PLANT SCIENCE TODAY
Vol 12(4): 1-6
https://doi.org/10.14719/pst.10355

eISSN 2348-1900

RESEARCH ARTICLE

Response of growth, yield and quality indicators of three zucchini hybrids to bentonite amendment under irrigation regimes

Falah Kamil Noor Almousawi[1*] & Nasser Jubair Radhi Alhasnawi[2]

[1]Department of Horticulture and Landscape Design, Faculty of Agriculture, University of Kufa, Najaf 540 01, Iraq
[2]Department of Ecology, Faculty of Science, University of Kufa, Najaf 540 01, Iraq

*Correspondence email - nasir.alhasnawi@uokufa.edu.iq

Received: 30 June 2025; Accepted: 21 August 2025; Available online: Version 1.0: 06 October 2025; Version 2.0: 17 October 2025

Cite this article: Falah KNA, Nasser JRA. Response of growth, yield and quality indicators of three zucchini hybrids to bentonite amendment under irrigation regimes. Plant Science Today. 2025; 12(4): 1-6. https://doi.org/10.14719/pst.10355

Abstract

A field experiment was performed during the 2024 growing season at the University of Kufa to investigate the effects of bentonite clay and irrigation regimes on zucchini hybrids. Major challenges lie in enhancing crop resilience under water-scarce environments while maintaining soil health and sustainable productivity in arid and semi-arid regions. Three water requirements (50, 75 and 100) of the actual water needs were applied as main plots on three zucchini hybrids as subplots (Amjad, Kavili and Wisam). Bentonite clay was incorporated into the soil at three levels (0, 75, 150 $g.plant^{-1}$) and set up as sub-subplots. A split-split-plot system was adopted based on a completely randomized block design. The full water requirement significantly improved growth and yield, including plant height 94.18 cm, fruit length 13.76 cm, early yield 12.56 kg $plant^{-1}$ and total yield 50.25 t ha^{-1}. The irrigation level at 75 achieved a remarkable enhancement compared to the level at 50, resulting in reasonable plant growth and production, which proves to be a suitable approach under water scarcity while reducing yield losses. Kavili hybrid recorded the highest significant averages for the number of branches, leaf area and total yield of 1.86 branches $plant^{-1}$, 1.45 $m^2.plant^{-1}$ and 10.651 $t.ha^{-1}$, consecutively. Amjad hybrid recorded the highest average fruit length 13.66 cm, whereas Wissam hybrid had the highest average fruit weight 136.13 g. Bentonite amendments at 150 $g.plant^{-1}$ had significant improvements in the plant yield 1.157 $kg.plant^{-1}$, early yield 11.629 $t.ha^{-1}$ and total yield 46.26 $t.ha^{-1}$. The triple interaction represented by W3H2B2 realized significant improvements in the plant height, leaf area, dry weight, plant yield and total yield, 101.00 cm, 1.72 m^2. $plant^{-1}$, 363.00 $g.plant^{-1}$, 1.37 $kg.plant^{-1}$ and 54.54 $t.ha^{-1}$, in the same sequence.

Keywords: bentonite clay; fruit yield; squash; vegetative growth; water requirements

Introduction

Summer squash (*Cucurbita pepo* L.), also known as zucchini, is one of the important summer vegetable crops belonging to the Cucurbitaceae family, which comprises four other cultivated species (1). It is considered a favourable vegetable for consumers, both cooked and fresh. About 100 g of its edible part contains a good amount of 340 mg K, 18 mg vit C, 17 mg Ca, 38 mg P, 140 IU vitamin A, 1.4 g protein, 3.9 g carbohydrate. However, its content is low in some nutrients as it contains 0.6 mg niacin (B3), 0.5 mg Fe, 0.2g fat, 0.07 mg B1 and 0.04 mg B2 (2). Furthermore, squash seeds are utilized in various medical treatments as a diuretic agent, vermifuge and hepato-nephro protective effects (3) and exhibit antibacterial and antifungal properties (4).

Natural, environmentally friendly biogenic amendments, whose efficiency is high, like bentonite, are preferred. Bentonite is a pure clay formed from volcanic eruptions and is associated with the Smectite mineral group. This mineral mixture enhances the nutrients in the soil due to its large surface area, which facilitates the gradual decomposition of nutrients and provides them readily to the plant (5). Moreover, bentonite clay can improve the chemical and physical properties of the soil, thereby reducing the need for synthetic fertilisers and contributing to the rapid elimination of salts. In Tianjin, China's Binhai New Area, coastal saline soil was treated with 15 kg of bentonite per m^3 in combination with 68 kg of compost made from garden waste. The soil salinity in the 0-20 cm and 20-40 cm layers decreased to around 3.95 g/kg and 3.82 g/kg, respectively, because of the combined application's above 50 % salt elimination rate with improving soil fertility and speeding up desalination (6).

Water is one of the primary components of plant cells and its deficiency has a negative impact on plant growth and productivity, resulting in a decrease in the rate of photosynthesis. Consequently, growth deteriorates and productivity declines (7). Water scarcity has become a widespread issue in agriculture worldwide due to climate change; therefore, it is necessary to adopt water deficit regimes to mitigate drought stress while maintaining balanced crop production. Considering the nutritional importance of the zucchini plant, this study aimed to test three zucchini genotypes and evaluate their morphological, biochemical and qualitative indicators to determine the optimal hybrid for cultivation in Iraqi environmental conditions. Furthermore, investigate the optimal level of bentonite addition as a type of superabsorbent natural material to mitigate the adverse effects of water stress by providing suitable moisture for plant growth and productivity. The most suitable combination of genotype, bentonite level and irrigation regime could be used as a suitable strategy for enhancing yield and stress tolerance in zucchini cultivation under arid and semi-arid conditions.

Materials and Methods

Experiment site and treatment details

A trial experiment was carried out during the growing season of 2024 at the research station at the University of Kufa to investigate the effects of bentonite clay and irrigation regimes on zucchini plants. The first factor included three different irrigation levels (50, 75 and 100) of the actual water requirements denoted by (W_1, W_2 and W_3), respectively. These water levels were applied when the plant reached 3-4 true leaves, or approximately 15 days after planting the seeds (8). The second factor involved planting three hybrids of zucchini (Amjad 'H_1', Kavili 'H_2' and Wisam 'H_3') directly in the field on 1/ 3/ 2024. Amjad super early hybrid zucchini is of Seminis U.S. origin, Kavili F_1 is a hybrid developed in the Netherlands, originally bred by the Dutch seed company Nunhems and Wisam F1 hybrid is produced by Hefei Hefeng Seed Co., Ltd. and is of Chinese origin. The third factor included three levels of bentonite clay (0, 75, 150 g. plant^{-1}) denoted by (B_0, B_1 and B_2), respectively, which was added to the soil pre-planting. Before planting, random samples of the field soil were taken from different places with a depth of (0-30) cm and then sent to the lab for soil testing (Table 1). Bentonite clay is purchased from a local company in Iraq and its composition is described in Table 2. Also, average maximum and minimum temperatures recorded for the period March-June 2024 (Table 3).

Field layout and management

Primary management of the field experiment was done through tillage and harrowing processes. Further, well-decomposed local farmyard manure (FYM) was incorporated with the soil at a rate of 2.5 kg.m^{-2} and all soil and crop management were achieved as needed during the entire season. The experimental area was divided into three blocks to implement a split-split-plot experiment according to the Randomized Complete Block Design (RCBD). Irrigation levels were placed as the main plot using a drip irrigation system along plant blocks. An electronic watering controller was installed at the beginning of each main pipe in the drip irrigation system to maintain the amount and pressure of irrigation for each designated treatment. Zucchini hybrids were established in the subplots, while bentonite clay levels were designated in the sub-subplots forming (3 water levels*3 hybrids*3 bentonite*3 reps), resulting in a total of 81 experimental units. Each experimental unit in the form of a furrow containing 16 plants distributed in two lines alternatively, was 4 m long, 1 m wide and 0.5 m between plants.

Table 1. Physicochemical properties of the soil test of the experimental location

Properties	Value	Unit	Properties	Value	Unit
Soil bulk density	1.41	Mg.m^{-3}	Clay	204	g.kg^{-1}
Soil particle density	2.65	Mg.m^{-3}	Silt	136	g.kg^{-1}
Available Water	0.19	cm^3	Sand	660	g.kg^{-1}
Volumetric soil moisture content at 33 kPa	0.28	m^3.m^{-3}	Porosity	0.47	
Volumetric soil moisture content at 1500 kPa	0.09	m^3.m^{-3}	Soil texture		Sandy loam

Table 2. Compositions of bentonite clay used in the study

Properties		Value	Unit
ECP		3.14	dS.m^{-1}
pH		7.00	---
Carbon Minerals		130.10	g.kg^{-1}
$CaSO_4.2H_2O$		2.40	g.kg^{-1}
Cl		0.05	
CEC		60.10	cmol$_c$.kg^{-1}
Content of Oxides	P_2O_5	0.65	
	K_2O	0.50	
	CaO	0.58	
	MgO	0.18	
	Fe_2O_3	1.52	
	Na_2O	0.18	
	SO_3	0.23	
	SiO_2	51.46	
	Al_2O_3	34.58	
Bentonite Particles	Sand	12.0	g.kg^{-1}
	Clay	889.0	g.kg^{-1}
	Silt	99.0	g.kg^{-1}

P_2O_5: Phosphorus Pentoxide, K_2O: Potassium Oxide, CaO: Calcium Oxide, MgO: Magnesium Oxide, Fe_2O_3: Ferric Oxide, Na_2O: Sodium Oxide, SO_3: Sulfur Trioxide, SiO_2: Silicon Dioxide, Al_2O_3: Aluminium Oxide.

Table 3. Average high and low temperatures in Najaf, Iraq, for the period March-June 2024

Month-2024	Avg. Max	Avg. Min	Characteristics
March	25°C	13°C	Mild spring
April	34°C	19°C	Warming phase
May	37°C	22°C	Early summer
June	45°C	29°C	Peak summer

Vegetative growth indicators

Plant indicators were measured for five plants taken randomly from each experimental unit and these included: plant length (cm), number of branches per plant (branches.plant^{-1}), number of total leaves per plant (leaf. plant^{-1}) and leaf area per plant (m^2.plant^{-1}). Additionally, the dry weight of the total shoot (g/ plant) was estimated at the end of the season, when the plants were cut and then dried in an electric oven at 75 °C for 48 hrs to ensure complete dryness (9).

Fruit yield indicators

The average of these indicators was determined as follows: fruit length (cm), fruit weight (g), single plant yield (kg.plant^{-1}), early yield (t.ha^{-1}) according to the first three harvests and the total yield per unit area (t.ha^{-1}) according to the cumulative yield of each experimental unit.

Data analysis

Analysis of Variance (ANOVA) test and the Least Significant Difference Test (LSD) were used to analyse the differences between treatments at a 0.05 probability level, as determined by the statistical software VSN International GenStat 12.1 (10). This study specifically focused only on the main effects and the triple interactions between factors (water levels*hybrids*bentonite levels). The two-way interaction effects were analysed in an independent study and will be reported in a forthcoming publication.

Results and Discussion

Vegetative growth indicators

The results in Table 4 show that there was a significant superiority of water demand in the vegetative growth indices, with irrigation level at 100 (W_3) the highest averages of studied characteristics including plant height, number of branches per plant, number of leaves per plant, leaf area, shoot dry weight, which recorded 94.18 cm, 2.02 branches.plant^{-1}, 35.14 leaves.plant^{-1}, 1.62 m^2.plant^{-1} and 331.21 g.plant^{-1}, respectively. In contrast, the watering requirement of 50 (W_1) yielded the lowest averages for the aforementioned indicators, at 74.14 cm and 1.36 branches.plant^{-1}, 28.38 leaves.plant^{-1}, 1.22 m^2.plant^{-1} and 200.99 g.plant^{-1}, respectively. The results of the same table show that there were significant differences between zucchini hybrids regarding the vegetation growth indices, where the Wisam hybrid exceeded the Amjad hybrid in plant height, with a maximum average of 90.84 cm compared to the Amjad hybrid's lowest plant height of 70.76 cm. Nevertheless, the rest of the vegetable growth indices - number of branches, total number of leaves, leaf area and shoot dry weight - were superior to the Kavili hybrid, yielding the maximum averages at 1.86 branches.plant^{-1}, 32.03 leaves.plant^{-1}, 1.45 m^2.plant^{-1} and 269.07 g.plant^{-1},consecutively. However, the Amjad hybrid gave the minimum averages for the same indices: 1.36 branches.plant^{-1}, 28.38 leaves.plant^{-1}, 1.22 m^2.plant^{-1} and 200.99 g.plant^{-1}.

The soil application of bentonite clay had a significant impact on vegetative growth traits, where 150 g plant^{1} yielded the highest averages of plant height (92.51 cm) and 1.86 branches.plant^{-1}, 34.13 leaves.plant^{-1}, leaf area 1.50 m^2.plant^{-1} and shoot dry weight 331.22 g.plant^{-1}, respectively. Conversely, the control treatment (no addition of bentonite) had the lowest averages for the same traits, at 73.12 cm and 1.17 branches. plant^{-1}, 27.39 leaves.plant^{-1}, 1.12 m^2. plant^{-1} and shoot dry weight 201.00 g.plant^{-1}.

The triple interaction of the experimental factors revealed a substantial superiority in all growth indices studied. Consequently, the tri-combination ($W_3H_2B_2$) recorded the highest improvement in each of the plant height 101.00 cm, 2.57 branches.plant^{-1}, 38.69 leaves.plant^{-1}, leaf area 1.72 m^2.plant^{-1} and shoot dry weight 363.00 g.plant^{-1}, compared with the other tri-combination ($W_1H_1B_0$), which gave the lowest averages in plant height 70.66 cm, 25.87 leaves.plant^{1} and shoot dry weight 175.00 g.plant^{-1}, respectively.

The results presented in Table 4 on vegetative growth indices were significantly enhanced as the irrigation levels increased from 50 to 100 and this may be attributed to the increased nutrient availability and easy uptake by plant roots, which encourages vegetable growth through cell division and expansion. However, plants irrigated with a low water level at 50 % could considerably hinder the absorption of nutrients such as nitrogen, which is necessary for the process of cell development,

Table 4. Vegetative growth indicators of three zucchini hybrids influenced by bentonite clay amendments under various irrigation levels

Treatments				Plant height (cm)	No. of branches. plant^{-1}	No. of leaves. plant^{-1}	Leaf area (m^2. plant^{-1})	Shoot dry weight (g.plant^{-1})
	50			74.14	1.36	28.38	1.22	200.99
Irrigation levels	75			80.77	1.65	30.44	1.40	258.21
	100			94.18	2.02	35.14	1.62	331.21
LSD$_{0.05}$				**0.411**	**0.010**	**0.311**	**0.001**	**5.390**
	H1			70.76	1.48	31.25	1.40	253.04
Hybrids	H2			77.28	1.86	32.03	1.45	269.07
	H3			90.84	1.70	30.69	1.39	268.33
LSD$_{0.05}$				**0.218**	**0.015**	**0.241**	**0.005**	**5.551**
	0			73.12	1.17	27.39	1.12	201.00
Bentonite levels	75			79.07	1.60	29.44	1.33	258.22
	150			92.51	1.86	34.13	1.50	331.22
LSD$_{0.05}$				**0.212**	**0.011**	**0.137**	**0.004**	**4.291**
		H1	0	70.66	1.12	25.87	1.13	175.00
		H1	75	72.00	1.22	28.55	1.25	183.33
		H1	150	72.66	1.10	31.62	1.32	189.33
		H2	0	76.00	1.26	28.04	1.17	195.33
	50	H2	75	76.33	1.32	29.54	1.24	221.00
		H2	150	77.00	1.50	31.53	1.35	235.33
		H3	0	73.33	1.16	25.74	1.12	186.00
		H3	75	74.33	1.24	26.92	1.18	201.33
		H3	150	75.00	1.26	27.67	1.28	222.33
		H1	0	77.33	1.46	28.73	1.35	218.33
Irrigation levels		H1	75	78.33	1.51	30.46	1.38	255.00
*		H1	150	79.00	1.12	31.64	1.42	278.33
Hybrids		H2	0	82.33	1.88	29.69	1.39	230.00
*	75	H2	75	83.33	1.98	30.44	1.45	247.00
Bentonite levels		H2	150	85.66	1.97	31.80	1.51	268.67
		H3	0	79.66	1.62	28.81	1.34	268.33
		H3	75	80.33	1.68	30.65	1.38	171.67
		H3	150	81.00	1.72	31.76	1.42	286.67
		H1	0	87.66	1.72	32.85	1.57	308.33
		H1	75	89.33	1.77	34.97	1.60	328.33
		H1	150	90.00	1.20	36.58	1.64	341.33
		H2	0	98.00	2.08	33.68	1.62	321.67
	100	H2	75	99.00	2.18	34.84	1.67	339.67
		H2	150	101.00	2.57	38.69	1.72	363.00
		H3	0	92.00	2.22	33.25	1.54	308.67
		H3	75	94.66	2.25	34.49	1.63	327.67
		H3	150	96.00	2.23	36.96	1.66	342.33
LSD$_{0.05}$				**0.662**	**0.033**	**0.254**	**0.0837**	**13.260**

which reflects positively on the outcome indicators as shown in Table 5 and this is in line with previous studies, verifying that sufficient irrigation for plant growth is crucial for physiological processes, nutrient uptake and promoting and development overall plant growth (11-14).

The results of Table 4 on plant growth indicators showed that the hybrid effect was significant in the vegetative growth indicators, which is due to the variability in the genetic composition of the hybrids. The genes of each hybrid crossed over in a manner different from those of the other hybrid, as well as the interplay of genetic factors and the surrounding environment, which affects hybrid performance. This is particularly evident in the Kavili hybrid, which is characterised by its vegetable growth, compared to the other hybrids in this study. As explained in Table 4, the physiologically different genetic structures in the representation of raw materials that support biological plant processes influence their morphological formation, increase productivity and speed of response to environmental factors. These results are consistent with the findings on how genetic composition can significantly influence plant processes, morphology, productivity and responsivity to environmental conditions, ultimately playing a crucial role in overall plant performance (15, 16).

The addition of bentonite clay had a positive effect on the increase of green growth by providing water permanently in the root zone. Bentonite functions as holding water in the soil and gradually releasing it to the plant. Thus, the suitable conditions for zucchini growth were provided. Bentonite can also prevent the leaching of some important nutrients, such as nitrogen and phosphorus, at various plant growth stages. In addition, it improves soil aeration, improves root respiration efficiency and maintains moisture and nutrient retention appropriately (17, 18). These ideal conditions significantly improved the vegetative growth of squash plants in contrast to those grown in untreated soils. Our results agree with recent research on bentonite's role in enhancing nutrient retention, preventing the leaching of essential nutrients like nitrogen and phosphorus and enhancing soil conditions, which together improve photosynthesis and yield quality (19, 20).

Fruit yield indicators

It is clear from the data in Table 5 that statistically significant variations existed between the levels of irrigation need used in the measured traits. Subsequently, the full watering level 100 (W_3) presented an increment in fruit length, fruit weight, single plant yield, early yield and total yield of 13.76 cm, 137.20 g.fruit^{-1}, 1.25 kg.plant^{-1}, 12.56 t.ha^{-1} and 50.25 ha^{-1}, respectively. Whereas the water level of 50 (W_1) reduced these traits to 1.31 g.plant^{-1}, 0.769 kg.plant^{-1}, 7.694 t.ha^{-1} and 30.78 t.ha^{-1}, in the same sequence.

The same data in Table 5 also showed significant increases in the characteristics of squash hybrids, where the Amjad hybrid (H_1) was superior in the fruit length 13.66 cm, compared with the Kavili hybrid (H_2), which gave the lowest fruit length 13.42 cm. In addition, Wisam hybrid (H_3) was superior in fruit weight, providing 134.6 g.fruit^{-1} compared to Amjad hybrid, which gave the lowest average of 133.7 g.fruit^{-1}. Kavili hybrid was substantially superior in single plant yield, early yield and total yield, giving higher averages of 1.06 kg.plant^{-1}, 10.65 t.ha^{-1}, 42,60 t.ha^{-1}, consecutively, in comparison with Amjad hybrid, affording the lowest averages for the same indices of 0.98 kg.plant^{-1}, 9.7 t.ha^{-1} and 39.47 t.ha^{-1}, respectively. Nonetheless, bentonite addition at 150 g.plant^{-1} recorded significant increases in the fruit length, fruit weight, single plant yield, early yield and total yield of 12.62 cm, 136.13 g.fruit^{-1}, 1.157 kg.plant^{-1}, 11.62 t.ha^{-1} and 46.26 t.ha^{-1}, consecutively. Plants with no addition of bentonite had the minimum averages of these traits, such as 12.14 cm, 130.01 g.fruit^{-1}, 0.75 kg.plant^{-1}, 7.17 t.ha^{-1} and 30.78 t.ha^{-1}, respectively.

The triple interaction of the experimental factors exposed a significant effect on all yield indicators, as the treatment of $W_3H_1B_2$ and $W_3H_3B_2$ yielded the highest averages of fruit length 14.16 cm and fruit weight 139.13 g.fruit^{-1}, respectively, while the treatment of $W_1H_2B_0$ and $W_1H_1B_0$ gave the lowest averages of fruit length 13.05 cm, 130.20 g.fruit^{-1}, respectively. Furthermore, significant improvements were found for plant yield 1.37 kg.plant^{-1}, early yield 13.63 t.ha^{-1} and total yield 54.54 t.ha^{-1} achieved by the combination of $W_3H_2B_2$. Contrarily, the minimum averages of plant yield 0.67 kg.plant^{-1}, early yield 6.76 t.ha^{-1} and total yield 27.06 t.ha^{-1} were obtained by the combination $W_1H_1B_0$.

Based on the vegetative growth data shown in Table 4, plants revealed the superiority of the traits irrigated with the full water level, may receive adequate nutrients and did not suffer any deficiency reflected in the formation of flower buds and increase in the number, size and weight of the fruit set, which ultimately increased the crop yield and its related. However, plants that received 50 of the water level were adversely affected by water stress conditions in which photosynthesis and carbon assimilation declined, in addition to lowering the production of metabolites, decreasing enzymatic activity and minimizing cell division and expansion. Consequently, less development of the vegetative buds plus their dormancy can cause a reduction in the number and weight of the fruits and as a result, lower yield. Our findings are consistent with previous studies, that deficit irrigation during different growth stages of various crops significantly reduced photosynthesis in plants, enzyme activity, chlorophyll content, fruit quality, water use efficiency and overall productivity, suggesting the sensitivity of pepper and potato to irrigation regimes (21-25).

The results in Table 5 indicated that there was substantial variance between zucchini hybrids in the plant yield and related traits, mainly due to their different genetic profile, besides their adaptation to environmental conditions within a given region and distinct from other genetic makeups. These results agree with those of (26-28), who collectively emphasize that a major factor influencing the biochemical, physiological and agronomic characteristics of tomato cultivars and related species is genetic diversity. Crop enhancement efforts that seek to increase market quality, stress resilience and nutritional value depend considerably on this genetic potential. This diversity suggests that the market quality, nutritional value and stress resilience of tomatoes are mostly determined by genetic variability.

This reflects positively on the nutrient availability necessary to stimulate the transformation of vegetable buds into flowering buds. This led to an increase in yield indicators and supports early-stage plants due to their positive effect on the fruit set ratio and hence improves yield traits. Moreover, the accumulation of plant products for metabolites reduces competition among fruits, thus increasing the rate of fruit set. These results are consistent with the recent agronomic research and well-established plant biology concepts that confirm achieving optimal production requires

Table 5. Yield indicators of three zucchini hybrids influenced by bentonite clay amendments under various irrigation levels

Treatments				Fruit length (cm)	Fruit weight (g)	Plant yield (kg. plant^{-1})	Early yield (t.ha^{-1})	Total yield (t.ha^{-1})
Irrigation levels	50			13.26	131.0	0.769	7.694	30.781
	75			13.47	134.0	1.053	10.588	42.173
	100			13.76	137.2	1.256	12.562	50.255
$LSD_{0.05}$				**0.020**	**0.14**	**0.004**	**0.030**	**0.122**
Hybrids	H1			13.66	133.7	0.986	9.871	39.476
	H2			13.42	134.0	1.065	10.651	42.606
	H3			13.44	134.6	1.027	10.281	41.127
$LSD_{0.05}$				**0.013**	**0.033**	**0.004**	**0.0402**	**0.158**
Bentonite levels	0			12.14	130.01	0.755	7.176	30.782
	75			12.35	133.0	0.986	10.545	42.172
	150			12.62	136.13	1.157	11.629	46.263
$LSD_{0.05}$				**0.012**	**0.035**	**0.002**	**0.025**	**0.09**
Irrigation levels * Hybrids * Bentonite levels	50	H1	0	13.22	130.20	0.676	6.766	27.067
		H1	75	13.49	130.70	0.744	7.443	29.773
		H1	150	13.64	131.53	0.815	8.150	32.600
		H2	0	13.05	130.60	0.730	7.306	29.227
		H2	75	13.19	130.93	0.785	7.850	31.400
		H2	150	13.37	131.60	0.859	8.593	34.373
		H3	0	13.06	130.80	0.732	7.320	29.280
		H3	75	13.15	131.40	0.770	7.703	30.823
		H3	150	13.25	131.80	0.812	8.123	32.493
	75	H1	0	13.46	133.30	0.959	9.590	38.363
		H1	75	13.55	133.60	1.001	10.016	40.067
		H1	150	13.67	134.40	1.046	10.490	41.853
		H2	0	13.25	133.60	1.055	10.550	42.200
		H2	75	13.38	134.20	1.104	11.043	44.173
		H2	150	13.49	134.80	1.158	11.586	46.347
		H3	0	13.34	133.80	1.016	10.163	40.653
		H3	75	13.47	134.30	1.056	10.560	42.240
		H3	150	13.64	134.80	1.091	10.913	43.653
	100	H1	0	13.83	135.70	1.166	11.666	46.667
		H1	75	13.96	136.70	1.211	12.116	48.467
		H1	150	14.16	137.60	1.260	12.606	50.427
		H2	0	13.44	136.46	1.241	12.423	49.693
		H2	75	13.60	137.00	1.287	12.873	51.493
		H2	150	13.85	137.70	1.372	13.636	54.547
		H3	0	13.54	137.43	1.209	12.106	48.430
		H3	75	13.68	138.13	1.256	12.566	50.267
		H3	150	13.86	139.13	1.307	13.076	52.307
$LSD_{0.05}$				**0.038**	**0.150**	**0.009**	**0.0837**	**0.328**

maintaining proper nutrient levels to support flower initiation, fruit development and promote hormonal balance. By boosting metabolic efficiency, physiological and agronomic attributes and overall plant health, this improved nutritional environment promotes early plant development, improves the fruit set ratio and thus higher yields (29, 30).

Conclusion

Our findings indicated that a 100 level of irrigation requirement with planting Kavili hybrid, along with applying bentonite clay at 150 g.plant^{-1} presented significant improvements in the plant growth and yield indicators of zucchini. The performance of zucchini hybrids played a pivotal role in determining plant growth and yield efficiency, where Kavili hybrid outperformed in most measured indicators, indicating a genetic profile adapted to the field conditions. Further, bentonite amendments obviously contributed to maintaining soil moisture, in turn boosting overall plant health, even under limited irrigation levels like 75 and helping mitigate water stress damage. Hence, bentonite can be a promising option for ameliorating water use efficiency and augmenting sustainable agriculture during drought conditions.

Acknowledgements

The authors gratefully acknowledge the staff of the Department of Horticulture, Faculty of Agriculture, University of Kufa, Iraq for their valuable help and technical assistance in conducting this research.

Authors' contributions

FKNA conducted the field experiment and collected field measurements. NJRA supervised the entire research and contributed to analysing the data. FKNA wrote, reviewed and edited this manuscript. All authors read and agreed to the published final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None

References

1. Muthoni J, Shimelis H. Pumpkin (*Cucurbita* spp): A neglected and underutilized crop with potential for production in Africa. Aust J Crop Sci. 2025;19(2):152-60. https://doi.org/10.21475/ajcs.25.19.02.p212
2. Dhaliwal S. Handbook of vegetable science. 2017;5:77-146.
3. Adepoju GK, Adebanjo AA. Effect of consumption of *Cucurbita pepo* seeds on haematological and biochemical parameters. Afr J Pharm Pharmacol. 2011;5(1):18-22. https://doi.org/10.5897/AJPP10.186
4. Lalelou FS, Fateh M. Effects of different concentrations of zinc on chlorophyll, starch, soluble sugars and proline content in *Cucurbita pepo*. Int J Biosci. 2014;4(10):6-12. https://doi.org/10.12692/ijb/4.10.6-12
5. Hussein SA, Ali HA. Stabilization of expansive soils using polypropylene fiber. Civil Eng J. 2019;5(3):624-35. http://doi.org/10.28991/cej-2019-03091274
6. Li J, Sun X, Li S. Effects of garden waste compost and bentonite on muddy coastal saline soil. Sustainability. 2020;12(9):3602. https://doi.org/10.3390/su12093602
7. Khanna SM. Plant metabolism during water deficit stress: A review. Agric Rev. 2024;45(3):448-55. https://doi.org/10.18805/ag.R-2381
8. Al-Bayati AS, Turk HA, Al-Tufaili AK, Aboohanah MA, Mohan RK, Qader HM. Characterization of green onion with NPK fertilization and foliar application of hornwort extract. SABRAO J Breed Genet. 2023;55(6):2140-8. https://doi.org/10.54910/sabrao2023.55.6.25
9. Hocking PJ, Randall PJ, De Marco D, Bamforth I. Assessment of the nitrogen status of field-grown canola (*Brassica napus*) by plant analysis. Aust J Exp Agric. 1997;37(1):83-92. https://doi.org/10.1071/EA95068
10. VSN International. GenStat for Windows 12th Edition. VSN International, Hemel Hempstead, UK. 2009.
11. Ahmad P. Water stress and crop plants: a sustainable approach. John Wiley & Sons. 2016;1. https://doi.org/10.1002/9781119054450
12. Al-Kazzaz AGM, Al-Saedi AJH, Al-Saady HARA, Yahya SS, Abed RHF. The influence of foliar application with proline acid on growth parameters and yield component of chamomile plant (*Matricaria chamomilla* L.) subjected to water stress. J Biot R Cen. 2016;10(1):78-83. https://doi.org/10.24126/jobrc.2016.10.1.469
13. Mohammed HA. Effect of exogenous application of zinc and selenium on quality characteristic for sunflower plant under water stress. Plant Arch. 2018;18(2):2661-71.
14. Al-Bayati AS, Jaafar HS, Alhasnawi NJ. Evaluation of eggplant via different drip irrigation intervals and foliar sprays with seaweed extract biostimulant. Int J Agric Stat Sci. 2020;16(2):633-9.
15. Burhan AK, Al-Taey DK. Effect of potassium humate, humic acid and compost of rice wastes in the growth and yield of two cultivars of dill under salt stress conditions. Adv Nat Appl Sci. 2018;12(11):1-6. https://doi.org/10.22587/anas.2018.12.10.1
16. Mohammed SAK, Salman FA. Effect of fertilization type and spraying with sulphur amino acids on three broccoli cultivars' physiological and vegetative indicators. Euphrates J Agric Sci. 2022;14(3):20-34.
17. Mi J, Gregorich EG, Xu S, McLaughlin NB, Liu J. Effect of bentonite as a soil amendment on field water-holding capacity and millet photosynthesis and grain quality. Sci Rep. 2020;10(1):18282. https://doi.org/10.1038/s41598-020-75350-9
18. Shahad RF, Hamid MM. Impact of bentonite and humic acid on the growth and flowering of *Catharanthus roseus* L. in sandy soil. J Environ Earth Sci. 2025;7(1):157-66. https://doi.org/10.30564/jees.v7i1.7368
19. Czaban J, Siebielec G. Effects of bentonite on sandy soil chemistry in a long-term plot experiment (II); effect on pH, CEC and macro- and micronutrients. Pol J Environ Stud. 2013;22(6):1669-76.
20. Nastari Nasrabadi H, Nemati H, Kafi M, Aroiee H. Application of bentonite and salicylic acid benefits growth and fruit yield of Khatooni melon under drought stress. Isfahan Univ Technol J Crop Prod Process. 2025;15(1):19-31. https://doi.org/10.47176/jcpp.15.1.37792
21. Dagdelen N, Yilmaz E, Sezgin F, Gürbüz T. Effects of water stress at different growth stages on processing pepper (*Capsicum annuum* cv. Kapija) yield, water use and quality characteristics. Pak J Biol Sci. 2004;7(12):2167-72. https://doi.org/10.3923/pjbs.2004.2167.2172
22. Karam F, Masaad R, Bachour R, Rhayem C, Rouphael Y. Water and radiation use efficiencies in drip-irrigated pepper (*Capsicum annuum* L.): response to full and deficit irrigation regimes. Eur J Hortic Sci. 2009;74(2):79-85. https://doi.org/10.1079/ejhs.2009/968069
23. Ismail SM. Influence of deficit irrigation on water use efficiency and bird pepper production (*Capsicum annuum* L.). Meteorol Environ Arid Land Agric Sci. 2010;21(2):29-43. https://doi.org/10.4197/Met.21-2.3
24. Tabrizi EF, Yarnia M, Farajzadeh N, Ahmadzadeh V. Effect of different irrigation level on potato yield. Ann Biol Res. 2011;2(5):548-51.
25. Sharma A, Kumar V, Shahzad B, Ramakrishnan M, Singh Sidhu GP, Bali AS, et al. Photosynthetic response of plants under different abiotic stresses: a review. J Plant Growth Regul. 2020;39:509-31. https://doi.org/10.1007/s00344-019-10018-x
26. Bhandari SR, Chae Y, Lee JG. Assessment of phytochemicals, quality attributes and antioxidant activities in commercial tomato cultivars. Korean J Hortic Sci Technol. 2016;34(5):677-91. http://doi.org/10.12972/kjhst.20160071
27. Tembe KO, Chemining'wa GN, Ambuko J, Owino W. Effect of water stress on yield and physiological traits among selected African tomato (*Solanum lycopersicum*) landraces. Int J Agron Agric Res. 2017;10(2):78-85.
28. Ugbaja CC, Fawibe OO, Oyelakin AS, Fadimu IO, Ajiboye AA, Agboola DA. Comparative phytochemical and nutritional composition of *Trichosanthes cucumerina* (L.) and some *Solanum lycopersicum* (L.) cultivars in Nigeria. Am J Plant Sci. 2017;8(2):297-309. https://doi.org/10.4236/ajps.2017.82021
29. Taiz L, Zeiger E. Plant physiology. 4th ed. Sunderland (MA): Sinauer Associates Inc.; 2006.
30. Hussain AJ, Al-Taey DK, Kadhum HJ. Biochar application increases the amount of nitrogen, phosphorus and potassium in the soil: a review. IOP Conf Ser Earth Environ Sci. 2023;1213(1):012023. https://doi.org/10.1088/1755-1315/1213/1/012023

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.