Effect of Organic Mulch and Water Supply on Yield and Profitability in Black Nightshade (*Solanum Scabrum* Mill.) in West Cameroon

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ABSTRACT

Water shortage and increased soil water evaporation are among challenges facing farmers in tropical regions subjected to prevailing climate change. Combinations of agricultural practices expected to improve yields of cultivated crops such as mulching has been described as a method to improve soil water storage and yields of cultivated crops including black nightshade. Unfortunately, up to date, few research works have addressed the yields and profitability of black nightshade. Combinations of rate of water, frequency of irrigation, mulch rate were tested during the 2021 and 2022 off-seasons for large-scale and cost-effective production of black nightshade, a staple food crop. A total of 18 triptych combinations of three irrigation volumes (V_n), three irrigation frequencies (F_n) and two mulch rates (M_n) were tested. Results showed that the best 5 yielding combinations (mean: 42.08 t/ha) represented 124% of the trial mean (33.80 t/ha) independently of the cropping year. However, combination $V_1F_3M_{10}$ i.e. applying an average of 5.8 mm/day of water every 3 days on 10 t/ha-mulch plots led to the highest yield (47.16 t/ha) and profit (304.60%). Therefore, the combination $V_1F_3M_{10}$ should be adopted for off-season production of black nightshade on Oxisol from West-Cameroon. Soil mulching at 10 t/ha promoted water saving by 402.3 mm and probably reduced soil water evaporation, weeds control, and improved water use efficiency.

Key words: Off-season, irrigation, soil water, evaporation, water productivity, Oxisol.

INTRODUCTION

Non-mechanized agriculture, the most practiced in rural areas of developing countries, including Cameroon, is on a long way to productivity. Furthermore, it is still highly dependent on climate. In fact, temperature, light, and more even water are the main drivers of crop growth (Molua and Lambi, 2007). The country's agriculture is now facing the challenge of providing sufficient food for the rapidly growing population. Local vegetables play a critical role in addressing the problems of food security and malnutrition. They are also sources of income in peri-urban areas of many African cities (Schippers, 2000; Abukutsa-Onyango, 2003). Broad-leaved black nightshade is the most important and most consumed among all local leafy vegetables in sub-Saharan Africa, in general, and particularly in Cameroon where the demand is ever-growing (Boukong *et al.*, 2018).

Solanum scabrum is a dicotyledonous species. It belongs to the Order Dicotyledons, family Solanaceae and to the genus Solanum (Tindall, 1983). A family it shares with tobacco (*Nicotiana tabacum*) another leafy annual crop and a genus it shares with tomato (*Solanum lycopersicum*). Black nightshade is rich in methionine (proteins) and iron at levels that could provide 50% and 100% of the recommended daily intakes, respectively (Abukutsa *et al.*, 2010), thus providing an alternative to fish and meat diets. Although *S. scabrum* is a highly demanded vegetable in Cameroon, there are some constraints limiting its production, which is insufficient to satisfy the increasing demands from new urban markets within Cameroon and neighbouring countries such as Equatorial Guinea, Nigeria, and Gabon (Boukong *et al.*, 2018). In West-Cameroon, the largest country off-season growing region, the three principal problems faced by producers of black nightshade are insects and fungal diseases (28.8%), low soil fertility and inadequate use of fertilizers (24.7%), and high cost of irrigation (20.3%) (Boukong, 2017). High cost of irrigation reduces the benefits generated by the production of black nightshade, leading to a low number of producers engaged in its off-season cultivation (9% of those growing during the rainy season). Hence, the need for cost-effective irrigation techniques and water losses mitigations practices.

In fact, no or very few data on the irrigation of *S. scabrum* in the West region of Cameroon are currently available. Most often, in tropical farming systems, producers randomly apply water in an attempt to enhance plant hydric nutrition and improve yield. The survey on *S. scabrum* production showed that most farmers who cultivate it during the off-season apply water at varying quantities and frequencies (Boukong, 2017). Specific baseline information is of paramount importance in order to recommend appropriate quantities and frequencies of irrigation for optimum growth and productivity of the vegetable on bare or mulched soils in the western highlands region of Cameroon. Therefore, it was necessary to explore new water management protocols to optimize the yield of black nightshade in West-Cameroon during the off-season. Furthermore, irrigation management must reconcile low water availability with water requirements for a relatively high production, and cost effectiveness.

Mulching is one of those most widely known water management methods traditionally applied. Mulch is a shallow layer that appears at the soil/air interface, with properties that differ from the original soil surface layer. Mulching or covering the soil surface with a layer of plant residue increases soil moisture, which is mainly attributed to reduced soil evaporation, increased infiltration and increased soil water retention. It reconciles low water availability and/or supply with plant’s hydric needs. Moreover, mulch can improve soil properties by decreasing soil crusting due to water droplets impact. Soil nutrients can be conserved effectively by reducing runoff and sediment based on short-term mulching and long-term mulching can significantly increase the soil organic matter and available nutrients due to degradation of mulching materials (Jiménez *et al.*, 2016). In fact, it suppresses evaporation, hence is an effective method of conserving water which creates a new microclimate which reduces the depletion of water within the root zone.

The study aimed to determine a combination of water supply volume, water supply frequency, and mulch application rates that could optimize the production of black nightshade. Given that water availability for irrigation and its cost of application are limiting factors during the off-season. The indicator responses were the marketable fresh yield and the estimated profitability of black nightshade.

MATERIALS AND METHODS

- **Site Description**

The off-seasons study was conducted on an Oxisol in the West region of Cameroon at latitude 5.515250° N and longitude 10.389861° E where two trials of the experiment unfolded from January to April 2021 and from March to May 2022. The terrain was sloppy (6% slope) and situated at 1291 m above sea level. The average temperature ranged from 23.1 to 23.3 °C (Table 2). The trial laid out in 2021 was repeated in 2022 to augment the chance of identifying a sustainable treatment that could lead to improved profitability of black nightshade in the off-season on Oxisol.

- **Materials**

The plant material was the variety SS09 of black nightshade characterized by large leaves was used. It is the most appreciated variety among producers and households of West-Cameroon.

The mulch material considered for the study was common beans (*Phaseolus vulgaris* L.) residues from previous cropping due to their availability during the off-season period. The moisture content of these residues was determined in order to quantify the mulch to be applied according to its dry matter content.

The irrigation water used was from an inexhaustible stream neighbouring the experimental plot whose physicochemical analysis was performed.

- **Experimental Setup**

Eighteen triptych combinations from three irrigation water volumes (V_1, V_2, V_3), three irrigation frequencies (F_1, F_2, F_3), and two mulch rates (M_0, M_{10}) were formed corresponding to 18 treatments (Table 1). The 18 treatments were laid out in a randomized complete block design. Three replications were set, 1.5 m apart, taking into account the slope of the experimental area. Each elementary plot covered 2.5 m^2 and was planted with 40 plants that is 120 plants per treatment. Plots were separated by 1 m to prevent lateral water interference between them. The water volumes, irrigation frequency and mulch rate were based on preliminary studies carried out by Tapa *et al.* (2021) (personal communication).

Table 1: Triptych combinations of irrigation water volumes, irrigation frequencies and mulch rates

		Volumes of water				
		V_1	V_2	V_3		
Frequencies of irrigation	F_1	$V_1F_1M_0$ (T_1)	$V_2F_1M_0$ (T_3)	$V_3F_1M_0$ (T_5)	M_0	Mulch rates
		$V_1F_1M_{10}$ (T_2)	$V_2F_1M_{10}$ (T_4)	$V_3F_1M_{10}$ (T_6)	M_{10}	
	F_2	$V_1F_2M_0$ (T_7)	$V_2F_2M_0$ (T_9)	$V_3F_2M_0$ (T_{11})	M_0	
		$V_1F_2M_{10}$ (T_8)	$V_2F_2M_{10}$ (T_{10})	$V_3F_2M_{10}$ (T_{12})	M_{10}	
	F_3	$V_1F_3M_0$ (T_{13})	$V_2F_3M_0$ (T_{15})	$V_3F_3M_0$ (T_{17})	M_0	
		$V_1F_3M_{10}$ (T_{14})	$V_2F_3M_{10}$ (T_{16})	$V_3F_3M_{10}$ (T_{18})	M_{10}	

$\mathbf{V_1}$: application of 5.5 mm/day in 2021 and 6.0 mm/day in 2022; $\mathbf{V_2}$: application of 8.0 mm/day in 2021 and 8.8 mm/day in 2022; $\mathbf{V_3}$: application of 11.9 mm/day in 2021 and 12.6 mm/day in 2022; $\mathbf{F_1}$: irrigation performed every day; $\mathbf{F_2}$: irrigation performed every two days; $\mathbf{F_3}$: irrigation performed every three days; $\mathbf{M_0}$: bare soil or zero mulch; $\mathbf{M_{10}}$: 10 t/ha of mulch dry matter.

The volumes of irrigation initially defined were based on the average daily potential evapotranspiration of 4 mm in the study region calculated according to Penman-Monteith (Allen *et al.*, 1998). Due to annual variability, applied volumes took into account the water supplied by unexpected rainy days during the off-season which slightly modified them for the same modality in each of the two years of experimentation (Table 2).

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Table 2: Volumes of water supplied and temperature prevailing during the two off-season cropping years

Water supplies	75 DAT					
	Year 2021			Year 2022		
	V_1	V_2	V_3	V_1	V_2	V_3
RD (days)	9			21		
P (mm)	274.5			346.6		
I (mm)	140.4	326.4	614.8	100.3	316.6	594.9
Total (mm)	414.9	600.9	889.3	446.9	663.2	941.5
MDW (mm/day)	5.5	8.0	11.9	6.0	8.8	12.6

DAT: days after transplanting; **RD**: rainy days; **P**: rainfall; **I**: irrigation; **MDW**: mean daily water supply.

Next to the main plot was a corresponding control experiment in each year with combination V_1F_1, V_1F_2, V_1F_3, V_2F_1, V_2F_2, V_2F_3, V_3F_1, V_3F_2 and V_3F_3 without fertilizers and mulch. The control experiment was laid out in a complete randomized block design and was followed out just as the main experiment and the yields used in the economic analysis.

- **Planting, follow up and harvesting**

In both years, five tons of layer droppings were applied per hectare two days before transplanting the one-month-old and six-leafed black nightshade seedlings of about 10 cm tall. Four days after transplanting (DAT), 600 kg/ha of NPK-20.10.10 bulk fertilizer were applied in lines at 5 cm from the plants. Plants were treated against blight using 50 g per 15 L of "*Mon champ*" (a.i. Mefenoxam and copper oxide), a systemic and contact fungicide, and against leaf pests using 36 cL per 15 L-sprayer of Cypercot 50 EC (a.i. Cypermethrine), every 10 days during the first month of the experiment and every 15 days after each harvest. Weeding was done manually at 21 day-intervals and the cost recorded.

The physical and chemical properties of the soil, manure and irrigation water used where analysed according to the procedures described by Pauwels *et al.* (1992) in the laboratory of soil analysis and chemistry of environment of the Faculty of Agronomy and Agricultural Sciences of the University of Dschang in Cameroon.

- **Parameters measured**

Parameters measured or estimated were marketable fresh yield and profitability. Marketable fresh yield was obtained from harvests carried out four times notably at 30, 45, 60 and 75 days after transplanting (DAT) whereby the primary stem was cut using a knife at 15 cm above ground level for the first harvest. The second, third and fourth harvests were done on ramifications of 5 cm length minimum by sectioning them at 1 cm-distance from the primary stem. Eighteen plants out of the 40 plants were harvested from the middle of the elementary plot. The 4 harvests of each triptych combination or treatment were weighed together to determine the marketable total biomass or yield.

- **Statistical Analyses**

The generated data were compiled using the Excel spreadsheet. The analysis of variance was performed for marketable fresh yield at the threshold of 5%. Mean values of treatments were separated using Duncan's Multiple Range Test (DMRT). The statistical analyses were performed using the software GENSTAT version 9.2. (VSN International Ltd, England, UK).

- **Economic Analyses**

The economic value of each of the high yielding treatments was assessed using Partial budget analysis. Benefit on cost ratio (BCR) and percentage profit (%P) were calculated to assess the profitability of fertilizers used under irrigation and mulching. BCR is used to measure the profitability of adopting a new technology minus the costs associated with its implementation. Profitability in the present study, was the additional revenue generated by additional yield obtained due to treatments minus the cost of additional expenses related to those treatments over the same value of expenses. The additional cost components used (Table 3) where estimated based on the market prices of fertilizers, the minimum monthly wage (75.33 US $/month) and the cost of 1 man-day (1 MD = 3.42 US $) in the country.

Table 3: Additional cost components

Components	Unit price
Fertilizer cost: *NPK 20 10 10	0.67 US $/kg
*Layer manure	0.09 US $/kg
Transport of NPK 20.10.10, layer manure and mulch	0.008 US $/kg within the city
Fertilizer application: *NPK 20 10 10	41.85 US $/ha
* layer manure	58.59 US $/ha
Mulch application	188.33 US $/ha
Cost of supplementary labor for the additional harvest	0.013 US $/kg (Boukong *et al.*, 2018)
Differential cost of additional manual weeding	110.16 US $/ha on bare plots
Water application	23.96 US $/day/ha for 8 mm
Pumping engine cost: *depreciation cost	21.48 US $/month
*Fuel cost	1.22 US $/L

The cost of mulch application in Table 3 was obtained based on the fact that 55 MD where needed to apply mulch on one-hectare black nightshade. The differential cost of additional manual weeding was the difference between the cost of manually weeding one hectare of black nightshade on a bare plot to that needed to manually weed one hectare mulched at 10 t/ha. The cost of irrigation was obtained by the addition of the costs of water application and that of the pumping engine. The latter corresponded to the depreciation of the motor pump adjusted to its maintenance costs plus fuel consumption which depends on the volume of water applied. The cost of water application was based on the fact that 7 MD were needed per hectare to apply 8 mm.

The total additional cost (TAC) was the sum of the different above-mentioned cost components. The interest on investment (II) of mulch production was obtained from the following formula:

$$II = [TAC \times 4.25\% \times (n / N)] \quad (1)$$

where **n** is the duration of production in days starting from the day of layer manure application, **N** is the number of days in the year, 4.25% is the annual interest rate applied in the Cameroon.

The total additional cost of production (TACP) when using fertilizers, irrigation and mulch thus becomes;

$$TACP = TAC + II \quad (2)$$

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Additional yield (AY) is the difference between the average yield of the mulched treatments and the average yield of the corresponding control combination without fertilizers and mulch i.e. V_1F_1, V_1F_2, V_1F_3, V_2F_1, V_2F_2, V_2F_3, V_3F_1, V_3F_2, V_3F_3. The value of additional yield (VAY) is the product of additional yield and unit price of the field sale (0.25 US $/kg in the off-season).

The benefit on cost ratio (BCR) was the ratio of the value of additional yield (VAY) over the total additional cost of production (TACP).

The percentage profit (%P) of fertilizer use under irrigation and mulch for each of the high yielding treatments was calculated as follows:

$$\%P = \frac{VAY - TACP}{TACP} \times 100 = (BCR - 1) \times 100 \qquad (3)$$

RESULTS

- **Soil, poultry manure and irrigation water characteristics**

Physicochemical analyses of the stream water revealed that the electrical conductivity (EC) (Table 4) of the irrigation water was very low (EC < 0.7 dS/m). The same applies to the sodium absorption ratio (SAR), which was very low [0.82 $(meq/L)^{1/2}$].

The soil average pH-H_2O was slightly acidic (pH = 6.5) to moderately acidic (pH = 5.6), and the organic matter quality of good (10.0 – 14.0) and poor quality (14.0 – 20.0) in 2021 and 2022, respectively. The available phosphorous was low to average in 2021 and 2022, respectively.

In both years, the layer manure applied had a very high total nitrogen content (> 0.3%), and a very high organic matter content (> 6.0%) of very good quality (C/N < 10). Its available phosphorus was high (> 46 ppm), and the sum of bases very high (> 15 meq/100g) in 2021 and 2022, respectively.

Table 4: Soil, Poultry manure and Water analyses results

Component	Soil		Poultry manure		Irrigation Water
	2021	**2022**	**2021**	**2022**	
pH-H_2O	6.5	5.6	7.3	7.6	9.3
C/N	11.7	19.0	8.0	9.0	–
$N_{tot.}$ (%)	0.4	0.2	4.4	3.5	0.1
P available (ppm)	9.9	17.3	6661.6	854.9	3.4
K (meq/100g)	0.6	1.2	64.2	48.3	0.8
∑bases (meq/100g)	11.6	12.3	136.6	329.2	37.5
SAR $(meq/L)^{1/2}$	–	–	–	–	0.8
EC (µS/cm)	–	–	–	–	0.2

$N_{tot.}$: total Nitrogen; **P available**: available phosphorous; **K**: Potassium; ∑**bases**: Sum of bases; **SAR**:Sodium Absorption Ratio; **EC**: Electrical Conductivity.

- **ANOVA for marketable fresh yield**

The analysis of variance for marketable fresh yield (Table 5) revealed that the triptych combination volume x frequency x mulch had a significant effect (P < 0.05) on the marketable fresh yield. The repetitions and

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interaction season x [volume x frequency x mulch] had no effect ($P \geq 0.05$) on the marketable fresh yield. Therefore, the yield of the two off-seasons 2021 and 2022 were grouped on per treatment basis and the values separated using DMRT (Figure 1).

Table 5: ANOVA for average fresh yield

Source of variation	DF	S.S.	F pr.
Repetition	2	1.052E+09	NS
Volume x frequency x mulch	4	3.230E+08	*
Season x [volume x frequency x mulch]	4	2.425E+08	NS
Residual	70	1.745E+09	–

DF: degrees of freedom; **S.S.:** Sum of Squares; ***:** value significant at 5%; **NS:** Non Significant; **F pr.:** probability of F value.

The values of average marketable fresh yield (Figure 1) varied from 47.16 t/ha for treatment $V_1F_3M_{10}$ to 22.72 t/ha for treatment $V_3F_2M_{10}$. The 5 most yielding treatments were $V_1F_1M_{10}$, $V_1F_2M_{10}$, $V_1F_3M_{10}$, $V_2F_2M_{10}$ and $V_2F_3M_0$ with average fresh yields of 38.83, 42.27, 47.16, 40.55 and 41.6 t/ha, respectively. The trial mean value was 33.80 t/ha and the mean of the 5 most yielding combinations was 42.80 t/ha, representing 124% of the trial mean. Applying water on the daily basis of 5.5 mm or 6.0 mm every 3 days when mulching with 10 t/ha ($V_1F_3M_{10}$) gave the highest marketable fresh yield of 47.16 t/ha. It was statistically identical to 42.27 t/ha and 41.60 t/ha, obtained when applying water on the daily basis of 5.5 mm or 6.0 mm every 2 days when mulching with 10 t/ha ($V_1F_2M_{10}$) and when applying on a base of 8.0 mm/day or 8.8 mm/day of water every 3 days on a bare soil ($V_2F_3M_0$), respectively. Also, treatment $V_2F_3M_0$ (water application of 8.0 or 8.8 mm/day every 3 days on bare plot) gave a statistically identical yield to the highest ones obtained with $V_1F_2M_{10}$ and $V_1F_2M_{10}$ (mulched plots).

Treatments having the same letters are not significantly different

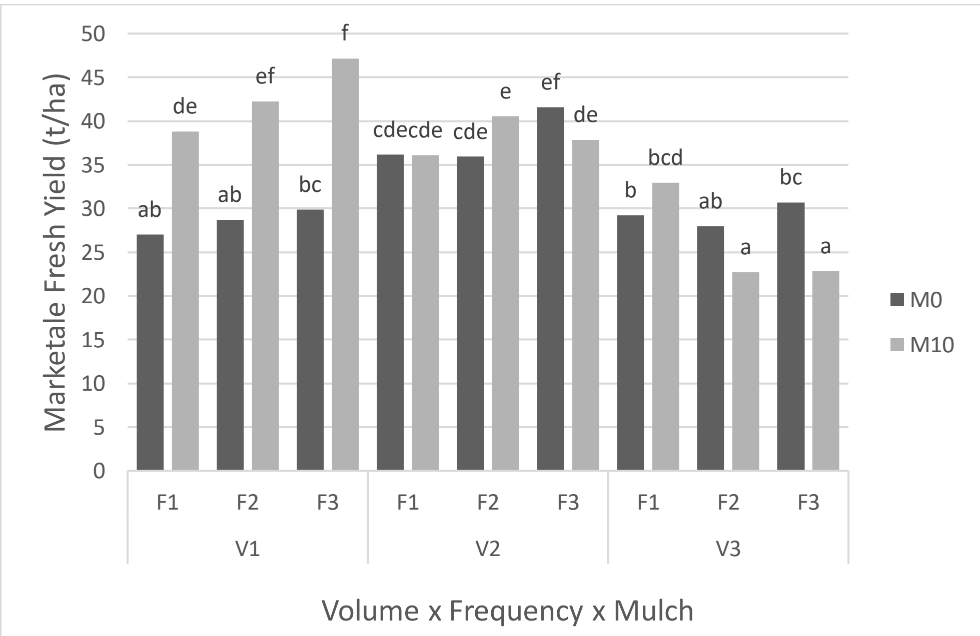

Figure 1: Separation of mean values of marketable fresh yield

In the contrary, applying 23.8 or 25.2 mm of water every 2 days on a 10 t/ha-mulched plot ($V_3F_2M_{10}$) gave the lowest marketable fresh yield of 22.72 t/ha. This yield obtained with $V_3F_2M_{10}$ was statistically not different from 22.82 t/ha, obtained when applying 35.7 or 37.8 mm of water every 3 days on a 10 t/ha-mulched plot ($V_3F_3M_{10}$). Also, applying 5.5 or 6.0 mm of water every day ($V_1F_1M_0$) on bare plot gave a low yield of 27.03 t/ha, statistically identical to the lowest yield (22.72 t/ha) obtained by the treatment $V_3F_2 M_{10}$.

- **Estimated profitability of best triptych combinations**

The analysis focused on grouped yields of the two campaigns on 2 hectares. The profitability of the 5 high yielding triptych combinations: $V_1F_1M_{10}$, $V_1F_2M_{10}$, $V_1F_3M_{10}$, $V_2F_2M_{10}$, $V_2F_3M_0$, for the two grouped years was estimated (Table 6). Table 6 shows that in 75 days, only 4 of the 5 high yielding triptych combinations improved the use of fertilizers by *S. scabrum*, hence were profitable and extendable to farmers. Three of which were obtained when mulching at 10 t/ha with the smallest volume of 5.5 to 6.0 mm/day and the fourth was obtained on bare soil with the application of 8.0 to 8.8 mm/day. The most profitable of the 4 being $V_1F_3M_{10}$ with a BCR of 4.05 and a profitability of 304.60%.

Table 6: Estimated profitability of first 5 well performing triptych combinations

Trts	CFB (t)	AY (t)	TAC (US $)	II (US $)	TACP (US $)	VAY (US $)	BCR	P (%)
$V_1F_1M_{10}$	77.65	40.52	4001	36	4037	10175	2.52	152.03
$V_1F_2M_{10}$	84.54	38.54	3977	36	4012	9676	2.41	141.17
$V_1F_3M_{10}$	94.31	71.35	4388	39	4428	17915	4.05	304.60
$V_2F_2M_{10}$	81.10	41.36	5381	48	5429	10386	1.91	91.30
$V_2F_3M_0$	83.20	44.33	5091	46	5137	11132	2.17	116.71

Trts: treatments; **CFB**: cumulative fresh yield; **AY**: yield increase due to fertilizer and treatments; **TAC**: total additional cost; **II**: interest on investment; **TACP**: total additional cost of production; **VAY**: value of additional yield; **BCR**: benefit/cost ratio; **P%**: percentage profit.

DISCUSSIONS

From the climate data (Table 2) obtained in this study, the average temperatures in the first and second seasons were 23.3 °C and 23.1 °C, respectively. These temperatures were suitable for the cultivation of black nightshade as Mwai *et al.* (2012) showed that the optimum temperatures for growth of this crop are between 15 °C and 35 °C. The irrigation water had no limitation for irrigation according to standards for irrigation water (OMS, 2006). Based on the water requirements of tobacco (*Nicotiana tabacum*) another leafy annual crop of the family Solanaceae like black nightshade described by Sys *et al.* (1993), the volume V_1 of water applied ranged between 400 to 500 mm (Table 2) and was marginal for production of the crop on bare soil in 2021 and 2022. The volumes V_2 and V_3 were in the range 600 to 1000 mm, proposed by Sys *et al.* (1993) as an optimum for its production on bare soil. The soil pH-water according to Oko (2002), were optimal values for the black nightshade production. The available phosphorus and total nitrogen of the poultry manure were high and very high, respectively in both years, hence improving the soil suitability for black nightshade production. Indeed, a good level of soil available phosphorus coupled to that of nitrogen permits the good growth of black nightshade. In fact, soil with available phosphorous content of lowest 7 ppm enable the production of black nightshade with the sole use nitrogenous fertilizers (Urea and NPK) without the need of poultry manure (Boukong, 2017).

The DMRT presented groups of means of marketable fresh yield overlapping each other. The feature (Figure 1) indicated that the treatments were comparable, implying that the main limiting factor to black nightshade cultivation in the off-season is water. Therefore, it can be thought that a positive response should be expected from water supply to the crop independently of the volume of water applied, the frequency of the applications, and the soil status i.e. bare or mulched. Figure 1 showed that at low water inputs (V_1), mulch improves soil water retention (Wang *et al.*, 2021) and promotes yield. Mulching with 10 t/ha of common beans residue gave highest yield when coupled to the lowest water application of 5.5 or 6.0 mm/day (V_1) applied every 2 or 3 days ($V_1F_2M_{10}$ and $V_1F_3M_{10}$). Applying 10 t/ha of mulch probably contributed to creating a soil microclimate which increased water retention and reduced soil water evaporation. In fact, Liu *et al.* (2002) reported that an increase in mulch quantity led to a reduction in evaporation. Furthermore, they found that the plant response (yield) was proportional to the quantity of mulch applied. In a previous study, Wang *et al.* (2021) obtained optimal yields with applications of 2.5 to 5 t/ha of organic mulch as it promoted better soil water retention. A similar result was obtained by Barros and Hanks (1993) who observed a significant increase in dry matter and seed yields of beans on plots mulched with 7 t/ha of wheat straw than on bare plots. Balwinder-singh *et al.* (2011) recorded a reduction in soil evaporation of 35 and 40 mm in relatively high and low rainfall years, respectively, and higher biomass production and grain yield of wheat in both years on mulched plots. Similarly, Zhang *et al.* (2007) observed a decreased soil evaporation by 78 mm/year (10%) and an increase in soil water storage by 19 mm/year on mulched plot than for the conventional and fallow crop treatments thereby producing a 42% higher WUE of wheat. The fact that applying 24.0 mm or 26.4 mm every 3 days on bare soil ($V_2F_3M_0$) gave a similar yield to those obtained by $V_1F_2M_{10}$ or $V_1F_3M_{10}$ (Mulched plots), was because that volume probably satisfied the plant's water requirement (crop evapotranspiration) and that of the atmosphere (potential evapotranspiration). Showing that applying 10 t/ha of mulch ($V_1F_3M_{10}$) reduced water application by 31.3% and 31.8% in 2021 and 2022, respectively when compared to the water application on bare soil ($V_2F_3M_0$) for a statistically identical yield. In contrary, $V_3F_2M_{10}$ and $V_3F_3M_{10}$ gave the lowest yields because the high volume of water applied tended to cause deep percolations enhanced by mulch application which favors the leaching of soil nutrients below the rooting zone of *S. scabrum* and probably decrease the nutrients available to plants. In addition, this high amount of water supply coupled with mulching probably reduces soil temperature which in return reduces the rate of physiological reactions in the roots hence nutrients absorption by the latter, characterized by a reduction in plant growth and yield. Zhang *et al.* (2007) showed that in the wettest months (high rainfall), water reached deeper horizons under the mulched than under bare soil, resulting in +15% (37 mm/year) deep percolation due to an increase in water volume. The fact that $V_1F_1M_0$ on bare plot also gave a low yield of 27.03 t/ha, statistically identical to that obtained by the mulched-treatment $V_3F_2M_{10}$ was because, on a bare soil, applying 5.5 or 6.0 mm of water every day was probably marginal as it could not satisfy both the crop's water requirement and that of the environment of 4 mm/day (PET), hence a water stress. Belaygue *et al.* (1996) observed that a reduction in the amount of water supplied (water stress) led to the inhibition of individual leaf expansion and reduced total number of leaves per plant of white clover. Indeed, faced with a deficit in soil water, plants reduce their leaf area to reduce the number of stomata and hence limiting loss of water via transpiration, resulting in yield reduction. Kumar *et al.* (1994) stated that water shortage leads to reduced carbon assimilation and consequently low biomass production. Water quantity and its temporal distribution are key factors influencing primary productivity (Huxman *et al.*, 2004) and regulate agricultural production (Kramer and Boyer, 1995). Mulching gave the highest and lowest yield when combined to different irrigation volumes and frequencies. Showing that mulch is beneficial when the water volume is marginal (V_1) and its importance tends to reduce with an increase in water volume from V_1 to V_3. Also, at low volumes of 5.5 mm/day to 6.0 mm/day (V_1) mulch gives relatively higher yields at low frequency of irrigation (F_3), whereas at high volumes of 11.9 mm/day to 12.6 mm/day, mulch gives relatively higher yields at high frequency of application (F_1). Similarly, Barros and Hanks (1993) observed a higher WUE (yield/ET) and hence a higher yield on mulched plots than on bare plots for a given irrigation rate but tended to decrease as irrigation rate increased. Furthermore, the work of Mulumba and Lal (2008), demonstrated that the effects of mulching on soil physical properties (water retention) and hence yield vary depending on soil type, climate, management type, mulch type and land use. The importance of mulch therefore varies according to the frequency of watering and the volume of water applied. With the most yielding triptych combination being the application of a total volume of water over the crop cycle of 75 days of 416 mm applied every 3 days based on an application of 5.8 mm/ day when mulching with 10 t/ha ($V_1F_3M_{10}$).

The BCR and %P were estimations of the profitability of fertilizer use by black nightshade influenced by the studied factors. FAO (2004) suggest that following fertilizer application in an environment where water is not a constraint, a BCR ≥ 2 is profitable and extensible as represents a 100 percent return on the money invested in fertilizer. In general, a BCR of 2 ensures good return and takes account of the risk of bad weather and other external factors. Thus the most profitable and extensible combination is the application of water every 3 days on the basis of 5.5 to 6.0 mm/day on a 10 t/ha-mulched ($V_1F_3M_{10}$)(Table 6). This combination promoted water saving by 402.3 mm and reduced irrigation cost by 1368.9 US $/ha for 2.5-month crop cycle when compared to $V_2F_3M_0$, another high yielding combination but on bare soil. The lower irrigation cost of $V_1F_3M_{10}$ might have resulted from increased water use efficiency of black nightshade, reduced soil water evaporation as well as increased soil water storage. In fact, 10 t/ha of mulch associated with the lower irrigation volume applied every 2 days and a low supply frequency led to the greatest profit. Earlier works by Raes *et al.* (2009) found that mulching promotes soil water retention by reducing soil evaporation, hence reducing the cost of water application. Economic analyses showed that total cost of water application (cost of water application, cost of fuel and depreciation of the pumping engine) constituted the major component of the variable cost; 24.53% for V_1, 44.01% for V_2, 61.57% for V_3 on 2 ha. Probably, mulch application modified the microclimatic conditions of the soil, helped to prevent weed growth, reduced evaporation and increased water infiltration (Yang *et al.*, 2003). The average revenue of the additional yield on 2 hectares on mulched plots (M_{10}) was +30% than on bare soil plots (M_0) which was of 6333.90 US $. In yam, Akinola and Owombo (2012) obtained a higher average revenue per hectare of +19% on mulched plots than on bare plots which was of 746.66 US $. Proving that mulching may improve on crop profitability.

CONCLUSION

Of the eighteen triptych combinations of the volumes of water applied, frequencies of water applications and organic mulch rates in off-season for maximum economic benefits, only five had a high marketable fresh yield representing 125% of the trial mean (33.80 t/ha). The most profitable treatment was $V_1F_3M_{10}$ enabling a water saving of 402.3 mm. Indeed, in situations where water is a limiting factor in addition to the high cost of irrigation, applying water on the basis of an average of 5.8 mm/day on 10 t/ha-mulched plots, every 3 days ($V_1F_3M_{10}$) would lead to improved water use efficiency, highest yield and profit. However, when water availability is not a limiting factor, profitable production on bare soil is possible with an average application of water on the basis of 8.4 mm/day, every 3 days ($V_2F_3M_0$). Mulching is therefore not a panacea as when water is available throughout the 75-day cropping the cycle (at least 8.4 mm/day, on average), it is no more necessary and even tend to reduce the yield. Mulching at 10 t/ha thus reduced the cost of irrigation by reducing the quantity of applied water from an average of 8.4 to 5.8 mm/day and decreased the frequency of irrigation from every day to every 3 days in off-season. This was achieved via the optimization of water use efficiency in black nightshade and hence maximizing its economic benefits which could improve the living standard of black nightshade producers.

This applied research to African indigenous leafy vegetables at the instar of black nightshades demonstrated that the effects of mulching can vary depending on the frequency of water supply, the volume applied and the quantity of mulch applied, but also on the climate and type of soil. Although in the short term (3 months) mulch is effective in conserving soil water and inhibiting weed growth, it has other advantages such as reducing soil erodibility in medium term and the contribute to soil organic matter increase through its long-term decomposition which should be studied. Because mulch application is costly, further experiments on mulching in different agro climatic areas with different types and quantities could be done to assess its effectiveness. Also, the determination of its crop coefficient (Kc) will add more precision to the hydric needs of this staple crop and hence enable its better production.

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