# Response of Growth Indicators and Yield of Three Zucchini Squash Hybrids to Bentonite Clay Addition Under Three Levels of Water Requirements

Falah K. N. Al-Mousawi[1] and Nasir J. R. Al-Hasnawi[2]

[1]Graduate Student, College of Agriculture, University of Kufa, Iraq.

[2]Assistant Professor, Department of Horticulture and Landscape Design, College of Agriculture, University of Kufa, Iraq

1falahk.almousawi@student.uokufa.edu.iq

2nasir.alhasnawi@uokufa.edu.iq

**Abstract**

This experiment was conducted during the 2025 agricultural season at the Agricultural Research Station of the University of Kufa to investigate the effects of three experimental factors. The first factor involved bentonite clay addition at three levels (0, 75, and 150 gm•plant$^{-1}$) in the root growth zone at 10 cm depth. The second factor included different water requirement levels (50%, 75%, and 100% of actual plant water needs), implemented when plants reached the true leaf. The third factor involved cultivation of three zucchini squash hybrids: Amjad (American, Seminis), Cavili (Dutch, Nunhems), and Wissam (Chinese, Hefei), planted on March 1, 2025. Seeds were directly sown in soil after bentonite clay addition.

Results demonstrated that water requirement levels significantly affected all studied parameters including plant height, leaf number, leaf area, dry weight of vegetative parts, plant yield, and total yield. The 100% water requirement achieved the highest values: 92.13 cm plant height, 33.14 leaves•plant$^{-1}$, 1.60 m$^2$•plant$^{-1}$ leaf area, 329.21 gm•plant$^{-1}$ dry weight, 1.254 kg•plant$^{-1}$ plant yield and 48.255 ton•ha$^{-1}$ total yield.

Hybrid effects were also significant, with Wessam hybrid recording the highest plant height (88.74 cm), while Cavalli hybrid excelled in other parameters with 32.03 leaves•plant$^{-1}$, 1.43 m$^2$•plant$^{-1}$ leaf area, 267.07 gm•plant$^{-1}$ dry weight, 1.063 kg•plant$^{-1}$ plant yield, and 40.606 ton•ha$^{-1}$ total yield.

The three-way interaction showed significant effects across all parameters, with treatment $W_3 H_2 B_2$ achieving optimal results: 100.00 cm plant height, 36.69 leaves•plant$^{-1}$, 1.70 m$^2$•plant$^{-1}$ leaf area, 361.00 gm•plant$^{-1}$ dry weight, 1.370 kg•plant$^{-1}$ plant yield and 52.547 ton•ha$^{-1}$ total yield.

**Keywords: zucchini squash hybrids, bentonite clay, water requirements.**

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Introduction

Summer squash (Cucurbita pepo L.) belongs to the Cucurbitaceae family, which includes four other species [15]. It is a popular vegetable consumed both cooked and fresh. The plant exhibits cold tolerance characteristics [17]. Fruits contain beneficial

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levels of niacin ($B_3$ ) and vitamins A, $B_2$ , and C, though nutritional content is relatively low, containing 3.6% carbohydrates and 1.2% protein [8]. The crop has medicinal applications, particularly for early prostate disorder relief due to zinc content, and seeds are used in various medical treatments [2]. It also exhibits antibacterial and antifungal properties [10.[

Recently, natural materials have been introduced to reduce water stress impacts, particularly environmentally friendly materials with high efficiency such as bentonite mineral. Bentonite is a pure clay formed from volcanic ash that enhances soil nutrient availability through its large surface area, facilitating nutrient decomposition and plant uptake [9]. Bentonite improves soil chemical and physical properties, reducing fertilizer requirements and making it suitable for poor soils [11.[

Water deficit management is critical for crop production, as water stress significantly reduces plant growth and productivity by limiting photosynthesis rates, impairing nutrient uptake, and restricting cell division and expansion processes. Determining optimal water requirements is essential for maximizing crop yield while ensuring efficient water use under various environmental conditions [7.[

Given the nutritional and medicinal importance of zucchini, this study aimed to:

.1 Evaluate vegetative growth and yield of three zucchini genotypes to identify the most suitable genotype for Iraqi soil conditions.

.2 Study the effect of bentonite mineral application on productivity and determine the optimal addition level for mitigating water stress effects.

.3 Determine optimal water requirements and their impact on quantity, quality, and vegetative growth productivity.

.4 Identify the best three-way interaction among experimental factors.

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Materials and Methods

Experimental Design and Location

The field experiment was conducted during the 2025 agricultural season at the University of Kufa Agricultural Research Station. The study investigated three factors: bentonite clay addition at three levels (0, 75, and 150 gm•plant$^{-1}$) applied at 10 cm depth before planting, water requirements (50%, 75%, and 100% of actual plant water needs) applied when plants reached three true leaves (approximately 15 days after planting), and three genotypes planted directly in the field on March 1, 2025: Amjad hybrid (American origin, Seminis company), Cavili hybrid (Dutch origin, Nunhems company), and Wissam hybrid (Chinese origin, Hefei company.(

Soil Preparation and Analysis

After field preparation including plowing, leveling, and harrowing, soil samples were collected randomly from various field locations at 0-30 cm depth, mixed homogeneously, dried, ground, and sieved through a 2 mm mesh. Physical and chemical analyses were performed as shown in Table 1. Decomposed organic fertilizer was added at a rate of 12.500 ton•ha$^{-1}$ before planting. The field was divided according to experimental design into three main plots for bentonite levels, each subdivided into three secondary plots for water requirements, then further divided into three sub-secondary plots for genotypes, resulting in 81 experimental units. Each experimental unit consisted of 16 plants arranged in rows with 50 cm spacing between plants and 50 cm between rows, with 1 m buffer zone separating experimental units. No chemical fertilizers were applied during the experiment.

**Table 1. Selected soil properties before seed planting**

| Property | Unit | Soil Depth (0.00-0.30m) |
|---|---|---|
| Sand | $gm \cdot kg^{-1}$ soil | 661 |
| Silt | $gm \cdot kg^{-1}$ soil | 175 |
| Clay | $gm \cdot kg^{-1}$ soil | 204 |
| Soil Texture | - | Sandy Loam |
| Bulk Density | $Mg \cdot m^{-3}$ | 1.42 |
| Particle Density | $Mg \cdot m^{-3}$ | 2.66 |
| Porosity | - | 0.44 |
| Volumetric Water Content at 33 kPa | - | 0.284 |
| Volumetric Water Content at 1500 kPa | - | 0.091 |
| Available Water | - | 0.193 |

**Table 2. Selected properties of bentonite clay used in the study**

| Property | Value | Unit |
|---|---|---|
| Electrical Conductivity (EC) | 3.14 | $dS \cdot m^{-1}$ |
| pH | 7.0 | - |
| Organic Matter | - | $gm \cdot kg^{-1}$ |
| Calcium Carbonate | 130.1 | $gm \cdot kg^{-1}$ |
| Gypsum | 2.4 | $gm \cdot kg^{-1}$ |
| Cation Exchange Capacity (CEC) | 60.1 | $cmol \cdot kg^{-1}$ |
| **Oxide Content** | | |
| $P_2O_5$ | 0.65 | % |
| $K_2O$ | 0.50 | % |
| CaO | 0.58 | % |
| MgO | 0.18 | % |
| $Fe_2O_3$ | 1.52 | % |
| $Na_2O$ | 0.18 | % |

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| | | |
|---|---|---|
| $SO_3$ | 0.23 | % |
| $SiO_2$ | 51.46 | % |
| $Al_2 O_3$ | 34.58 | % |
| Cl | 0.05 | % |
| **Particle Size Distribution** | | |
| Sand | 2.0 | $gm \cdot kg^{-1}$ |
| Clay | 889.0 | $gm \cdot kg^{-1}$ |
| Silt | 99.0 | $gm \cdot kg^{-1}$ |

Statistical Analysis

Data were analyzed using split-split plot system in Randomized Complete Block Design (RCBD). Analysis of variance (ANOVA) was performed, and mean differences were tested using Least Significant Difference (LSD) test at 0.05 probability level [3]. Data analysis was conducted using GenStat 12.1 [18.[

Irrigation Management

Water requirements were determined based on irrigation duration and frequency. Three water requirement levels were applied every 5 days starting when plants reached the three true-leaf stage: 50% water requirement (15 minutes irrigation duration), 75% water requirement (22.5 minutes irrigation duration), and 100% water requirement (30 minutes irrigation duration.(

Measured Parameters

Vegetative Growth and Yield Parameters

Measurements were conducted on five randomly selected plants from each experimental unit:

.1 Plant Height (cm): Measured from soil surface to growing tip using measuring tape.

.2 Total Leaf Number ($leaves \cdot plant^{-1}$): All leaves on main stem and lateral branches were counted.

.3 Leaf Area ($m^2 \cdot plant^{-1}$): Three fully expanded leaves per plant were measured using scanner with Digimizer software following [4] method as described by [16.[

.4 Shoot Dry Weight ($gm \cdot plant^{-1}$): Plants were cut at season end and dried in electric oven at 75°C for 48 hours until complete drying.

.5 Plant Yield ($kg \cdot plant^{-1}$): Calculated from harvest beginning to end for each experimental unit: Plant Yield ($kg \cdot plant^{-1}$) = Total Unit Yield (kg) / Number of Plants per Unit

.6 Total Yield ($tons \cdot ha^{-1}$): Based on total harvest from experimental units during 12 harvest periods until May 28, 2025: Total Yield ($tons \cdot ha^{-1}$) = (Unit Yield × Hectare Area) / Experimental Unit Area

Results

Vegetative Growth and Yield Parameters

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Results in Table 3 demonstrate significant effects of water requirements on vegetative growth and yield parameters. The 100% water requirement ($W_3$) achieved the highest values for all studied traits: plant height, leaf number, leaf area, dry weight, plant yield, and total yield, recording 92.13 cm, 33.14 leaves•plant$^{-1}$, 1.60 m$^2$•plant$^{-1}$, 329.21 gm•plant$^{-1}$, 1.254 kg•plant$^{-1}$, and 48.255 tons•ha$^{-1}$, respectively, compared to 50% water requirement ($W_1$) which produced the lowest values of 72.24 cm, 28.38 leaves•plant$^{-1}$, 1.20 m$^2$•plant$^{-1}$, 198.99 gm•plant$^{-1}$, 0.767 kg•plant$^{-1}$, and 28.781 tons•ha$^{-1}$, respectively.

Results showed significant differences among genotypes in vegetative growth parameters. Wisam hybrid excelled in plant height with 88.74 cm compared to Amjad hybrid with 68.56 cm. However, Cavelli hybrid surpassed others in remaining vegetative growth and yield parameters, recording 32.03 leaves•plant$^{-1}$, 1.43 m$^2$•plant$^{-1}$, 267.07 gm•plant$^{-1}$, 1.063 kg•plant$^{-1}$, and 40.606 tons•ha$^{-1}$, respectively, compared to Amjad hybrid which showed the lowest values of 29.25 leaves•plant$^{-1}$, 1.36 m$^2$•plant$^{-1}$, 252.04 gm•plant$^{-1}$, 0.984 kg•plant$^{-1}$, and 37.476 tons•ha$^{-1}$.

Bentonite addition showed significant effects on studied vegetative growth and yield traits. Addition of 150 gm•plant$^{-1}$ bentonite recorded elevated values of 90.51 cm, 32.13 leaves•plant$^{-1}$, 1.50 m$^2$•plant$^{-1}$, 331.22 gm•plant$^{-1}$, 1.155 kg•plant$^{-1}$, and 44.263 tons•ha$^{-1}$, respectively, compared to control treatment which produced the lowest values of 71.11 cm, 25.39 leaves•plant$^{-1}$, 1.10 m$^2$•plant$^{-1}$, 199.00 gm•plant$^{-1}$, 0.753 kg•plant$^{-1}$, and 28.782 tons•ha$^{-1}$, respectively.

The three-way interaction among water requirement, genotype, and bentonite addition showed significant differences in all studied vegetative growth and yield parameters. Treatment combination $W_3 H_2 B_2$ achieved the highest values of 100.00 cm, 36.69 leaves•plant$^{-1}$, 1.70 m$^2$•plant$^{-1}$, 361.00 gm•plant$^{-1}$, 1.370 kg•plant$^{-1}$, and 52.547 tons•ha$^{-1}$, respectively, compared to treatment combination $W_1 H_1 B_0$ which produced the lowest values of 68.66 cm, 23.87 leaves•plant$^{-1}$, 1.11 m$^2$•plant$^{-1}$, 173.00 gm•plant$^{-1}$, 0.674 kg•plant$^{-1}$, and 25.067 tons•ha$^{-1}$, respectively.

**Table 3. Effect of water requirements, hybrids, and bentonite addition on vegetative growth and yield**

| **Factor/Treatment** | **Height (cm)** | **Leaf Number (leaves·plant$^{-1}$)** | **Leaf Area (m$^2$·plant$^{-1}$)** | **Dry Weight (gm·plant$^{-1}$)** | **Plant Yield (kg·plant$^{-1}$)** | **Total Yield (tons·ha$^{-1}$)** |
|---|---|---|---|---|---|---|
| Water 50% | 72.24 | 28.38 | 1.20 | 198.99 | 0.767 | 28.781 |
| Water 75% | 78.67 | 30.44 | 1.38 | 256.21 | 1.051 | 40.173 |
| Water 100% | 92.13 | 33.14 | 1.60 | 329.21 | 1.254 | 48.255 |
| **LSD (Water)** | **0.407** | **0.311** | **0.001** | **5.39** | **0.004** | **0.122** |
| H1-Amjad | 68.56 | 29.25 | 1.36 | 252.04 | 0.984 | 37.476 |
| H2-Cavili | 75.28 | 32.03 | 1.43 | 267.07 | 1.063 | 40.606 |

| | | | | | | |
|---|---|---|---|---|---|---|
| H3-Wasam | 88.74 | 29.69 | 1.37 | 266.33 | 1.025 | 39.127 |
| **LSD (Hybrid)** | **0.214** | **0.239** | **0.005** | **5.551** | **0.004** | **0.158** |
| Bentonite 0 gm | 71.11 | 25.39 | 1.10 | 199.00 | 0.753 | 28.782 |
| Bentonite 75 gm | 77.07 | 29.44 | 1.31 | 256.22 | 0.984 | 40.172 |
| Bentonite 150 gm | 90.51 | 32.13 | 1.48 | 329.22 | 1.155 | 44.263 |
| **LSD (Bentonite)** | **0.21** | **0.135** | **0.004** | **4.291** | **0.002** | **0.09** |
| Min Interaction ($W_1$ $H_1$ $B_0$ ) | 68.66 | 23.87 | 1.11 | 173.00 | 0.674 | 25.067 |
| Max Interaction ($W_3$ $H_2$ $B_2$ ) | 100.00 | 36.69 | 1.70 | 361.00 | 1.370 | 52.547 |
| **LSD (Interaction)** | **0.662** | **0.252** | **0.084** | **13.26** | **0.007** | **0.328** |

Discussion

Water Requirement Effects

The superior performance of 100% water requirement compared to 50% and 75% levels can be attributed to optimal soil moisture conditions that maintained adequate turgor pressure and enabled efficient physiological processes. Sufficient water availability facilitated better cell division, expansion, and elongation in plant tissues, resulting in enhanced vegetative growth. Water stress at 50% level impaired these growth processes and reduced metabolic activities including photosynthesis and nutrient transport. Adequate water supply also promoted better root development, which improved the plant's ability to access soil resources and enhanced overall plant vigor. These findings positively influenced yield parameters and are consistent with results reported by [1] and [12.[

Genotype Effects

Significant differences among hybrids reflect genetic variation, where each hybrid expressed genes differently due to genotype-environment interactions. Quantitative traits are controlled by numerous genes with minor effects, making them highly environment-responsive. The interaction between genetics and environment enhances the effectiveness of dormant genes that manifest under specific environmental conditions. Cavelli hybrid's superior vegetative growth indicates its adaptation to local conditions and higher photosynthetic efficiency, leading to increased carbohydrate production. These results align with [5] and [13.[

Bentonite Effects

Bentonite addition positively influenced vegetative growth by maintaining consistent soil moisture in the root zone. Bentonite retains water and releases it gradually to plants, creating optimal growing conditions. Additionally, bentonite contains essential nutrients required during various growth stages, including nitrogen and phosphorus. It also improves soil aeration and creates favorable conditions for soil microorganisms that enhance nutrient availability, leading to increased vegetative growth and plant yield. These results agree with [6] and [14.[

## Conclusions

Based on the experimental results, the following conclusions can be drawn:

.1 Water requirement at 100% of plant needs significantly enhanced all growth and yield parameters compared to lower water levels.

.2 Among the tested hybrids, Cavelli showed superior performance in most measured parameters, indicating it is the most suitable hybrid for local cultivation conditions.

.3 Bentonite application at 150 gm•plant$^{-1}$ significantly improved plant growth and yield compared to control and lower application rates.

.4 The interaction between 100% water requirement, Cavelli hybrid, and 150 gm•plant$^{-1}$ bentonite ($W_3$ $H_2$ $B_2$ ) produced the optimal combination for maximizing zucchini production. These findings provide valuable insights for optimizing zucchini cultivation practices under Iraqi growing conditions through integrated water and soil management approaches.

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