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Agronomic Performance of Kale (*Brassica oleracea*) and Swiss Chard (*Beta vulgaris*) Grown on Soil Amended with Black Soldier Fly Frass Fertilizer under Wonder Multistorey Gardening System

Andrew Agrey Abiya [1,2], David Mfuti Kupesa [1,3], Dennis Beesigamukama [1,4], Menale Kassie [1], Dennis Mureithi [5], Daniel Thairu [5], John Wesonga [2], Chrysantus M. Tanga [1] and Saliou Niassy [1,*]

[1] International Centre of Insect Physiology and Ecology (*icipe*), P.O. Box 30772, Nairobi 00100, Kenya
[2] Department of Horticulture and Food Security, Jomo Kenyatta University of Agriculture and Technology (Jkuat), P.O. Box 62000, Juja 00200, Kenya
[3] National Institute for Agricultural Research Studies (INERA), Kinshasa BP 2037, Congo
[4] Department of Crop Production and Management, Busitema University, Tororo P.O. Box 236, Uganda
[5] Farming Wonder, Kenyatta Road Exit 14, P.O. Box 25229, Nairobi 00100, Kenya
* Correspondence: sniassy@icipe.org; Tel.: +254-(0)-792215880

Abstract: The wonder multistorey garden (WMSG) is an innovative vertical farming system tailored for urban settings that can be constrained by the irrigation regime, and by types and levels of fertilizer application. This study evaluated the effects of applying NPK fertilizer and black soldier fly frass fertilizer (BSFFF) under different irrigation regimes on the growth, yield, and pest infestation of kale (*Brassica oleracea*) and Swiss chard (*Beta vulgaris*). The fertilizers were applied at rates equivalent to 371 kg N ha^{-1}. For each crop, the BSFFF or NPK was applied to supply 100% of the N required (100% BSFFF), and then a combination of BSFFF and NPK was applied so that each fertilizer supplied 50% of the N required (50% BSFFF + 50% NPK). Crops' water requirements were provided using three irrigation regimes: daily, every two days, and every three days. The control treatment was not amended with any fertilizer, while water was provided ad libitum. The results revealed that the irrigation regime significantly affected the leaf production of both vegetables. Irrigation regimes significantly influenced kale plant height, where plants provided with water daily achieved the highest average heights of 20 cm, 46 cm, and 54 cm at 14, 28, and 42 days after transplanting (DAT), respectively. Furthermore, the application of 100% BSFFF produced kale with significantly higher plant heights (55 cm) and number of leaves (9.9 leaves) at 42 DAT compared to other treatments. The interaction between irrigation regimes and fertilizer significantly influenced kale height at 14 DAT and 42 DAT. Use of daily irrigation regime and 100% BSFFF produced the tallest kale plants of 59 cm at 42 DAT. Application of 50% BSFFF + 50% NPK or 100% BSFFF with daily irrigation achieved the highest values of kale and Swiss chard leaf chlorophyll concentration, recorded at 42 DAT. Fertilizer application significantly affected pest population, with the lowest pest infestation being recorded from kale and Swiss chard grown in soil amended with BSFFF. The application of 100% BSFFF or NPK, together with daily irrigation, significantly increased the fresh shoot weight and leaf dry matter of kale and Swiss chard, as compared with the control. The fresh shoot yields of kale and Swiss chard achieved through using a combination of 100% BSFFF and daily irrigation were 14–69% and 13–56% higher than those of NPK, respectively. The same treatment combination also produced kales and Swiss chard with 8–73% and 16–81% higher leaf dry matter compared to NPK, respectively. It was noted that soil amendment with BSFFF maintained higher values of kale (41–50%) and Swiss chard (33–49%) leaf dry matter compared with NPK treatments, during periods of water stress. Our study has demonstrated the high potential of single (100% BSFFF) or combined applications of BSFFF (50% BSFFF + 50% NPK) with a daily irrigation regime to improve the growth, yield, and pest management in Swiss chard and kale under vertical farming. Our study advocates for the scaling of WMSG and BSFFF for sustainable food systems in urban settings.

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1. Introduction

The global population is expected to reach 9.7 billion in 2050 [1], with half of this growth occurring in sub-Saharan Africa (SSA). Approximately 66% and 34% of this population will live in urban and rural settings, respectively [2,3]. This population growth will likely increase pressure on natural resources, such as land and water, consequently affecting food security, dietary patterns, recycling of waste, and employment opportunities [4]. Therefore, a rise in food production by about 69% from the production of 2009 is required to meet global consumption in 2050 [5] in order to reduce malnutrition in Africa, which is currently estimated to affect nearly a quarter of the total population [6]. In Kenya, the urban population has been growing steadily [7]. This has resulted in a population boom around Nairobi city and other towns across the country, as people migrate to urban centers searching for employment opportunities and better livelihoods [3]. High population and rapid urban growth have led to congestion and lack of space, water shortages, poor health, pollution, poverty, and food insecurity [8]. For instance, over 4 million urban dwellers in Kenya live in food-insecure areas with limited space for farming, with almost one-third of them being located in Nairobi [9]. These poorest urban residents spend up to 75% of their income on staple foods alone and rely on supplies from rural agricultural areas and imports from neighboring countries. There is a need to develop improved farming technologies that save space to help urban households to carry out crop production and ensure food and nutrition security for city dwellers [10]. This will help reduce reliance on the supply of agricultural produce from underperforming rural agricultural production systems, which are challenged by soil infertility, climate change, pests, and diseases, among other factors [11,12].

The awareness of the health benefits arising from vegetable consumption, together with increased incomes, especially in urban areas with high populations, creates a rise in market demand for fruits and vegetables as consumers seek to diversify their diets [13]. However, vegetable production in urban areas faces numerous agronomic constraints, such as safety, and insecticide residues, which need to be overcome in urban settings that are characterized by water scarcity, pollution, and high population [14,15]. There is an urgent need to use technologies that allow for space optimization, water use efficiency, and input management to improve fruit and vegetable production [16]. By adopting vertical gardens, the available vertical space can be utilized to increase the number of plants grown per unit area [17]. Vertical gardens are a popular and preferred method for roof-top, indoor, balcony, and other forms of urban agriculture, with high productivity of vegetables at a lower cost [18]. In Kenya, vertical gardens, such as sack gardens, hanging tin can gardens, linear multistorey gardens, pipe gardens, outdoor wall gardens, and car park gardens, have been adopted by many farmers to produce fruits and vegetables [19]. These gardens are established to grow vegetables safe for home consumption and for the sale of surplus [19]. However, most of these technologies face various limitations, such as difficulties in irrigation, inefficiency, and high-cost fertilizer inputs [18]. Therefore, there is a need to adopt innovations that are more efficient in fertilizer and water use, with greater cost-effectiveness, to produce safe and healthy vegetables.

The wonder multistorey garden (WMSG) technology, also referred to as a "tower gardens" or "food towers", is an innovative vertical farming technology that is useful for space optimization, and water and input efficiency. This technology allows different crops to be grown year-round in vertically stacked layers made of high-density polythene material (HDPE) that form a pyramid structure with terraces containing soil that forms the growth media (Figure 1). The WMSG can hold up to 120 plants in an area that would conventionally accommodate only 16 plants, implying that one unit can produce up to

9 kg of vegetables per week, enough to feed a household. The establishment of these gardens does not require technical expertise and is economically friendly, with a cost of USD 25 per unit.

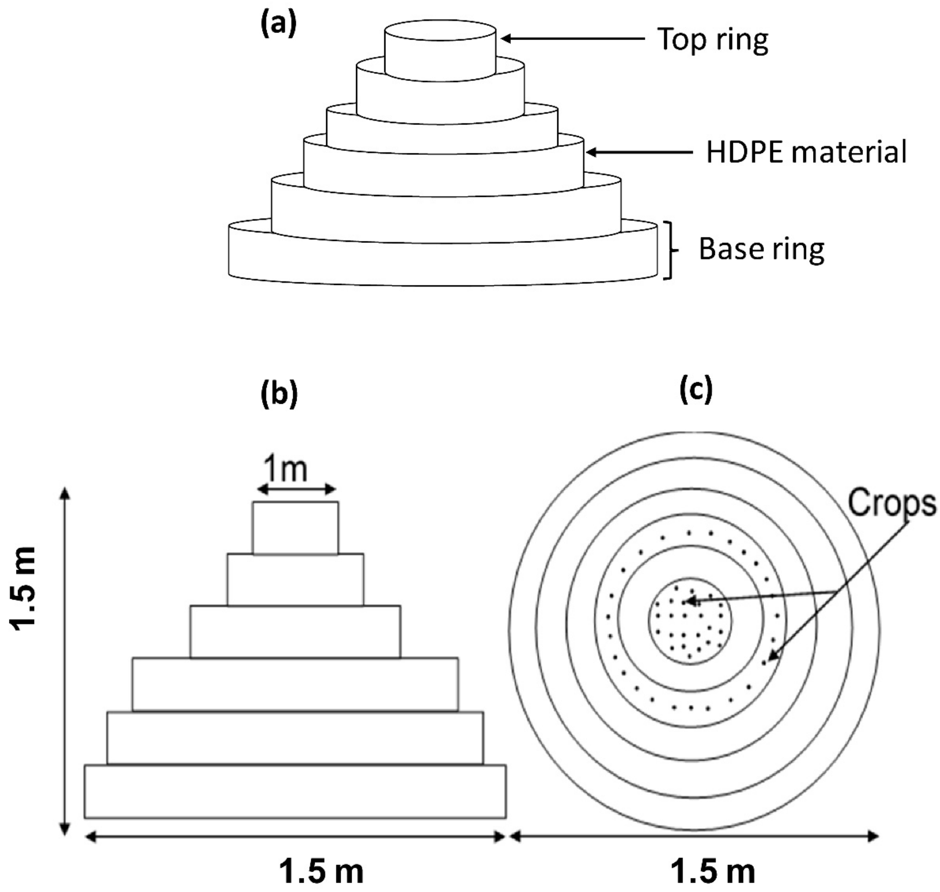

Figure 1. High-density polythene (HDPE) material is stacked upwards and filled with soil to form terraces for planting different crops: design of a wonder multistorey garden (**a**); view from the side (**b**) and top (**c**), showing the stacked rings for planting different crops.

The soil used in the WMSG devices is optimized for productivity by supplementing essential crop nutrients through the addition of available fertilizers and amendments such, as the use of commercial fertilizer, organic fertilizer, and insect frass. Although WMSG is reputable for minimizing land and water use, limited attention has been given to the efficiency of this technology, particularly regarding the ratio of fertilizer inputs, irrigation frequency (water usage), pest incidence, and damage. For instance, very little is known about its efficiency in managing biotic stress such as pest damage and abiotic stressors such as moisture and nutrients for optimum plant growth.

Rapid urbanization implies an increase in waste production, and there is more and more emphasis are being place on a circular economy for resilient cities. In East Africa, several medium- to large-scale farms producing black soldier fly (BSF) have emerged in the context of using insects as food and feed, and for the promotion of bioeconomy with the conversion of organic waste streams into commercial products for the enhancement of employment and food security [20–25]. Black soldier fly frass fertilizer is a by-product of BSF rearing, and it contains substantial amounts of nutrients essential in crop production [22,26]. The integration of BSFFF into WMSG technology to produce leafy vegetables such as kale and Swiss chard is a critical step towards building resilience in urban settings in the context of the COVID-19 pandemic; however, an examination of this requires empirical data.

In addition, there is no study that gives details on input levels of fertilizer, soil, and seeds. As water quality and quantity is limited in urban areas, new options are sought to increase water use efficiency in agricultural production. There is a strong interest in adapting farming systems to guide the efficient usage of water. This can be achieved by determining the best irrigation regime to use. Therefore, the present paper aims to provide a comparative analysis of qualitative and quantitative data on the performance of Swiss chard and kale grown under WMSG technology treated with BSFFF under varying irrigation regimes.

2. Materials and Methods

2.1. Study Site

The study was conducted at the International Centre of Insect Physiology and Ecology (*icipe*), Nairobi (1.221° S, 36.896° E; 1616 m above sea level) [27]. The mean monthly minimum and maximum temperatures range between 12 and 29 °C. The site has a bimodal rainfall pattern with an average annual rainfall of 787 mm. The long rains occur between March and June, while the short rains start in October and end in December. The soils of the study sites are predominantly sandy clay, and well-drained, and classified as humic Nitisols [27]. The evapotranspiration rate is 2400 mm $year^{-1}$. The experimental conditions were characterized by high acidity and low levels of organic matter, macronutrients, and micronutrients. Details of the physical and chemical properties of the experimental soil are presented in our sister paper [21].

2.2. Experimental Crops

The crops selected for the experiments were kale (*Brassica oleracea* var acephala cv Thousand Headed) and Swiss chard (*Beta vulgaris* var. cicla cv Fordhook Giant). These varieties were chosen because they are the vegetables that are consumed the most in Nairobi, Kenya [28]. Furthermore, they are important sources of income and are extensively grown by a large population of farmers in Kenya. Moreover, kale and Swiss chard grow well in the raised garden beds and containers that are used in urban farming systems. Twenty-day-old vigorous and healthy seedlings sourced from an established nursery at the Kimplanter seedlings company, in Kiambu County, Kenya, were used as test crops.

2.3. The Design of Wonder Multistorey Garden

Wonder multistorey gardens are conical-shaped structures made from high-density polythene (HDPE) materials sourced from Amiran Kenya Ltd., Nairobi, Kenya (Figure 1a). The materials have a long lifespan of over 10 years, given that they are ultraviolet heat treated. These HDPE materials were cut into different sizes and fastened using bolts and nuts to form circular rings. The base ring diameter was 1.5 m, and the rows were reduced in size by 2–4 inches upwards, creating a pyramid-shaped structure with terraces that allow for the smooth flow of water downwards (Figure 1b,c). The garden is comprised of six terraces staggered at a height of 1.5 m, with an extensive base (diameter of 1.5 m) for stability. One storey covered approximately 1.5 m^2 area. The soil used around the terrace was mixed with less acidic and excellent goat manure in a 1:1 ratio. Ten experimental gardens were constructed in a single plot, with replications for each treatment.

2.4. Experimental Design and Treatment Application

The experiment was laid out in a randomized complete block design, split-plot with six replications, and each garden represented a block. The main plot factor was the irrigation regime, whereby the crops were irrigated daily, every two days, every three days, and on an as-needed basis (ad lib). The subplot factor comprised the fertilizer treatments, that included commercial mineral fertilizer (NPK) and BSFFF (Table 1). The BSFFF was obtained from composting BSF frass at *icipe* following procedures described by Beesigamukama et al. [22]. The mature BSFFF had nitrogen, phosphorus, and potassium concentrations of 3.6%, 0.5%, and 0.3%, respectively. Details of the physical-chemical characteristics of the BSFFF used in the study are presented in our sister paper [21]. The BSFFF and NPK were applied at rates equivalent to 371 kg of N ha^{-1} [21]. For each crop, the BSFFF or NPK was applied to supply 100% of the N required. The quantities of BSFFF and NPK used to supply 100% of crop nitrogen requirements were equivalent to 10.3 t ha^{-1} (dry weight) and 645 kg ha^{-1}, respectively. The third treatment included a combination of BSFFF and NPK so that each fertilizer supplied 50% of the N required (i.e, 185.5 kg N ha^{-1}). The quantities of BSFFF and NPK applied to supply 50% of the nitrogen required were equivalent to 5.15 t ha^{-1} (dry weight) and 322.5 kg ha^{-1}, respectively. The treatments in which BSFFF or NPK was applied to supply 100% of the total nitrogen required were denoted as 100BSFFF and NPK, respectively. Treatments in which BSFFF was used to supply 50% of the total nitrogen required were denoted as 50BSFFF. The NPK fertilizer was NPK 17:17:17, and it was purchased from an agrovet (Nairobi, Kenya). The control treatment consisted of unfertilized soil.

Table 1. Fertilizer and irrigation treatments.

Treatment	Fertilizer Treatment	Irrigation Regime
T1	100BSFFF	Daily
T2	50BSFFF	Daily
T3	NPK	Daily
T4	100BSFFF	Every two days
T5	50BSFFF	Every two days
T6	NPK	Every two days
T7	100BSFFF	Every three days
T8	50BSFFF	Every three days
T9	NPK	Every three days
T0	Control	Ad lib

100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment.

2.5. Garden Preparation, Plant Establishment and Maintenance

The gardens were ploughed and harrowed using a handheld fork once before planting for every trial. Twenty-day-old seedlings of uniform size were transplanted into the WMSGs in a spacing of 30cm from plant to plant [29]. The base ring/terrace accommodated 16 plants, while the 2nd, 3rd, 4th, 5th, and 6th rings held 14, 12, 10, 8, and 6 plants, respectively. Three plants in the middle of each ring/terrace were randomly selected and tagged for data collection in each garden. Weeding was carried out manually at two-week intervals from the second week until the end of the cropping season.

2.6. Data Collection—Growth and Yield Variables

Data collection procedures on growth and yield were adopted from Mwaura and Isutsa [30]. Data were collected every two weeks, from 14 days after transplanting until harvesting, on three randomly tagged plants.

The numbers of fully expanded leaves was determined by counting. Plant height was measured by using a tape measure placed at the base of the plant up to the topmost leaf. During data collection, crops were selected at random and physically checked for the presence of major pests, which included Aphids *Aphis* spp., diamondback moth (DBM), *Plutella xylostella*, whiteflies *Bemisia tabaci*, and leaf miners *Liriomyza* spp. The damage on the leaves was estimated on randomly selected plants through using Bioleaf foliar analysis as described by Machado [31] to score foliar defoliation.

Leaf chlorophyll concentration was measured by using a chlorophyll meter (SPAD-502, Soil-Plant Analysis Development Section, Minolta Camera Co., Osaka, Japan). Here, an average of absolute SPAD values was recorded from the fourth fully opened leaf from the top [32]. The chlorophyll meter (SPAD-502) is a handheld device that calculates the red light absorbed by the plant leaf. The output is a unitless parameter recorded and approached as an absolute or relative SPAD value [22]. At harvest, leaves from every treatment were weighed by using an electronic weighing balance to determine the total fresh weight, before drying at 60 °C to determine leaf dry matter of all plants per treatment.

2.7. Data Analysis

Before analysis, data values were checked for normality through using the Shapiro–Wilk test. Data on plant height, chlorophyll concentration, leaf damage score, and fresh weight were normally distributed and subjected to an analysis of variance test (ANOVA). Data on the number of leaves and pest incidences were not normally distributed and were analyzed using a generalized linear model with "quasi-Poisson" and the "MASS" package. Computation of least squares means was done using the "lsmeans" package, followed by mean separation using an adjusted Tukey's method implemented using the "cld" function from the "multicompView" package. The mean separation of analysis from normally distributed data was performed using the agricolae package and compared with Tukey HSD test at 5% significance level. All the statistical analyses were conducted using R statistical software version 3.6.0 [33].

3. Results

3.1. Effects of Irrigation Regime and Fertilizer Treatments on Vegetable Growth

3.1.1. Number of Leaves and Plant Height

The irrigation regime and fertilizer treatments showed a highly significant effect on the number of leaves for both kale and Swiss chard, especially in the later days of plant growth (Table 2a). Irrigation had no significant effect on the height of Swiss chard but significantly affected the height of kale.

The height of kale varied significantly due to different fertilizer treatments applied, although this difference was not significant for Swiss chard. Kale height increased to peak values at 42 days after transplanting (Table 2b). The number of leaves and the height of plants grown on soil treated with 100% BSFFF were higher than the 50% BSFFF, NPK, and control.

Table 2. (**a**) Main effects of irrigation and fertilizer on the number of leaves. (**b**) Main effects of irrigation and fertilizer on the plant height (cm).

(**a**)

	Kale			**Swiss Chard**		
	14DAT	**28DAT**	**42DAT**	**14DAT**	**28DAT**	**42DAT**
Irrigation regimes						
Daily	6.23 ± 0.09a	9.29 ± 0.16a	9.77 ± 0.18a	6.15 ± 0.15a	9.12 ± 0.17a	9.81 ± 0.18a
Every two days	5.90 ± 0.16a	8.65 ± 0.20b	9.43 ± 0.23a	6.10 ± 0.18a	8.72 ± 0.24ab	9.54 ± 0.26a
Every three days	5.80 ± 0.11a	8.68 ± 0.15b	9.28 ± 0.18ab	5.80 ± 0.11a	8.83 ± 0.18ab	9.52 ± 0.16a
Ad lib	5.77 ± 0.14a	8.39 ± 0.94b	8.66 ± 0.78b	5.78 ± 0.13a	8.31 ± 0.14b	8.46 ± 0.16b
F-value	2.69	5.52	6.64	1.77	3.36	9.62
df	3.68	3.68	3.68	3.68	3.68	3.68
p-value	0.053	0.002	0.001	0.162	0.024	<0.001
Fertilizer treatments						
100BSFFF	6.07 ± 0.14a	9.10 ± 0.22a	9.93 ± 0.19a	6.07 ± 0.14a	9.02 ± 0.19a	9.93 ± 0.19a
50BSFFF	6.01 ± 0.11a	8.91 ± 0.17ab	9.50 ± 0.17ab	5.93 ± 0.16a	8.78 ± 0.19ab	9.54 ± 0.18a
NPK	5.84 ± 0.14a	8.61 ± 0.16ab	9.06 ± 0.20bc	6.05 ± 0.17a	8.86 ± 0.22a	9.41 ± 0.22a
Control	5.77 ± 0.14a	8.39 ± 0.10b	8.66 ± 0.11c	5.78 ± 0.13a	8.31 ± 0.14b	8.46 ± 0.16b
F-value	1.14	3.45	10.36	0.82	2.74	10.87
df	3.68	3.68	3.68	3.68	3.68	3.68
p-value	0.339	0.021	<0.001	0.489	0.049	<0.001

Table 2. *Cont.*

(**b**)						
	Kale			**Swiss Chard**		
	14DAT	**28DAT**	**42DAT**	**14DAT**	**28DAT**	**42DAT**
Irrigation regimes						
Daily	20.4 ± 1.02a	45.7 ± 1.25a	54.0 ± 1.84a	29.9 ± 1.49a	34.5 ± 1.67a	41.9 ± 1.58a
Every two days	18.1 ± 1.37ab	37.8 ± 2.16ab	43.0 ± 3.01ab	29.3 ± 1.50a	32.6 ± 1.47a	40.2 ± 1.68a
Every three days	16.5 ± 1.12ab	37.1 ± 1.29ab	44.3 ± 1.84b	28.4 ± 1.34a	32.4 ± 1.36a	39.9 ± 1.80a
Ad lib	16.9 ± 1.94b	32.9 ± 1.25c	33.3 ± 1.84c	27.0 ± 1.30a	30.9 ± 1.63a	37.7 ± 2.33a
F-value	6.43	11.29	31.91	0.80	0.91	0.85
Df	3.68	3.68	3.68	3.68	3.68	3.68
p-value	<0.001	<0.001	<0.001	0.49	0.44	0.46
Fertilizer treatments						
100BSFFF	17.8 ± 0.87a	42.7 ± 1.59a	55.3 ± 2.01a	29.3 ± 1.27a	33.3 ± 1.32a	41.6 ± 1.50a
50BSFFF	20.0 ± 0.66a	41.4 ± 1.15a	47.8 ± 1.22ab	29.5 ± 1.68a	33.0 ± 1.73a	40.4 ± 1.89a
NPK	19.2 ± 0.75a	38.2 ± 1.32ab	44.6 ± 1.49b	28.9 ± 1.37a	33.2 ± 1.48a	40.1 ± 1.68a
Control	16.9 ± 0.99a	32.9 ± 1.96b	33.3 ± 1.05c	27.0 ± 1.30a	30.9 ± 1.63a	37.7 ± 2.33a
F-value	2.739	8.049	27.86	0.64	0.55	0.73
df	3.68	3.68	3.68	3.68	3.68	3.68
p-value	0.5	<0.001	<0.001	0.58	0.64	0.53

100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means (±SE) followed by the same letters within a column are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

Interaction between irrigation frequency and fertilizer treatments significantly influenced the plant height for kale but had no significant effect on Swiss chard height. The combined application of daily irrigation with 100% BSFFF produced the tallest kale plants at 42DAT (59.0 ± 2.78 cm), while the control produced lower plant height, followed by NPK fertilizer with irrigation every three days (Table 3a). The interaction had no significant effect on the number of leaves for both crops (Table 3b).

Table 3. (**a**) Interactive effects of irrigation and fertilizer on plant height (cm). (**b**) Interactive effects of irrigation and fertilizer on number of leaves.

(**a**)							
Irrigation Regimes	**Fertilizer Treatments**	**Kale**			**Swiss Chard**		
		14DAT	**28DAT**	**42DAT**	**14DAT**	**28DAT**	**42DAT**
Daily	100BSFFF	18.9 ± 0.54bc	48.0 ± 2.03a	59.0 ± 2.78a	30.1 ± 2.24a	35.1 ± 2.47a	45.1 ± 2.50a
Daily	50BSFFF	19.7 ± 1.04bc	45.8 ± 1.16a	52.0 ± 1.14ab	30.6 ± 3.35a	34.1 ± 3.64a	39.9 ± 3.14a
Daily	NPK	22.5 ± 0.61a	43.4 ± 1.35a	51.0 ± 1.72ab	29.1 ± 2.46a	34.1 ± 2.98a	40.8 ± 2.49a
Every two days	100BSFFF	20.6 ± 0.83ab	40.1 ± 1.44a	47.6 ± 1.62bc	29.3 ± 2.16a	31.8 ± 1.81a	40.0 ± 2.08a
Every two days	50BSFFF	21.6 ± 0.90ab	40.5 ± 1.00a	46.3 ± 1.36bc	28.9 ± 3.65a	32.4 ± 3.78a	40.5 ± 4.31a
Every two days	NPK	18.1 ± 1.25bc	37.8 ± 2.08a	43.0 ± 2.30bc	29.7 ± 2.20a	33.7 ± 2.02a	40.2 ± 2.41a
Every three days	100BSFFF	14.0 ± 1.43c	39.9 ± 3.30a	47.8 ± 3.74bc	28.4 ± 2.53a	33.0 ± 2.67a	39.6 ± 2.96a
Every three days	50BSFFF	18.6 ± 1.30bc	38.0 ± 2.16a	45.1 ± 2.57bc	29.0 ± 1.99a	32.4 ± 1.63a	40.9 ± 2.79a
Every three days	NPK	17.0 ± 0.55abc	33.5 ± 1.39a	39.9 ± 1.16cd	27.9 ± 2.81a	31.8 ± 2.99a	39.3 ± 4.04a
Ad lib	Control	16.9 ± 0.99bc	32.9 ± 1.96a	33.3 ± 1.05d	27.0 ± 2.39a	30.9 ± 3.01a	37.7 ± 4.29a
F-value		2.91	0.21	0.63	0.06	0.10	0.29
df		4.62	4.62	4.62	4.62	4.62	4.62
p-value		0.02	0.93	0.04	0.99	0.98	0.88

Table 3. *Cont.*

(**b**)

Irrigation Regimes	Fertilizer Treatments	Kale			Swiss Chard		
		14DAT	28DAT	42DAT	14DAT	28DAT	42DAT
Daily	100BSFFF	6.08 ± 0.11a	9.76 ± 0.18a	10.01 ± 0.16a	6.08 ± 0.11a	9.53 ± 0.11a	10.01 ± 0.16a
Daily	50BSFFF	6.30 ± 0.06a	9.11 ± 0.17a	9.72 ± 0.15a	6.07 ± 0.23a	8.82 ± 0.20a	9.84 ± 0.19a
Daily	NPK	6.29 ± 0.11a	9.01 ± 0.16a	9.58 ± 0.20a	6.08 ± 0.11a	9.01 ± 0.16a	9.44 ± 0.20a
Every two days	100BSFFF	6.15 ± 0.23a	8.61 ± 0.26a	9.91 ± 0.27a	6.15 ± 0.23a	8.61 ± 0.26a	9.91 ± 0.27a
Every two days	50BSFFF	5.94 ± 0.15a	8.95 ± 0.20a	9.53 ± 0.21a	5.79 ± 0.15a	8.86 ± 0.24a	9.53 ± 0.21a
Every two days	NPK	5.76 ± 0.09a	8.38 ± 0.12a	8.86 ± 0.18a	6.37 ± 0.17a	8.68 ± 0.26a	9.17 ± 0.31a
Every three days	100BSFFF	5.97 ± 0.04a	8.92 ± 0.12a	9.86 ± 0.14a	5.97 ± 0.04a	8.92 ± 0.12a	9.86 ± 0.14a
Every three days	50BSFFF	5.94 ± 0.08a	8.66 ± 0.14a	9.24 ± 0.15a	5.94 ± 0.08a	8.66 ± 0.15a	9.24 ± 0.15a
Every three days	NPK	5.48 ± 0.15a	8.45 ± 0.18a	8.74 ± 0.20a	5.63 ± 0.14a	8.88 ± 0.25a	9.65 ± 0.18a
Ad libitum	Control	5.77 ± 0.15a	8.39 ± 0.11a	8.66 ± 0.11a	5.78 ± 0.14a	8.31 ± 0.14a	8.46 ± 0.17a
F-value		1.01	0.80	0.47	0.76	0.61	0.47
df		4.62	4.62	4.62	4.62	4.62	4.62
p-value		0.407	0.528	0.754	0.553	0.6581	0.759

100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means (±SE) followed by the same letters within a column are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

3.1.2. Leaf Chlorophyll Concentration

The chlorophyll concentration in both plant types was observed to vary significantly due to fertilizer and irrigation treatments (Table 4). The chlorophyll concentration of kale leaves reached peak values at 42 DAT, with minimal changes observed between 14 and 28 DAT in 100% BSFFF compared to the control, while NPK produced higher chlorophyll concentration in Swiss chard than the control and other treatments (Table 4). The daily irrigation regime produced the highest mean chlorophyll concentration in both crops.

Table 4. Main effects of irrigation and fertilizer on chlorophyll concentration (SPAD value).

	Kale			Swiss Chard		
	14DAT	28DAT	42DAT	14DAT	28DAT	42DAT
Irrigation regimes						
Daily	43.8 ± 0.63a	42.5 ± 0.81a	43.2 ± 0.25a	34.7 ± 0.80a	33.2 ± 0.60a	34.5 ± 0.56a
Every two days	41.3 ± 0.32ab	42.7 ± 0.77a	41.3 ± 0.43b	33.5 ± 1.16ab	33.1 ± 0.68a	33.9 ± 0.51ab
Every three days	40.6 ± 0.42ab	41.8 ± 0.66a	41.3 ± 0.40b	34.4 ± 0.86a	33.7 ± 0.75a	33.5 ± 0.66ab
Ad lib	38.5 ± 0.65b	41.5 ± 1.20a	40.2 ± 1.28b	29.9 ± 1.16b	31.9 ± 0.39a	30.9 ± 1.12b
F-value	7.22	1.24	4.71	4.84	1.53	2.84
df	3.68	3.68	3.68	3.68	3.68	3.68
p-value	0.01	0.37	0.05	0.001	0.22	0.05
Fertilizer treatments						
100BSFFF	42.4 ± 0.58a	43.0 ± 0.67a	42.9 ± 0.48a	32.6 ± 0.63b	32.7 ± 0.60b	32.6 ± 0.43b
50BSFFF	42.8 ± 0.54a	40.9 ± 0.82a	41.8 ± 0.40ab	32.4 ± 0.10b	32.2 ± 0.63b	32.3 ± 0.57b
NPK	41.4 ± 0.53a	40.8 ± 0.82a	41.2 ± 0.51ab	35.0 ± 0.78a	37.1 ± 0.64a	35.8 ± 0.46a
Control	38.5 ± 0.65a	41.5 ± 1.20a	40.0 ± 1.28b	31.9 ± 1.15b	29.9 ± 0.39b	30.8 ± 1.12b
F-value	3.72	0.89	3.07	5.86	11.16	14.10
df	3.68	3.68	3.68	3.68	3.68	3.68
p-value	0.06	0.48	0.05	0.001	0.002	0.01

100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means (±SE) followed by the same letters within a column are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

Chlorophyll concentration varied significantly according to the interaction between fertilizer and irrigation regime (Table 5). Average chlorophyll content was the highest at 42 DAT, while the lowest average value was recorded at 14 DAT. Among the different treatment combinations, a higher chlorophyll concentration was recorded with the 100% BSFFF and daily irrigation combination than the control (Table 5).

Table 5. Interactive effects of irrigation regime and fertilizer on leaf chlorophyll concentration (SPAD value).

Irrigation Regimes	Fertilizer Treatments	Kale			Swiss Chard		
		14DAT	28DAT	42DAT	14DAT	28DAT	42DAT
Daily	100BSFFF	42.7 ± 1.04a	45.29 ± 0.75a	46.29 ± 1.30a	31.0 ± 0.61b	32.30 ± 0.80bc	36.83 ± 0.67a
Daily	50BSFFF	41.4 ± 1.41a	44.61 ± 0.88ab	41.41 ± 0.82ab	34.0 ± 0.74ab	34.10 ± 0.98abc	34.00 ± 1.09ab
Daily	NPK	40.3 ± 2.21a	41.43 ± 1.02abc	45.70 ± 1.04a	34.5 ± 0.81ab	37.72 ± 1.37a	34.49 ± 0.82ab
Every two days	100BSFFF	42.7 ± 1.09a	41.34 ± 0.42abc	42.73 ± 1.10ab	34.3 ± 0.60ab	33.53 ± 1.56bc	34.26 ± 1.37ab
Every two days	50BSFFF	39.6 ± 0.94a	42.03 ± 0.68ab	39.61 ± 0.94b	31.4 ± 0.66b	29.14 ± 2.11c	31.43 ± 1.14b
Every two days	NPK	39.0 ± 0.35a	43.07 ± 0.35b	38.97 ± 1.51b	33.7 ± 0.96ab	36.20 ± 1.29ab	33.73 ± 0.83ab
Every three days	100BSFFF	40.5 ± 0.99a	40.59 ± 0.41cd	40.45 ± 0.99ab	32.4 ± 0.51ab	32.33 ± 0.91bc	32.44 ± 0.55ab
Every three days	50 BSFFF	41.7 ± 0.82a	41.68 ± 0.82abc	41.71 ± 0.82ab	31.9 ± 0.55b	33.35 ± 1.14bc	31.89 ± 0.89b
Every three days	NPK	33.3 ± 0.82a	39.64 ± 0.72cd	43.29 ± 1.41ab	36.8 ± 0.93a	37.43 ± 1.57a	31.06 ± 1.32b
Ad libitum	Control	39.5 ± 1.51a	38.54 ± 1.21d	41.50 ± 2.21ab	28.7 ± 1.28b	29.85 ± 2.14bc	31.91 ± 0.72b
F-value		2.35	3.11	3.38	3.98	3.99	3.35
df		4.62	4.62	4.62	4.62	4.62	4.62
p-value		0.060	0.020	0.050	0.006	0.010	0.010

100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means (±SE) followed by the same letters within a column are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

The fertilizer treatments caused significant differences in the mean numbers of pests infesting kale (Table 6). In treatments where NPK fertilizer was applied, the pest incidences were on par with the control but significantly higher ($p < 0.01$) than those recorded on the 50% BSFFF and 100% BSFFF treatments. The irrigation regime showed no significant difference in the percentage of pest incidences recorded on both crops. The major pests of brassica, which included aphids, leaf miners, diamondback, and whitefly, were recorded attacking the plants, but this was not statistically significant.

The irrigation regime did not significantly affect the foliar damage score recorded for Swiss chard and kale. Continuous feeding of insects resulted in a higher defoliation rate at 42 DAT in all the treatments. The defoliation scores of both plant types were observed to vary due to fertilizer amendments, with the highest defoliation scores observed in the controls (Table 7). However, this defoliation was not severe (<20%) as compared with conventional gardens, where leaf damages were reported to be between 26 and 100% in uncontrolled infestation by major brassica pests according to previous studies.

The interaction effect of fertilizer treatments and irrigation regimes did not cause any significant differences in the foliar damage by major pests of kale and Swiss chard (Table 8). The foliar damage score was statistically on par for all the treatments of kale. However, the highest leaf damage scores were recorded in the control, being approximately 15.4% and 19.8% higher than the interaction treatments of 50% BSFFF once every three days of irrigation and 50% BSFFF once every two days of irrigation, respectively.

Table 6. Incidences of major insect pests recorded on kale plants for different irrigation regimes and fertilizer.

	Irrigation Regimes			
Insect Species	**Daily**	**Every Two Days**	**Every Three Days**	**Ad Lib**
Aphid	5.75 ± 1.18a	5.62 ± 1.18a	5.60 ± 1.18a	6.36 ± 1.24a
DBM	2.09 ± 0.54a	1.98 ± 0.54a	2.10 ± 0.54a	2.14 ± 0.53a
Whitefly	2.09 ± 0.54a	2.09 ± 0.54a	2.09 ± 0.54a	2.59 ± 0.57a
Leafminer	5.75 ± 1.18a	5.62 ± 1.18a	5.60 ± 1.18a	6.36 ± 1.24a
F-value	1.00	0.98	1.01	1.67
df	3.68	3.68	3.68	3.68
p-value	0.600	0.310	0.110	0.660
	Fertilizer Treatments			
	100BSFFF	**50BSFFF**	**NPK**	**Control**
Aphid	1.88 ± 0.39c	3.78 ± 0.39b	3.59 ± 0.39ab	4.65 ± 0.50a
DBM	0.14 ± 0.07a	0.19 ± 0.07a	0.21 ± 0.07a	0.26 ± 0.07a
Whitefly	0.06 ± 0.07a	0.09 ± 0.07a	0.25 ± 0.07a	0.29 ± 0.09a
Leafminer	5.00 ± 1.00d	3.19 ± 1.00bcd	8.06 ± 1.00ab	9.06 ± 1.00a
F-value	4.50	2.04	1.89	1.95
df	3.68	3.68	3.68	3.68
p-value	0.010	0.050	0.010	0.050

100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means (±SE) followed by the same letter within each row are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

Table 7. Main effects of fertilizer and irrigation regime on foliar damage score (Bioleaf analysis).

	Kale			Swiss Chard		
	14DAT	**28DAT**	**42DAT**	**14DAT**	**28DAT**	**42DAT**
Irrigation regimes						
Daily	3.02 ± 0.01a	7.11 ± 0.02a	11.19 ± 0.02a	1.64 ± 0.01b	3.86 ± 0.01b	9.2 ± 0.02a
Every two days	1.37 ± 0.01a	3.82 ± 0.01b	9.59 ± 0.03a	4.39 ± 0.02ab	7.09 ± 0.03ab	12.8 ± 0.03a
Every three days	2.79 ± 0.02a	4.17 ± 0.02b	10.23 ± 0.03a	1.03 ± 0.01b	3.48 ± 0.01b	8.9 ± 0.02a
Ad lib	2.60 ± 0.01a	11.86 ± 0.02a	18.87 ± 0.03a	10.47 ± 0.03a	13.15 ± 0.03a	19.2 ± 0.04a
F-value	0.45	4.85	2.31	6.22	3.36	2.74
df	3.68	3.68	3.68	3.68	3.68	3.68
p-value	0.718	0.004	0.084	<0.001	0.024	0.050
Fertilizer treatments						
100BSFFF	2.42 ± 0.01a	4.66 ± 0.01b	9.79 ± 0.03ab	4.71 ± 0.02ab	8.82 ± 0.03b	13.88 ± 0.03ab
50BSFFF	1.26 ± 0.00a	4.12 ± 0.01b	7.45 ± 0.01b	1.23 ± 0.01b	3.41 ± 0.06b	7.79 ± 0.02b
NPK	3.51 ± 0.01a	6.31 ± 0.02ab	13.77 ± 0.03ab	1.13 ± 0.00b	2.20 ± 0.01b	9.19 ± 0.02ab
Control	2.60 ± 0.01a	11.86 ± 0.02a	18.87 ± 0.03a	10.47 ± 0.03a	13.15 ± 0.03a	19.19 ± 0.04a
F-value	0.72	4.31	3.22	6.49	4.50	3.25
df	3.68	3.68	3.68	3.68	3.68	3.68
p-value	0.542	0.007	0.028	<0.001	0.006	0.027

100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means (±SE) followed by the same letter within each column are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

Table 8. Interactive effects of irrigation and fertilizer on the leaf damage score during experiments.

Irrigation Regimes	Fertilizer Treatments	Kale			Swiss Chard		
		14DAT	28DAT	42DAT	14DAT	28DAT	42DAT
Daily	100BSFFF	2.87 ± 0.02a	5.1 ± 0.03a	7.6 ± 0.03 a	1.29 ± 0.01a	3.36 ± 0.02a	5.84 ± 0.04a
Daily	50BSFFF	2.19 ± 0.01a	6.03 ± 0.03a	7.61 ± 0.03a	1.67 ± 0.01a	5.94 ± 0.03a	8.74 ± 0.04a
Daily	NPK	4.00 ± 0.02a	10.14 ± 0.03a	18.35 ± 0.04a	1.97 ± 0.01a	2.27 ± 0.02a	7.03 ± 0.04a
Every two days	100BSFFF	3.42 ± 0.03a	5.33 ± 0.04a	12.19 ± 0.07a	3.11 ± 0.05a	8.13 ± 0.07a	11.40 ± 0.07a
Every two days	50BSFFF	0.35 ± 0.00a	4.36 ± 0.02a	7.20 ± 0.03a	1.60 ± 0.02a	3.12 ± 0.03a	7.75 ± 0.04a
Every two days	NPK	0.35 ± 0.00a	1.78 ± 0.01a	9.37 ± 0.05a	0.45 ± 0.00a	0.45 ± 0.00a	7.14 ± 0.02a
Every three days	100BSFFF	0.95 ± 0.01a	3.50 ± 0.01a	9.56 ± 0.03a	1.71 ± 0.02a	4.95 ± 0.03a	8.41 ± 0.04a
Every three days	50BSFFF	1.23 ± 0.01a	1.97 ± 0.01a	7.55 ± 0.03a	0.42 ± 0.00a	1.17 ± 0.01a	6.90 ± 0.02a
Every three days	NPK	6.18 ± 0.04a	7.03 ± 0.04a	13.58 ± 0.07a	0.97 ± 0.00a	4.32 ± 0.03a	7.40 ± 0.04a
Ad lib	Control	2.60 ± 0.02a	11.86 ± 0.04a	18.87 ± 0.06a	2.47 ± 0.05a	3.16 ± 0.06a	9.19 ± 0.07a
F- value		0.94	1.05	0.40	1.28	1.97	1.60
df		2.50	2.50	2.50	4.62	4.62	4.62
p-value		0.398	0.358	0.671	0.286	0.110	0.186

100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means (±SE) followed by the same letters within a column are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

3.2. Effects of Irrigation Regimes and Fertilizer Treatments on Vegetable Yields

The yields of both kale and Swiss chard plants grown under different irrigation regimes varied significantly during the experiment. Crops grown under daily irrigation achieved significantly higher yields than other treatments did (Figure 2a). The leaves fresh weight yields of both crops were significantly influenced by different fertilizer treatments under the wonder multistorey garden conditions (Figure 3a,b). All fertilizer treatments produced a significantly higher fresh weight of leaves than the control did (Figure 3a,b). Treatment with 100% BSFFF produced significantly higher kale yields (Figure 2a) than the other treatments did, while those treated with 50% BSFFF produced significantly higher Swiss chard yields than other treatments did (Figure 2b).

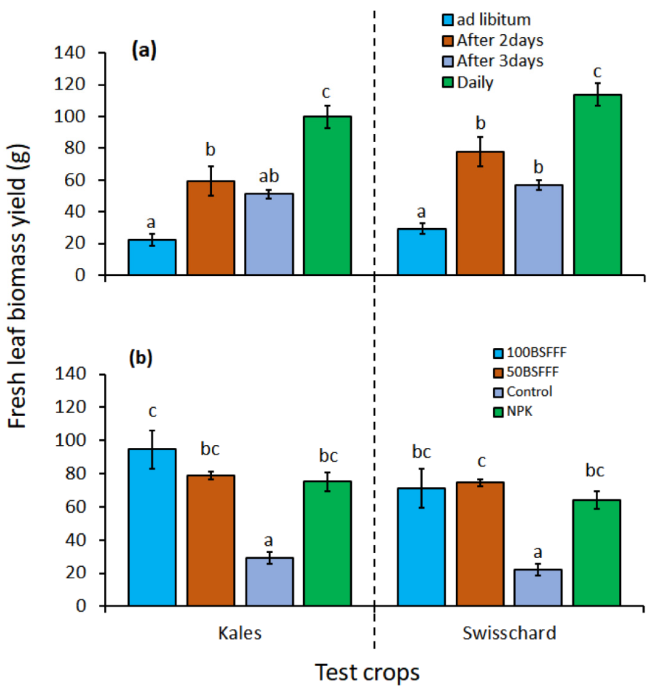

Figure 2. Effect of irrigation regime (**a**) and fertilizer application (**b**) on the fresh leaf biomass yields of kale and Swiss chard. Means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$). Bars represent standard errors.

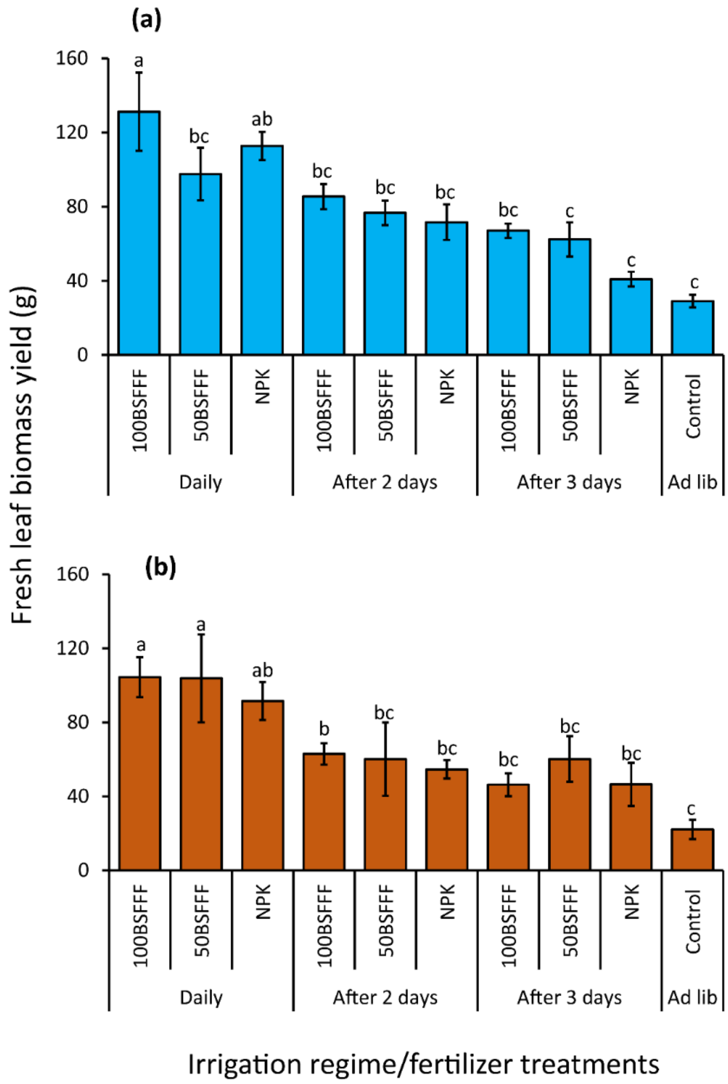

Figure 3. Interactive effects of irrigation regime and fertilizer treatments on fresh leaf biomass yields of kale (**a**) and Swiss chard (**b**). 100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

Furthermore, similar to the fresh weight of leaves, the dry leaf matter of both crops was significantly influenced by fertilizer treatments under the wonder multistorey garden conditions. The dry leaf matter was higher in all fertilizer treatments, as compared with the control. The treatments with 100% BSFFF, 50% BSFFF, and NPK recorded higher leaf dry matter figures, significantly different to other treatments ($p < 0.001$). However, the dry leaf matter with the NPK treatment dropped significantly with different irrigation regimes, as compared with treatments 100% BSFFF and 50% BSFFF (Figure 4a,b).

The interactions of irrigation regimes and fertilizer treatments significantly affected both fresh-leaf biomass yields and leaf dry matter of kale and Swiss chard, respectively ($p < 0.001$; $p < 0.001$). The yields of fresh-leaf biomass and the dry matter of kale obtained using 100% BSFFF fertilizer treatments were significantly ($p < 0.001$, $p < 0.001$) higher than those obtained in the control were (Figures 3a and 4a). The combination of 100% BSFFF and daily irrigation produced the highest kale yields when compared with the other treatments, while its dry matter remained higher even with the three-day irrigation regime

(Figure 4a). The Swiss chard yields achieved using 50% BSFFF and daily irrigation were significantly ($p < 0.001$) higher than with other combinations but were found to be at par with the treatment containing NPK and a daily irrigation regime (Figure 3b). The dry matter values obtained from Swiss chard with treatments of 100% BSFFF and 50% BSFFF were higher and significantly different ($p < 0.001$) when compared with the other treatments for daily and two-day irrigation regimes (Figure 4b). At irrigation regimes of two and three days, vegetable yields did not vary significantly between fertilizer treatments but showed ~10% lower yield than similar treatments provided with daily irrigation. On the other hand, the application of 100% BSFFF and 50% BSFFF fertilizers interacted positively with daily irrigation to give the heaviest leaf fresh weights for Swiss chard (104.39 and 103.78 g, respectively) (Figure 3b).

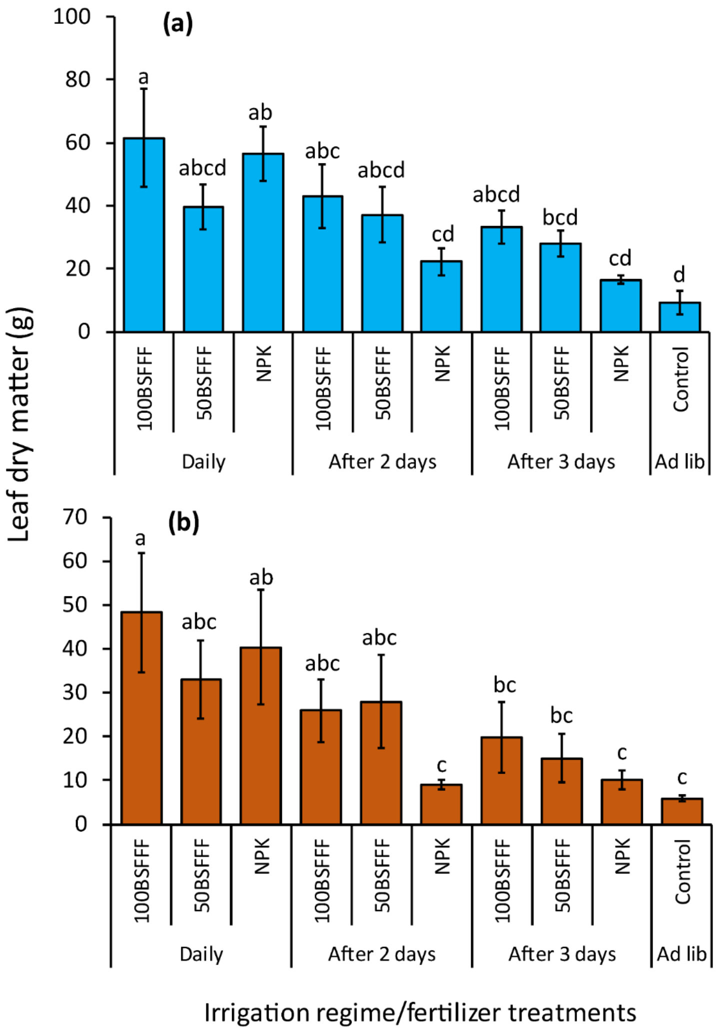

Figure 4. Interactive effects of irrigation regime and fertilizer treatments on dry leaf matters of kale (**a**) and Swiss chard (**b**). 100BSFFF = application of BSFFF to supply 100% of the total nitrogen (i.e., 371 kg N ha^{-1}) required by the crop; 50BSFFF = combined application of BSFFF and NPK so that each supplies 50% (i.e., 185.5 kg N ha^{-1}) of the total nitrogen required by the crop; NPK = commercial mineral fertilizer applied supply to supply 100% of the total nitrogen required by the crop; control = unfertilized treatment. Means followed by the same letter are not significantly different according to Tukey's honestly significantly different test ($p \leq 0.05$).

4. Discussion

Water and plant nutrients are very critical for increasing and maintaining crop yields [34]. Their proper application contributes effectively to achieving full crop production potential [34]. To meet crop needs throughout a growing season, water and soil fertility must be kept consistently adequate or high. The several nutrients that are required for plants are subdivided into macronutrients, secondary nutrients, and micronutrients. They are supplied to plants from soil and fertilizer sources [35]. The macronutrients such as nitrogen (N), phosphorous (P), and potassium (K) are used in relatively larger amounts by the plant. They can be supplied through inorganic fertilizers, organic manures, plant residues, and biological nitrogen fixation [35]. The secondary nutrients of calcium, magnesium, and sulfur can be found in the soil and are supplied to crops through chemical weathering and atmospheric deposition. Micronutrients (manganese, copper, iron, zinc, boron, and sodium) are essential nutrients for plant growth that are used in relatively small amounts by crops. Deficiencies in these micronutrients can be equally damaging to crop yield and profitability. The soil organic matter is a major reservoir of micronutrients. In many cases, micronutrients can also be supplied through foliar sprays [35]. In view of the above details, the current research study investigated the production of kale and Swiss chard in a WMSG, as affected by variations of irrigation regimes combined with different levels of BSFFF in comparison with the inorganic fertilizer NPK.

Our study showed that BSFFF, being an organic fertilizer, performed better than the inorganic fertilizer NPK did on the growth and yield of kale and Swiss chard. This was demonstrated by the positive influence on plant height, the number of leaves, and yield (i.e., fresh and dry weights of leaves). These results agree with the findings of Gärttling and Schulz [36] and Anyega et al. [21], who reported higher N (3.4–3.6%), P (0.5–2.9%), and K (0.3–3.5%) concentrations in BSFFF and observed the growth and yield of kale grown using BSFFF. Furthermore, Beesigamukama et al. [22] revealed in their investigation that frass fertilizers from all the insect species under study had adequate concentrations and contents of macronutrients, secondary nutrients, and micronutrients, with the BSFFF presenting significantly higher nitrogen and potassium concentrations than the frass fertilizers produced by other insect species. Doubling the amount of BSFFF in our research experiment has positively influenced the fresh and dry leaf yields of both test crops. This is because the addition of BSFFF leads to an increase in plant nutrients as a result of a high mineralization rate, thus partly contributing to better synchrony of the nutrient supply for vegetables and high yields [37,38]. Lata and Dubey [39] also found similar results when studying coriander (*Coriandrum sativum* L.). The adequate composition of BSFFF amended soil achieved a better crop yield compared to when commercial inorganic fertilizers were used. These results agree with the findings of previous studies carried out on conventional gardens but not as yet on vertical gardens [21,22,25].

Furthermore, our results demonstrated that WMSGs as amended with either 50% BSFFF or 100% BSFFF produced higher fresh and dry leaf yields than those treated with NPK and control did. This indicates that BSFFF contains a good range of essential macro-, secondary, and micronutrients required for healthy and vigorous plant growth [36].

The main and interactive effects of irrigation regimes were significant with the three-day irrigation regime achieving reduced fresh-leaf weight, as compared with where irrigation was applied either daily or after two days with similar fertilizer treatments. The daily irrigation regime with 100% BSFFF produced heavier fresh leaf weight for kales, while 50% BSFFF with the same irrigation produced the heaviest fresh-leaf weight for Swiss chard; however, it was on par with 100% BSFFF. This indicates the negative impact of water stress on crop growth and nutrient uptake, which could lead to stunted growth and low yield. Daily irrigation combined with any fertilizer treatment increased vegetable height compared to the other treatments. Thus, most crops maintained the same number of leaves with either short or long irrigation intervals. However, water is crucial for plant growth and leaf production, and a high leaf number was observed in treatments with shorter irrigation intervals. Walker [40] also demonstrated that if plants are stressed, the leaves shrink and are reduced in number, whereas the availability of water to plants keeps leaves turgid, preventing them from ageing.

The application of organic fertilizers (100% BSFFF and 50% BSFFF) with daily irrigation increased leaf chlorophyll concentration better than the other treatments did, indicating higher nutrient uptake, especially nitrogen in vegetables treated with BSFFF, which corroborates other studies conducted on crops such as kale, French beans, tomatoes, maize, and lettuce with different organic fertilizers [21,22,25,29,41–43]. The possible explanation for the remarkable increase of chlorophyll by crops grown in soil amended with 100% BSFFF could be attributed to the higher Mg^{2+} content in the fertilizer, which has been reported to play a central role in chlorophyll production [44]. Higher chlorophyll synthesis is known to accelerate photosynthetic activities in plants, and it is therefore necessary in the maintenance of plant health. Our findings revealed that water made available through irrigation facilitated an increase in chlorophyll accumulation necessary for photosynthesis [44]. These results are consistent with those of Beesigamukama et al. [22,41] and Tanga et al. [25], who demonstrated a significant increase in chlorophyll concentration at the late vegetative and silking stages of maize leaves grown under BSFFF during the long rain season.

Our findings showed that frequent irrigation regimes (daily) applied to plants grown in soil amended with 100% BSFFF favored the production of large leaves for both crops. We also found that pest incidences influenced plant performance, where significant differences were found in the foliar damage scores. The foliar damage scores of kale were lower at 42 DAT for treatments with 100% BSFFF and 50% BSFFF than NPK and control, while for Swiss chard, it was lower at 42 DAT for treatments with 50% BSFFF and NPK compared to 100% BSFFF and control. The differences in irrigation regime could be the main raison causing differences in the soil moisture levels of the treatments. Galhena et al. [42] reported that frequent irrigation increased the leaf damage scores of wheat plants due to creation of favorable micro-conditions for pest population build-up. The interaction of fertilizer and irrigation on pest incidences and foliar damage was not significant. However, aphids were the most predominant pests on kale grown on soil amended with BSFFF, although their damage was low compared with those found on the unamended soil (control) and the soil amended with NPK.

Diamondback moth larvae and other leaf miners are also serious pests of kale. A low diamondback infestation rate was noticed throughout the growth period. Whiteflies occurred in higher incidences during the later growth stages, with very little visible damage. Some of the insect pests' attacks on the crops led to feeding pressures on the leaves, leaving large boreholes that reduce the photosynthetic ability of plants. Similarly, Jaetzold et al. [27] reported that defoliation alters hormone balance, starch, sugar, protein, and chlorophyll contents of plant leaves, the stomatal resistance, and the senescence rate.

The increase in vegetable yield achieved through using irrigation is similar to that reported by Galhena et al. [42], who showed that vegetables that received more frequent irrigation achieved higher yields than those subjected to longer irrigation intervals. The higher vegetable yields achieved using BSFFF are consistent with [21,43], who reported a significant increase in the yields of vegetable crops grown using BSFFF, as compared with plants grown on unamended soil (control treatment), which recorded the lowest fresh leaf weight when compared with all the other treatments. These results indicate the impact of soil degradation on crop production [44–47]. However, the leaf weight was generally better; therefore, the higher vegetable yields under the wonder multistorey gardens could be attributed to ideal conditions, especially the adequate moisture retention for plant growth provided by the vertical garden and the sufficient nutrient supply from BSFFF.

5. Conclusions

The WMSG strategy is an input- and space-optimizing technology adapted to urban settings. The amendment of soil with 50% BSFFF or 100% BSFFF produced higher vegetable yields and leaf dry matter compared with the yields and leaf dry matter grown in unamended soil or soil amended with NPK. The frequency of watering of the vegetables grown under WMSG is crucial, with the daily provision of water significantly influencing the growth and yield of both crops. Furthermore, the pest incidence on kale and Swiss chard grown on soil treated with BSFFF was low, indicating the role of soil health on crop health. We therefore recommend 100% BSFFF with daily irrigation and 50% BSFFF with daily irrigation as the optimal combinations of fertilization and irrigation for kale and Swiss chard plants, respectively, to improve their growth and yield. This information provides a useful guide regarding the improved usage of WMSG in urban settings. Further research will be necessary to assess the impacts of irrigation regimes and BSFFF application on soil health, nutritional quality of kale and other vegetables, and the profitability of vegetable production under the WMSG system.

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