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Biomass yield and partitioning of greenhouse-grown wild watermelon *Cucumis africanus* in response to different irrigation intervals and NPK fertilizer levels

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A study was conducted during the 2009-2010 summer growing season to determine the effects of varying irrigation frequencies and NPK application rate on biomass yield and partitioning to fractions of Cucumis *africanus*. The experiment was laid out in a split-plot design arrangement and replicated three times. Three irrigation frequencies, namely, 2, 4 and 6 days interval, were the main plots and sub-plot treatments were application rates of three NPK fertilizer levels combined in a ratio 3:2:1and a control treatment of 0 Kg NPK ha^{-1}. Total and plant fraction biomass yield were higher in the four day irrigation frequencies and 120-80-40 kg NPK ha^{-}1 fertilizer rate treatment combination. In conclusion, the results indicate that the plant can produce adequately under conditions of limited water supply provided there are supplemental nutrients available.

Key words: Irrigation frequency, biomass yield, root/shoot ratio, ethnobotanicals.

INTRODUCTION

Wild-watermelon *Cucumis africanus*, is a member of the family Cucurbitaceae. Fresh young leaves of the plant are eaten as a pot herb by many people in the rural communities of South Africa. Other research workers found that the leaves are rich in calcium, iron, nicotinic acid and vitamin C. Harvesting for leafy vegetable is usually carried out in the morning to maintain the full rigidity of the leaves and other fleshy parts of the plant. In South African traditional medicine the roots, shoots or fruits of *C. africanus* is used as an emetic, purgative or enema for various ailments. The boiled leaf is used as a poultice and it is also reported that the plant is useful in animal medicine (Botha and Perinth, 2008).

Considering the growing problem of human population explosion and poor nutrition of foods exhibited among developing countries, the use of indigenous leafy vegetable species as high-mineral and vitamin source, as well as high-quality ethnobotanical linctus producer merits greater research (Tilman et al., 2002). As important sources of Vitamin A and other micronutrients indigenous leafy crops including *C. africanus* deserve pride in the rural economy, laboratory and trial fields (Obadai, 2007). Successful indigenous leafy-vegetable technology and transfer into conventional farming system

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depends on the species potential to germinate and emerge in the given soil physical and chemical conditions, as well as the ability of the seedlings to grow and develop (Linnemann and Craufurd, 1994). Seedling growth covers the period in the life cycle of the plant, from emergence of the radicle through the seed coat until the appearance of enough green leaves to make the plant independent of stored energy (Salisbury and Ross, 1992; Hopkins, 1992).

Dry matter partitioning is the end result of a co-ordinated set of transport and metabolic processes governing the flow of assimilates from source organs via a transport path to sink organs (Marcelis et al., 1998). Gardner et al. (1985) refers to the analysis of biomass distribution to different plant fractions as an important tool in order to understand the physiological principles and processes underlying the portioning of minerals and photosynthetic by-products to the nutritionally and economically significant harvestable plant fractions.

Roots are dependent on shoots for carbohydrates, growth regulators, and some other organic compounds and shoots are dependent on roots for growth regulators such as abscisic acid, cytokinins and gibberellins (Kramer and Boyer, 1995). Severe reduction in leaf area by pruning, insect defoliation, grazing, or diversion of food into fruit and seed production is likely to reduce the root growth. In a similar pattern, damage to root system will reduce water and mineral absorption, which in turn inhibits shoot growth (Summerfield et al., 1997).

The root/shoot a ratio which is the relationship between above- and below-ground biomass gives an indication of the functional, hormone-mediated equilibrium that governs the partitioning of assimilates between roots and shoots which know at the core of most models of plant growth (Hunt, 1979). High root/shoot ratios indicate that the plant is partitioning more assimilates to the roots, while lower ones indicate the opposite. There is a pronounced interdependence of roots and shoots and it is suggested that there might be some optimum ratio of roots to shoots (Stoskopf, 1981). However, root-shoot ratios vary widely among species, with age, and with environmental conditions. These variations results in part from the wide variations in water supply and other environmental factors to which plants often are subjected during a particular growing season, as well as to genetic variations among plants such as grasses and root crops. Perhaps the root-shoot ratio should be considered in terms of root and leaf surface, but it is difficult to measure root surface (Tesar, 1984; Mulvaney, 1996; Marcelis, 1996).

The current study seeks to evaluate and determine agronomic performance of traditional leafy-vegetable and ethnobotanical crop *Cucumis africanus* in terms of biomass yield, biomass partitioning to plant fractions and root/shoot ratios as influenced by irrigation water application frequency and NPK fertilizer application rate under greenhouse regime.

MATERIALS AND METHODS

Site specifications

The experiment was conducted at Horticultural Research Facility of University of Limpopo, Limpopo Province, South Africa (23°53'10'' S; 29˚44'15'' E) during the 2009-2010 summer growing season. Ambient day/night temperatures averaged 28/21°C, with maximum temperatures controlled using thermostatically-activated fans. Other greenhouse variables such as relative humidity, photosynthetically active radiation and solar radiation were not measured.

Experimental layout and treatments

The experiment was laid out in a split-plot design arrangement and replicated five times. Three irrigation intervals, namely, 2, 4 and 6 days, were accorded as main plots. During each irrigation interval, 1000 ml tap-water was applied per pot. Irrigation water application treatments were applied seven days after transplanting, using the gravimetric method of irrigation requirement. Sub-plot treatments were accorded to varying NPK application rates which were 0 kg NPK ha^{-1}, 60-40-30 kg NPK ha^{-1}, 120-80-60 kg NPK ha^{-1} and 180-120-90 kg NPK ha^{-1}, the rate were interpolated and applied in accordance to pot size.

Experimental procedures

Seedlings were raised in seedling trays using Mafeo and Mashela's method (2009). Thirty-cm-diameter plastic pots, filled with 10 L steam-pasteurised sand and Hygromix (3:1 v/v), were placed on greenhouse benches at 0.5 m inter-row and 0.6 m intra-row spacing. Uniform three-week-old *Cucumis* seedlings (one seedling per pot) were transplanted to the pots one day after irrigating the growing medium to field capacity. The first experiment was harvested at 40 days after transplanting (DAT) and the second at 60 DAT. NPK fertilizer (2:3:2) was given in split doses. First dose was applied at transplanting of seedlings into 30 cm plastic pots, while the second dose was applied 10 days after the first dose and while the remaining dose was given at 20 days.

Cultural practices, data collection and analysis

Agronomic cultural practices of pest control and weed removal were carried out throughout the growing season as recommended. Plants were harvested 40 days after transplanting (40 DAT) to determine vegetative yield responsiveness. The data was recorded using a standard balance scale for biomass yield, leaf, stem and root, root/shoot ratios and productivity score of fresh samples. The samples were later subjected to oven dry at 65°C for 24 h to determine the dry biomass of the same parameters.

The data of all the above mentioned was extrapolated from dry matter g pot^{-1} to kg ha^{-1} and were individually subjected to the analysis of variance techniques and mean comparisons were done using least significance difference (LSD) at 0.05 level of probability (Gomez and Gomez, 1984; Kuehl, 2000).

RESULTS

The results showed that dry biomass yields were influenced ($P < 0.05$) by the interaction between irrigation frequency and NPK fertilizer application rate (Table 1). Irrigation frequency and NPK fertilizer application rate

Table 1. Analysis of variance for biomass yield of *Cucumis africanus* as affected by irrigation interval and NPK application rate at 40 days after transplanting (40 DAT) during the 2009/10 growing season.

Source of variation	Df	Total Biomass yield (kg ha^{-1})	
		SS	%
Replicate (A)	2	66529	1.06
Irrigation (B)	2	845908	13.46
Error (A*B)	4	1464106	23.30
NPK rate (C)	3	216240	3.44
B*C	6	1827770	29.09**
Error (A*B*C)	18	1863054	29.65
Total	35	6283607	100

**Significant (P< 0.05); Df = degree of freedom; SS = sum of squares.

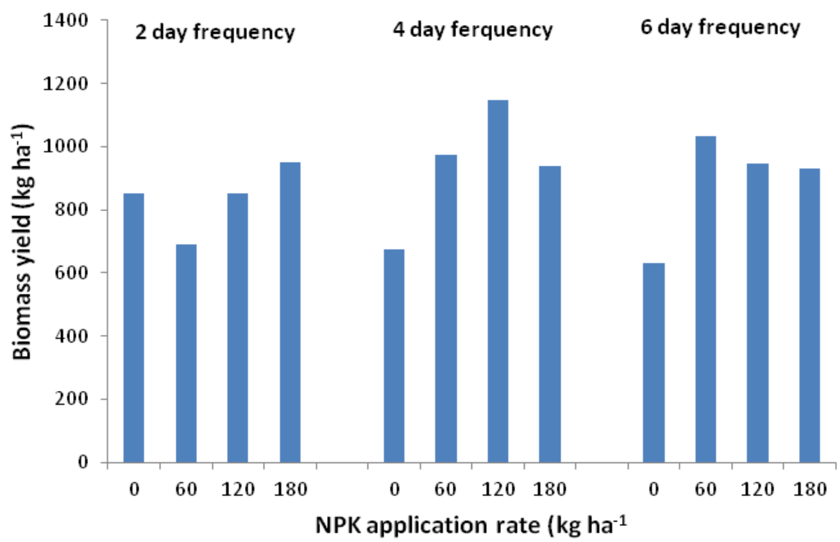

Figure 1. Biomass yield of *C. africanus* as affected by irrigation frequency and rate of NPK application during the 2009/10 summer growing season.

contributed 29% to the total treatment. The highest dry biomass yield was 59% higher than lowest biomass yields (Figure 1).

Significant differences (P< 0.05) were observed on biomass partitioning to stems, leaves and shoots of *C. africanus*, while distribution to roots was non-significant. Stems responded positively to irrigation frequency while leaves responded to NPK fertilizer application rate, both showed response to the interaction between irrigation frequency and NPK fertilizer application rate. Stem biomass was influenced by the interaction between irrigation frequency and NPK application rate which contributed 56% to the total variation (Table 2). The highest stem biomass yields were 414% higher than lowest stem biomass yields (Table 3). NPK application rate contributed 21% while the interaction between irrigation application frequency and NPK application accounted for 30% of the total variation for leaf biomass yields, respectively (Table 2). Leaf biomass yield was 454% higher than lowest yielding treatment (Table 3).

Highly significant (P < 0.01) differences were demonstrated in shoot biomass accumulation in response to irrigation frequency and NPK fertilizer application rate. Interaction between irrigation application frequency and NPK application accounted for 34.69% of the total variation for dry shoot biomass yield, while NPK application rate contributed 15.98% (Table 2). The highest shoot biomass accumulation was 295% higher than lowest yielding treatment (Table 3). Root/shoot ratio showed differences (P < 0.05) as a result of treatment application with NPK fertilizer application rate and the interaction between irrigation frequency and NPK rate contributing 13.6 and 21.76% to total treatment variation, respectively (Table 3).

Table 2. Analysis of variance for biomass partitioning to plant fractions and root/shoot ratios of *Cucumis africanus* as affected by irrigation frequency and NPK application rate during the 2009/10 summer growing season.

Source of variation	Df	Plant fraction (g m^{-2})									
		Roots		Stems		Leaves		Shoot		R:S ratio	
		SS	%	SS	%	SS	%	SS	%	SS	%
Replicate (A)	2	1564.5	6.11	252.2	1.92	1720.0	8.47	2982.0	6.99	1.089	9.79
Irrigation (B)	2	7650.5	29.89^{ns}	1998.9	15.21**	1829.8	9.01	5158.5	12.09	3.523	31.68
Error (A*B)	4	6108.1	23.87	1304.7	9.93	842.9	4.15	2770.2	6.49	1.343	12.08
NPK rate (C)	3	2575.8	10.07^{ns}	356.7	2.71	4241.4	20.88**	6820.2	15.98**	1.508	13.56***
B*C	6	2579.6	10.08^{ns}	7405.1	56.34***	6105.0	30.05**	14811.0	34.69***	2.419	21.76***
Error (A*B*C)	18	5112.0	19.98	1826.7	13.89	5576.1	27.45	10141.7	23.76	1.237	11.13
Total	35	25590.6	100	13144.3	100	20315.1	100	42683.7	100	11.119	100

**Significant (P< 0.05); ***Significant (P< 0.01); Df = degree of freedom; SS = sum of squares; R:S =Root to shoot, ns = non-significant.

Table 3. Biomass partitioning to plant fractions and root/shoot relationships of *Cucumis africanus* as affected by irrigation frequency and NPK application rate at during the 2009/10 summer growing season.

Interval(days)	NPK(kg ha^{-1})	Plant fraction (g m^{-2})				
		Roots	Stems	Leaves	Shoots	Root:Shoot
2	0	19.88b	16.05^{cde}	59.26^{abc}	75.31^{bcdef}	0.316^{b}
	60-40-30	23.58^{b}	13.58^{de}	41.98^{bcde}	55.56^{cdef}	0.244^{b}
	120-80-60	21.11^{b}	25.93^{cde}	48.15^{abcd}	74.07^{bcdef}	0.146^{b}
	180-120-90	24.69^{ab}	24.69^{cde}	45.68^{abcd}	70.35^{bcdef}	0.362^{b}
4	0	49.26^{a}	58.03^{ab}	34.57^{cde}	92.59^{abc}	0.595^{b}
	60-40-30	51.73^{a}	23.46^{cde}	13.35^{e}	35.80^{f}	1.696^{a}
	120-80-60	67.16^{a}	63.58^{a}	74.07^{a}	141.5^{a}	0.475^{b}
	180-120-90	40.62^{ab}	17.28^{cde}	25.93^{de}	43.21^{ef}	1.226^{a}
6	0	28.52^{b}	12.35^{e}	32.10^{cde}	44.44^{def}	0.588^{b}
	60-40-30	27.28^{b}	38.27^{bcd}	67.90^{ab}	106.17^{ab}	0.165^{b}
	120-80-60	26.05^{b}	61.73^{a}	72.84^{a}	133.57^{a}	0.119^{b}
	180-120-90	40.62^{ab}	40.74^{bc}	41.98^{bcde}	82.72^{bcde}	0.580^{b}

Column means with the same letter were not different at 5% level according to the LSD test. ns = none significant. LSD = Least significant difference.

DISCUSSION

Adequate biomass supply of indigenous crops such as *C. africanus* are required for both consumption as a leafy vegetable and use as ethnobotanicals in many rural areas of developing regions (Jansen van Rensburg et al., 2007; Ndlovu and Afolayan, 2008;). The results of the study show that by applying intermediate irrigation frequency and NPK rate substantially high amounts of fresh and dry biomass yields of *C. africanus* that are required by the rural populace can be achieved. Consequently, with the advent of escalating water shortages (Auwalu and Babatunde, 2007) and lack of inorganic fertilizer-inputs supplies (Atta et al., 2011) in rural communities it can be deduced from the above findings that smallholder farmers can produce *C. africanus* with infrequent irrigation episodes and minimal nutrient inputs applications. An additional benefit to diets of indigenous leafy vegetables consumers is that it is reported by several workers that they can contribute with significant amounts of vitamins and minerals, and are especially excellent sources of protein, carotene, iron and ascorbic acid (Van Soest et al., 1997; Luyen and Preston, 2004); an attribute that can greatly assist in the fight against the hidden hunger prevalent in many rural areas.

In our study partitioning of biomass to roots, stems and leaves, was found to be significantly influenced by irrigation frequency and NPK rate at intermediate levels of application. These results agrees with findings by several workers on other vegetable crops, Erdem et al. (2001) in watermelon, Waseem et al. (2008) in cucumber, Khan et al. (2005) in bell pepper, van Averbeke et al.

(2007) in *Brassica rapa* L. subsp. *Chinensis* and *Solanum retroflexum* Dun. In contrast, Sensoy et al. (2007) found good responses with treatments employing greatest frequency and quantity of irrigation in field-grown melon and Singh et al. (2009) found that NPK dose above the recommended was required to minimize the adverse impacts of nutrient shortages in cropping systems.

In this study, highly significant (P≤ 0.05) variances were observed for root/shoot ratio. Applying irrigation at four day frequency and 60-40-30 NPK kg ha^{-1} rate produced the highest root/shoot ratio which was 92.98% higher than the lowest root/shoot ratio, an indication that in this treatment more assimilates where to the roots (Gardner et al., 1985; Hopkins, 1992; Prusinkiewicz, 2004). The lowest root/shoot ratio was given by irrigating on a six day frequency basis and applying 120-80-60 NPK kg ha^{-1} which supported production of above-ground portions as opposed to the below ones. Nonetheless, these treatments were not superior in terms of total and plant fraction biomass yield.

Conclusion

The results of the study showed significant influences that varying irrigation water application frequencies and NPK fertilizer application rates has on biomass yield and portioning, as well as the relationship between the above- and below-ground plant parts. The highest *C. africanus* plant fraction harvest of stem (61.73 g m^{-2}); leaf (72.84 g m^{-2}) and shoot (143.57g m^{-2}) were obtained in the four day irrigation interval and fertilizer combination of 120-80-40 kg NPK ha^{-1} rate. A crop biomass harvest under these conditions produced fresh and dry biomass yields of correspondingly 2049.4 and 1506.2 kg ha^{-1}.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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