marginally lower especially for lower rates Ba or Br.

Storage root N (Table 4) was higher in all treatments except with 1/3 Br at planting in combination with 1/3Sdr1. The highest root N was obtained with 1/3Br/Ba at planting. The results for root N concentration agree with published reports by Scott and Bouwkamp (1974); Hammet et al. (1984) and Mortley and Hill (1990) being less than foliar N but seemingly high enough to sustain storage root yield. Root P, Ca, and Mg were similar among treatments while root K increased significantly among plants receiving 1/3Br/Ba compared to plants receiving a similar quantity Ba, Ba with side dressing, Ba in wider bands, or 1/3Ba with two side dressings. Thus, there was a stronger K response in the root tissue than was obtained in the leaf tissue as seen by other researchers (Hammett et al., 1984). Plants receiving 2/3Ba, 1/3Ba/Br or 1/3Ba with two side dressings had higher root Mn than plants in the untreated check.

Storage root Mn was much lower than leaf Mn. Other researchers have reported that the distribution of Mn

Table 4. fertilizer placement effects on elemental concentration in storage roots of 'Whatley/Loretan' Sweetpotato.

Treatments	N^z	P	K	Ca	Mg	Mn	Fe	B
	(%)					((µg g^{-1})		
Check	0.59^{de}	0.18^{a}	1.03^{d}	0.05^{a}	0.07^{a}	12.5^{c}	21.0^{a}	4.3^{a}
1/3Ba^y	0.66^{cde}	0.14^{a}	1.42^{cd}	0.07^{a}	0.09^{a}	20.8^{abc}	24.7^{a}	4.3^{a}
1/3Br	0.52^{e}	0.15^{a}	1.05^{d}	0.06^{a}	0.06^{a}	19.3^{bc}	20.3^{a}	3.8^{a}
2/3Ba	0.79^{bc}	0.15^{a}	1.38^{bc}	0.06^{a}	0.08^{a}	34.3^{a}	24.0^{a}	3.8^{a}
2/3Br	0.82^{bc}	0.14^{a}	1.52^{ab}	0.06^{a}	0.08^{a}	22.0^{abc}	28.0^{a}	4.5^{a}
1Br	0.82^{bc}	0.14^{a}	1.59^{ab}	0.06^{a}	0.07^{a}	25.3^{abc}	25.0^{a}	4.6^{a}
1/3Br/Ba	1.1^{a}	0.16^{a}	1.75^{a}	0.06^{a}	0.09^{a}	31.3^{ab}	26.7^{a}	4.5^{a}
1/3Ba/Sd_1	0.76^{bcd}	0.16^{a}	1.39^{bc}	0.06^{a}	0.08^{a}	24.0^{abc}	23.0^{a}	3.8^{a}
1/3Ba/2/3Sd_2	0.85^{b}	0.14^{a}	1.29^{bcd}	0.07^{a}	0.08^{a}	28.5^{ab}	22.3^{a}	4.0^{a}
2/3WBa	0.79^{bc}	0.16^{a}	1.34^{bcd}	0.05^{a}	0.07^{a}	22.5^{abc}	24.5^{a}	4.0^{a}

[z]Mean separation in columns by Waller-Duncan's Bayesian K-ratio t-test at K=100. Means not followed by the same letter are significantly different. [y]Banded (Ba) broadcast (Br), combined broadcast/banded (Br/Ba), combination of banding with one or two side dressings (Ba/Sd_1, Ba/Sd_2), wide bands (WBa). Bands were placed 10 cm on either side of the plants except WBa which were placed 15 cm on either side. All bands were 10 cm deep.

between the tops and roots varies among plant species. For example, Ward (1997) found the greatest accumulation of Mn in the roots of greenhouse0-grown tomatoes. Mn concentrations in the roots of alfalfa, tomato and barley relative to the tops. Manganese tolerance in some species attributed to various tolerance mechanisms including activation of the antioxidant system, regulation of Mn uptake and homeostasis, and compartmentalization of Mn into subcellular compartments (e.g., vacuoles, endoplasmic reticulum, Golgi apparatus, and cell walls), suggesting that several genes are involved in specific pathways controlling Mn detoxification (Jifu et al., 2019). Leaf Mn levels were within the sufficiency ranges of 40-250 µg g^{-1} (Mills and Jones, 1996) except among plants receiving 2/3 Br or Ba, the full rate Br of 1/3 Br/Ba. Root Ca was reduced significantly (no shown data) among plants treated with 2/3 Br or applied in wider bands and tended to be lower in the other treatments relative to the untreated check.

Conclusion

The results show that differences in vine yield were not evident among the comparable broadcast or banded NPK treatments. However, these results do suggest that a combined Br/Ba NPK fertilizer at two-thirds the recommended rate will enhance sweetpotato vine yield compared to Ba with either one or two side dressings. Total yield of US # 1 storage roots increased markedly by banding 2/3 the recommended rate at planting versus either the same rate or full rate Br. This suggests that economically optimum production of US # 1 storage roots can be obtained if the fertilizer is banded rather than when broadcasted at planting. In some countries and even in certain ethnic communities in the United States, sweetpotato is grown for its leaves to be used as a green vegetable like spinach because of its nutrient content or storage roots are used for ethanol production. The optimum fertilizer placement to meet most of the above sweetpotato production characteristics and uses appears to be the 2/3 banded rate. Although there were relatively few clear differences among comparable Br and Ba or combined treatments in uptake of nutrients, the data suggest that the tissue concentrations were enough for yield as no deficiency symptoms were evident.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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