Effect of irrigation frequency and NPK level on yield efficiency, resource use and harvest index of indigenous wild cucumber *Cucumis africanus*

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Abstract

In South African traditional medicine the roots, stems, leaves or fruit of wild cucumber, *Cucumis africanus*, are used as an emetic, purgative or enema for various ailments. The fresh young leaves are eaten as a pot herb by many rural people. A study was conducted to show the effects of irrigation frequency and NPK fertilizer application rate on leaf yield characters, harvest index and resource use efficiencies of *C. 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, were assigned as main plots and Nitrogen, Phosphorus and Potassium (NPK) application rates of 0 Kg NPK ha^{-1}, 60-40-20 kg NPK ha^{-1}, 120-80-40 kg NPK ha^{-1} and 180-120-60 kg NPK ha^{-1} were sub-plots. EYR, YER, AHI and SHI were significantly (P< 0.05) higher in the intermediate treatment of four day irrigation frequency and 120-80-60 kg NPK ha^{-1}, while WUE and NUE were pronounced in the six day irrigation frequency and 180-120-60 kg NPK ha^{-1}. WUE was significantly (P< 0.05) affected by both irrigation frequency and the interaction between irrigation frequency and NPK application rate, while NUE responded to NPK level only.
Keywords: edible yield rate, yield efficiency rate, harvest index, water use efficiency.

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1 Introduction

In South African traditional medicine the roots, stems, leaves or fruit of wild cucumber, *Cucumis africanus*, are used as an emetic, purgative or enema for various ailments. The fresh young leaves are eaten as a pot herb by many rural people. Since antiquity to date, indigenous wild useful plants have been handled by human societies for food and ethno-botanical purposes. While, the smallholder farmer societies still continue to profess such livelihoods, the agricultural community did not exploit the use of non-cultivated resources. In recent times, most human plant food is based on rather limited number of crops, 12 crops contribute more than 85–90% of world's caloric intake [1]. However, it is clear that in many parts of the world, especially in rural peripheries of developing regions, the use of wild plants is not negligible [2] and warrants greater need for research on crop responses to conventional agronomic methods of production such as integrated irrigation and fertilizer application [3].

Irrigation and NPK fertilizer combinations play a vital role in enhancing crop yields [1]. Agronomic management practices of integrated irrigation water and NPK application increases leaf area development and improves leaf area duration (LAD) after flowering and increases overall crop assimilation, thus contributing to increased seed yield [4; 5]. Other workers [6] concluded that irrigation and NPK fertilizer increases yield by influencing a variety of growth parameters such as the number of branches per plant, the number of pods per plant, the total plant weight, and leaf area index (LAI). Agricultural research studies on crop agronomic and diet surveys tend to ignore wild plants in comparison to cultivated ones, and this is a methodological deficiency [7].

The agronomic efficiency of resource inputs is the amount of increase in yield of harvestable product per kg of applied resource inputs where high yields are obtained [8]. In smallholder farming systems, increase in yield could best be achieved by adopting high potential traditional leafy/ethno-botanical crops, and supplementing soils with required plant nutrients and irrigation water.

Critical to sustainable production of indigenous multi-purpose leafy-vegetable and ethno-botanical crops will be augmenting vegetative harvest yields and cropping area. Consequently, important statistical information for leafy and ethno-botanical crops is on edible yield rate (EYR) and yield efficiency rate (YER). EYR is the rate of edible (leaf) dry biomass produced by a crop per unit growth area (g m^{-2} day^{-1}). YER is expressed in units of g dry weight (DW) edible biomass/m^2 per day per g DW non-edible biomass.

2 Materials and methods

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.

The experiment was laid out in a split-plot design arrangement and replicated five times. Three irrigation frequencies, namely, 2, 4 and 6 days, were accorded as main plots. During each irrigation frequency, 1 000 ml tap-water was applied per pot. Irrigation water application treatments were applied seven days after transplanting. Sub-plot treatments were accorded to varying NPK application rates which were 0 Kg NPK ha^{-1}, 60-40-20 kg NPK ha^{-1}, 120-80-40 kg NPK ha^{-1} and 180-120-60 kg NPK ha^{-1}.

Seedlings were raised in seedling trays using thirty-cm-diameter plastic pots, filled with 10 L steam-pasteurised sand and Hygromix (3:1 v/v), which were placed on greenhouse benches at 0.5 m inter-row and 0.6 m intra-row spacing. Uniform three-week-old *Cucumis africanus* seedlings 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 (3:2:1) was given in split doses. First dose was applied at transplanting of seedlings into 30 cm plastic pots, while the remaining dose was applied 20 days after the first dose.

Harvesting was done at 40 days after transplanting (DAT) and data was recorded for water use efficiency (WUE), nutrient use efficiency (NUE), Edible yield rate (EYR), yield efficiency rate (YER), apparent harvest index (APHI); shoot harvest index (SHI), and Water and NPK use efficiencies were computed for the experiments.

The following formula was used to compute WUE:

$$\mathrm{WUE} = \frac{\text{crop biomass yield (kg ha}^{-1})}{\text{TWU (m}^{3}\ \text{m}^{-2})}$$

where, TWU is the total water applied.

The classical method for evaluating fertilizer use efficiency was determined by the following equation:

$$\text{NUE (g biomass\textbackslash g N)} = \frac{\mathrm{Y_N - Y_0}}{\mathrm{F_N}}$$

where, Y_N and Y_0 are crop biomass yields (kg ha^{-1}) of fertilized crop and in the control treatment, respectively, Nrefers to particular nutrient being computed and $F_N$is the amount of fertilizer applied (kg ha^{-1}).

Edible yield rate (EYR), yield efficiency rate, and apparent (AHI) and structural (SHI) harvest indexes were computed using the following expressions:

$$\text{EYR (g m}^{-2}\text{day}^{-1}) = \frac{\text{edible shoot DW}}{\text{growth area}^{-1}\text{ per cropping time}^{-1}}$$

$$\text{YER (g m}^{-2}\text{day}^{-1}\text{g}^{-1}) = \frac{\text{EYR}}{\text{nonedible shoot W}^{-1}}$$

$$\text{AHI} = \frac{\text{edible leaf W}}{\text{total shoot W}}$$

$$\mathrm{SHI} = \frac{\text{edible leaf W}}{\text{total biomass DW} - \text{edible leaf W}}$$

where, W is biomass fresh or dry weight.

The data of all the above mentioned were individually subjected to the analysis of variance techniques using Statistix 8.1 software (Statistix, Analytical Software, Statistix; Tallahassee, FL, USA, 1985-2003). Mean comparisons were done using least significance difference (LSD) at 0.05 level of probability [9, 10]. When treatments were significant sum of squares were partitioned to determine the percentage contribution of source of variation to the total treatment variation [11].

3 Results

3.1 Edible yield rate and yield efficiency rate

EYR and YER showed significant (P< 0.05) variations in response to irrigation frequency and NPK fertilizer application rate treatments (Table 1). 30% and 39% of EYR and YER total treatment variation was contributed to by the interaction between NPK application rate and irrigation frequency, respectively. The highest EYR and YER was 83 and 80% higher than lowest, respectively (Table 2).

Table 1: Analysis of variance for efficiency yield rate (EYR) and yield efficiency rate (YER) of *Cucumis myriocarpus* as affected by irrigation frequency and NPK application rate during the 2009/10 summer growing season.

Source of variation	**Df**	**EYR**		**YER**	
		SS	**%**	**SS**	**%**
Replicate (A)	2	653.800	1.420	0.478	8.470
Irrigation (B)	2	1284.60	2.790ns	0.508	9.000
Error (A*B)	4	7821.10	17.01	0.234	4.150
NPK rate (C)	3	3060.40	6.660ns	1.178	20.88**
B*C	6	18051.0	39.27**	1.696	30.05**
Error (A*B*C)	18	15099.3	32.85	1.549	27.45
Total	35	45970.3	100.0	5.643	100.0

***Significant (P< 0.01), **Significant (P< 0.05), Df=degree of freedom, SS=sum of squares, ns=non-significant.

3.2 Water and nutrient use efficiency

The highest water and NPK use efficiency were 86 and 76% higher than lowest use efficiency among the treatment mixtures, respectively (Table 2). Water and nutrient (NPK) use efficiency exhibited highly significant (P<0.01) differences as a response to the irrigation frequency treatment which contributed 61 and 32% of the treatment variation respectively. On the other hand, NPK use efficiency

Table 2: Yield and resource use efficiencies of *Cucumis africanus* in response to irrigation frequency and NPK application rate during the 2009/10 growing season.

Interval (days)	NPK rate (kg ha^{-1})	Yield efficiency		Resource use efficiency	
		EYR	YER	WUE	NUE
2	0	0.99abc	74.07ab	0.041e	-
	60-40-20	0.69bcde	52.78ab	0.049e	0.320bc
	120-80-40	0.80abcd	32.10b	0.057e	0.294c
	180-120-60	0.76abcd	32.84b	0.063e	0.267bc
4	0	0.58cde	19.86b	0.203bcd	-
	60-40-20	0.21e	45.68b	0.130de	0.793abc
	120-80-40	1.83a	88.74a	0.153cde	0.541bc
	180-120-60	0.43de	24.44b	0.125de	0.331bc
6	0	0.54cde	61.90ab	0.139de	-
	60-40-20	1.13ab	30.42b	0.474abc	1.225a
	120-80-40	1.21a	29.71b	0.335a	0.839ab
	180-120-60	0.69bcde	24.44b	0.296ab	0.463bc

Column means with the same letter were not different at 5% level according to the least significant difference test. ns = non-significant.

Table 3: Analysis of variance for nutrient and water use efficiencies of *Cucumis myriocarpus* as affected by irrigation frequency and NPK application rate during the 2009/10 summer growing season.

Source of variation	**Df**	**WUE**		**NUE**	
		SS	**%**	**SS**	**%**
Replicate (A)	2	0.004	0.96	0.217	5.30
Irrigation (B)	2	0.254	60.91***	1.309	31.97***
Error (A*B)	4	0.037	8.87	0.764	18.66
NPK rate (C)	3	0.011	2.64	0.778	19.00
B*C	6	0.065	15.59**	0.415	10.13
Error (A*B*C)	18	0.046	11.03	0.611	14.92
Total	35	0.417	100	4.095	100

*** Significant (P< 0.01), ** Significant (P< 0.05), Df=degree of freedom, SS=sum of squares, ns=non-significant.

was also affected significantly (P<0.05) by irrigation frequency which contributed 32% to total treatment variation (Table 3).

3.3 Apparent and structural harvest index

Significant (P < 0.05) differences in AHI and SHI were observed as a result of the interaction between irrigation frequency and the rate of NPK fertilizer application (Table 4).Interaction between irrigation application frequency and NPK application accounted for 25 and 37% of the total variation for AHI and SHI, respectively. NPK fertilizer application rate accounted for 13% of treatment variation of AHI, while SHI was non-significant (Table 4). The highest harvest index was respectively 67.7 and 56.6% higher than lowest index in AHI and SHI (Table 5).

Table 4: Analysis of variance for apparent and structural harvest indexes of *Cucumis africanus* as affected by irrigation frequency and NPK application rate during the 2009/10 summer growing season.

Source of variation	**Df**	**Apparent HI**		**Structural HI**	
		SS	**%**	**SS**	**%**
Replicate (A)	2	167.11	4.41	210.0	1.51
Irrigation (B)	2	1119.6	29.55ns	2174	15.67ns
Error (A*B)	4	456.29	12.04	1571	11.32
NPK rate (C)	3	482.47	12.73***	563.4	4.06ns
B*C	6	943.68	24.91***	5159	37.18***
Error (A*B*C)	18	619.75	16.36	4199	30.26
Total	35	3788.87	100	13877	100

*** Significant ($P< 0.01$), ** Significant ($P< 0.05$), Df=degree of freedom, SS=sum of squares, ns=non-significant.

Table 5: Harvest indexes (HI) of *Cucumis africanus* as affected by irrigation frequency and NPK application rate at during the 2009/10 growing season.

Interval (days)	NPK rate (kg ha^{-1})	HI (%)	
		Apparent	Structural
2	0	39.09a	80.88ab
	60-40-20	37.94a	75.56ab
	120-80-40	36.32a	65.31abc
	180-120-60	32.32ab	65.09abc
4	0	19.16bc	37.15c
	60-40-20	12.75c	36.29c
	120-80-40	39.47a	83.54a
	180-120-60	20.35bc	53.73bc
6	0	35.19ab	74.12ab
	60-40-20	35.39a	64.39abc
	120-80-40	32.61ab	54.10abc
	180-120-60	25.80abc	55.19abc

Column means with the same letter were not different at 5% level according to the least significant difference test.

4 Discussion

Traditional harvest practices of different cultures in South Africa demonstrate that multiple parts of *Cucumis africanus* plant are edible, either as a leafy vegetable or used as ethno-botanicals. EYR, YER and HIs (apparent and structural) are important crop statistic for controlled environments for crop production (e.g. greenhouses, tunnels, etc.), because they give an indication of how much harvest time, cropping area and non-edible crop residue can be minimized. Significant ($P < 0.05$) responses of EYR, YER and HIs were observed as a result of varying irrigation frequencies and NPK fertilizer application rate (Tables 1, 3 and 4).

Four day frequency x 120-60-30 NPK rate treatment produced higher EYR, AHI, SHI and YER which were correspondingly 29, 35, 60 and 90% higher than average across all the treatments. These results support work by Stefanelli *et al.* [12] that moderate application rates of NPK fertilizer produces good vegetable yield characters, whereas high rates produces imbalances by promoting more vegetative components compromising other parts and low rate leads to poor quality and/or crop failure. Thus, intermediate irrigation and NPK applications can assist in improving the production of *Cucumis africanus* under greenhouse regimes.

The vegetative efficiency of *Cucumis africanus* is critical to sustainable production of the multi-purpose crop plant. Ohler and Mitchell [13] suggested that higher EYR, YER and HIs indicates good edible leaf yield or shoot products that could be used to add nutritional value and fibre to diets. Protein of leaves and other vegetative plant components provide amino acids complementarities to that of cereal grains. To achieve success, good agronomic practice such weed and pest control, low amelioration activities, irrigation scheduling, split fertilizer application, etc. must also be taken into account.

Water and NPK use efficiency ranged from 0.294 to 1.225 and 0.05 to 0.34 respectively. The highest water and NPK use efficiency were observed in irrigation frequency of 6 days and NPK rates of 120 and 60 kg NPK ha^{-1}, respectively. These results agrees with the finding by several [5] in canola, [14] in glory lily, who found that 120 kg ha^{-1} nutrient application level produced maximum values for all these traits as compared to minimum in control. Khan *et al*. [15]) also concluded that irrigation frequency of 5 days was the better irrigation frequency as compared to other treatment in a study with onion varieties. The study results confirm that *Cucumis africanus* can be successfully produced by smallholder farmers who reside mainly in areas where water is a scarce resource. The result is attributed to the fact that *Cucumis africanus* is an indigenous crop plant that grows in harsh wild conditions which means that it has some degree of inert drought tolerance and stress survival mechanisms.

5 Conclusions

The study results revealed that the intermediate category of 4 days interval and 120-80-40 kg NPK rate treatment produced better results ($P < 0.05$) in most of the parameters studied. The values of EYR, YER, AHI and SHI obtained in the study confirms that *Cucumis africanus* can be grown successfully for the production vegetative and root components to sustain its use as leafy vegetable and ethno-botanicals to improve smallholder farmer livelihoods. In addition, the lengthy irrigation frequency of six day interval and moderate nutrient application rate were efficient in water and NPK use, thereby confirming that *Cucumis africanus* can be grown under conditions of limited water supplies and minimal nutrient inputs.

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