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# Influence of Hydrogel and Graded Levels of Fertigation on Soil Nutrient Status and Biochemical Compositions of Mulberry

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## Abstract

A field experiment was conducted to evaluate the effect of graded levels of fertigation integrated with Zeba hydrogel on soil properties, nutrient availability, physiological traits and biochemical quality of mulberry. The experiment was laid out in Randomized Complete Block Design (RCBD) with eight treatment combinations and three replications. The treatments consisted of varied levels of recommended doses of nitrogen and potassium through fertigation with and without hydrogel, along with conventional recommended doses of fertilizers and recommended doses of nitrogen and

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potassium as controls. Results revealed that soil pH, electrical conductivity and organic carbon were not significantly affected by treatments, indicating no adverse impact on soil chemical properties. However, post-harvest soil available N, P and K were significantly higher under fertigation combined with hydrogel, with the highest values recorded in $T_6$ (100 % RDNK through fertigation + Zeba hydrogel @ 6 kg $ac^{-1}$). Leaf nutrient status (N, P and K), chlorophyll content, leaf moisture, carbohydrate, crude protein and crude fibre contents were also significantly enhanced under hydrogel, assisted fertigation, especially in $T_6$ (100 % RDNK through fertigation + Zeba hydrogel @ 6 kg $ac^{-1}$). The improvement was attributed to efficient nutrient delivery, reduced leaching losses and improved soil moisture retention under hydrogel application. The study concludes that integration of fertigation with Zeba hydrogel is a sustainable and efficient approach for improving soil fertility, physiological performance and leaf quality of mulberry.

*Keywords: Mulberry; hydrogel; fertigation; nutrient status; biochemical.*

## 1. Introduction

"Mulberry (*Morus* spp.) is the sole food plant of the silkworm (*Bombyx mori* L.) and forms the biological foundation of the sericulture industry. The quantity and quality of mulberry leaves directly influence silkworm growth, cocoon yield and silk quality. India is one of the leading producers of silk, and for which sustainable mulberry production is essential to meet the growing demand of the sericulture sector" (Naik and Singh, 1999). However, "conventional soil application of fertilizers is often associated with low nutrient-use efficiency, higher losses through leaching and volatilization and increased cost of cultivation, particularly under irrigated conditions" (Yaseen et al., 2023).

"Fertigation, the application of fertilizers through drip irrigation emerged as highly efficient nutrient management strategy due to precise and timely delivery of nutrients directly to the root zone, resulting in improved nutrient uptake, reduced losses and enhanced productivity" (Padmanabha et al., 2018; Mahesh et al., 2022). Despite its advantages, nutrient efficiency under fertigation can still be constrained under moisture stress conditions. "Increased soil water retention due to polymer use implies that fertigation would not meet the crops' needs because fertigation rates are recommended considering a soil without the polymer." (de Oliveira Neto et al., 2024). In this context, hydrogels have gained importance as soil conditioners because of their high water absorption and slow-release properties, which improve soil moisture retention, reduce irrigation frequency and minimize nutrient leaching (Ghobashy et al., 2024; Wu et al., 2024). Zeba hydrogel, in particular, has been reported to improve soil moisture availability, nutrient absorption and crop performance under diverse agro-climatic conditions (Harshitha Mala et al., 2023).

"Several studies have reported positive responses of mulberry to fertigation and hydrogel application in terms of improved leaf yield, leaf nutrient status and biochemical quality" (Mahesh et al., 2022; Harshitha Mala et al., 2024). However, systematic information on the combined influence of graded fertigation levels and hydrogel on soil chemical properties, post-harvest nutrient status, physiological traits and biochemical quality of mulberry is limited. Hence, the present investigation was undertaken to evaluate the effect of fertigation integrated with Zeba hydrogel on soil fertility, leaf nutrient composition, chlorophyll content, leaf moisture and biochemical quality of mulberry under irrigated conditions.

## 2. Materials and Methods

The experiment was conducted during 2025 in well-established V1 mulberry garden at L-block, Agroforestry based IFS demo unit, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bengaluru. The field is located at a latitude of 12°58' N and longitude of 77°35' East and at an altitude of 930 m above mean sea level in the Eastern Dry Zone (Zone 5) of Karnataka. The experiment was established with eight treatment combinations *viz*., (Table 1).

Zeba hydrogel application was carried out only once for first crop after the pruning. Fertigation ($T_1$ to $T_6$) application was carried out in three equal splits at weekly intervals (15th to 29th days after pruning) for both first and second crop (Mahesh et al., 2022), $T_7$ (without P for second crop) and $T_8$ (with P for both crops) were acted as control treatments. "The fertilizers for $T_7$ and $T_8$ were applied at 20 days after pruning as per Dandin and Giridhar (2014). FYM @ 20 t $ha^{-1}$ $yr^{-1}$ was applied after pruning of mulberry and irrigation was given based on soil moisture content for all the treatments. Nitrogen (Urea) and Potassium

(Murate of potash) were applied through fertigation for both the crops. Phosphorus is immobile in soil, while is mainly responsible for root growth, so applied only once as basal dose for all the treatments except $T_8$" (Arunadevi and Selvaraj, 2013).

Single point sensors were placed at 15 cm depth to ensure enough water for crop growth. Soil moisture indicator was developed by Sugarcane Breeding Institute, Coimbatore which works on principle of resistance but, the depiction will be in the form of colour (https://sugarcane.icar.gov.in/index.php/soil-moisture-indicator/).

The data on Soil and leaf quality parameters at 60 DAP of mulberry crop were recorded and mean value was worked out. The experimental data collected on soil and plant quality parameters were subjected to Fisher's method of Analysis of Variance (ANOVA) as outlined by Sundararaj et al. (1972).

## 2.1 Estimation of Chemical Properties of Soil

The chemical properties in soil and plant were determined by following the standard procedure as follows: Table 3.

## 2.2 Soil pH and Electrical Conductivity

"Soil pH was estimated in 1:2.5 soil water suspension, using pH meter" Jackson (1973). "The clear supernatant of the soil water suspension was removed and the Electrical conductivity (EC) was measured using conductivity bridge" Jackson (1973).

**Table 1. Experimental treatment details**

| Treatment Number | Description |
|---|---|
| $T_1$ | 50 % RDNK through fertigation |
| $T_2$ | 50 % RDNK through fertigation + Zeba hydrogel @ 6 kg ac$^{-1}$ |
| $T_3$ | 75 % RDNK through fertigation |
| $T_4$ | 75 % RDNK through fertigation + Zeba hydrogel @ 6 kg ac$^{-1}$ |
| $T_5$ | 100 % RDNK through fertigation |
| $T_6$ | 100 % RDNK through fertigation +Zeba hydrogel @ 6 kg ac$^{-1}$ |
| $T_7$ | Control (RDNK as per Package of Practice) |
| $T_8$ | Control (RDF as per Package of Practice) |

*These treatments were laid out in RCBD design with three replications.*

**Table 2. Indicator readings and soil moisture status**

| Colour of LED | Soil Moisture Percentage | Soil moisture status | Inference |
|---|---|---|---|
| Blue | 75 – 100 % | Ample moisture | No need of irrigation |
| Green | 50 – 74 % | Sufficient moisture | Immediate irrigation not required |
| Orange | 25 – 49 % | Low moisture | Irrigation advisable |
| Red | <25 % | Very low moisture | Immediate irrigation necessary |

**Table 3. Standard methods adopted for soil analysis**

| Sl. No. | Parameter | Method | Procedure outlined by |
|---|---|---|---|
| 1 | Soil reaction (pH) | Potentiometric method | Jackson, 1973 |
| 2 | Electrical conductivity (dS m$^{-1}$) | Conductivity Bridge | Jackson, 1973 |
| 3 | Organic carbon (%) | Wet oxidation Method | Walkley and Blacks, 1934 |
| 4 | Avail. N (kg ha$^{-1}$) | Alkaline $KMnO_4$ method | Subbiah and Asija,1956 |
| 5 | Avail. $P_2O_5$ (kg ha$^{-1}$) | Bray's/Olsen's method | Jackson, 1973 |
| 6 | Avail. $K_2O$ (kg ha$^{-1}$) | Flame photometric method | Jackson, 1973 |

## 2.3 Soil Organic Carbon

The wet oxidation process was used to estimate soil organic carbon (Walkley and Black 1934).

## 2.4 Available Nitrogen

"Soil of 5 g was distilled with 25 ml of 0.1N $KMnO_4$ and 25 ml of 2.5 per cent NaOH. During distillation the ammonia released was trapped in 4 per cent boric acid containing mixed indicator and titrated against standard $H_2SO_4$ and the available nitrogen was expressed in kg/ha" (Subbiah and Asija 1956).

## 2.5 Available Phosphorus

"The available phosphorus present in the soil was extracted with Olsen's reagent. The extracted phosphorus content was then estimated by Ascorbic acid reduced blue color method. The intensity of blue color was read in spectrophotometer" (Jackson 1973).

## 2.6 Available Potassium

"The available potassium in the soil was extracted with neutral normal ammonium acetate solution and was estimated using flame photometer" as described by (Jackson 1973).

## 2.7 Analysis of Elemental and Biochemical Composition in Mulberry Leaves

### 2.7.1 Collection of Plant Samples

Plant samples were randomly collected from tagged plants in each treatment, cleaned with distilled water, air dried and then dried in hot-air oven for about 18 hr at 60 °C. The samples were then powdered and stored in polythene covers. These samples were analyzed for nutrient and biochemical analysis of mulberry leaves. The different methods adopted for plant analysis is given in Table 4.

## 2.8 Estimation of Nitrogen

Nitrogen was determined by Kjeldahl digestion-distillation method. Plant sample (1 g) was digested in digestion flask using digestion mixture and sulphuric acid. After complete digestion, the digested material was distilled in alkaline medium and the liberated ammonia was trapped in 2 per cent boric acid solution containing mixed indicator. The trapped ammonia was titrated against standard sulphuric acid (Kjeldahl 1883).

$$\mathrm{N\ (\%)} = \frac{\mathrm{TV\ X\ N.\,of\ acid\ X\ 0.014\ X\ Vol.\,of\ digested\ sample}}{\mathrm{Weight\ of\ the\ sample}\ \times \mathrm{aliquot\ taken}} \times 100$$

Where in,

TV= titration value

### 2.8.1 Digestion of Leaf Samples for Other Elements (Except N)

Powdered leaf samples (1 g) were treated with 10 ml of concentrated HNO3 and kept overnight for pre-digestion. Then the samples were digested with 10 ml of the di-acid mixture (9:4ratio of HNO3 and HClO4) until the snow-white residue remained. The residue was cooled and diluted to 100 ml using double distilled water, filtered and used to analyze all the elements except nitrogen.

**Table 4. Standard methods adopted for plant analysis**

| Sl. No. | Parameter | Plant analysis Procedure | Procedure outlined by |
|---|---|---|---|
| 1 | Nitrogen (%) | Kjeldahl's digestion distillation method | Kjeldahl 1883 |
| 2 | Phosphorus (%) | Di-acid digestion and Vanadomolybdate method | Murphy and Riley, 1962 |
| 3 | Potassium (%) | Flame photometric method | Havre, 1961 |
| 4 | Total Chlorophyll, Chlorophyll a, b (mg $g^{-1}$) | Arnon method | Hiscox and Israelstam, 1979 |
| 5 | Leaf moisture content (%) | Gravimetric method | Turner, 1981 |
| 6 | Total carbohydrate (%) | Anthrone reagent method | Dubois et al., 1956 |
| 7 | Crude protein (mg $g^{-1}$) | Kjeldahl's method | Kjeldahl 1883 |
| 8 | Crude fibre (%) | Gravimetric method | Mertens 2002 |

### 2.8.2 Estimation of Phosphorus

Phosphorus content in the di-acid digested extract was estimated by Vanadomolybdo- phosphoric yellow colour method in nitric acid medium and the colour intensity was measured at 420 nm wave length as described by (Murphy and Riley, 1962).

### 2.8.3 Estimation of Potassium

Potassium in the plant sample was determined by atomizing the diluted di-acid extract in a flame photometer as outlined by (Havre, 1961).

### 2.8.4 Chlorophyll Estimation

The content of chlorophyll in mulberry leaf was calculated by following procedure defined by Hiscox and Isrealstam (1979). The total leaf chlorophyll content was determined using the formula;

$$\text{Chlorophyll "a" ( fresh weight}\frac{\text{mg}}{\text{g}} = \frac{12.7\ (\text{O.D.}663) - 2.69\ (\text{O.D.}645) \times \text{Volume}}{1000 \times \text{ weight of leaves (g)}}$$

$$\text{Chlorophyll "b" ( fresh weight}\frac{\text{mg}}{\text{g}}) = \frac{22.9(\text{O.D.}645) - 4.68\ (\text{O.D.}663)\ \times \text{Volume}}{1000 \times \text{ weight of leaves (g)}}$$

$$\text{Total chlorophyll (fresh weight mg/g)} = \frac{20.2(\text{O.D.}645) + 8.02(\text{O.D.}663) \times \text{Volume}}{1000\text{ g weight of leaves}}$$

### 2.8.5 Leaf moisture Content (%)

Moisture content in the mulberry leaves was expressed in percentage on wet basis and it was determined by drying mulberry leaves in hot air oven (60 ±1°C for 24 hr) and the same procedure continued till constant weight was obtained and then moisture content was determined by following formula (Turner, 1981).

$$\text{Moisture content (\%)} = \frac{(\text{Initial wt. of sample}) - (\text{Final wt. of sample})}{(\text{Initial weight of the sample })} \times 100$$

### 2.8.6 Estimation of Total Carbohydrate (%)

Total carbohydrate of mulberry leaf was estimated by following the method of (Dubois et al., 1956) using glucose as standard. The total anthrone positive substances were expressed as mg of carbohydrate/g dry weight of leaf sample.

### 2.8.7 Estimation of Crude Protein (%)

Protein content of the mulberry leaf was assessed after determining the total nitrogen content in the leaf (0.5 g leaf sample) using Macro-Kjeldhal method. The protein content of the leaf was computed by multiplying the per cent nitrogen of the sample with the factor 6.25 (Kjeldahl 1883).

Crude protein (%) = N (%) × 6.25

### 2.8.8 Estimation of Crude Fibre in Plant Sample (%)

The crude fibre of the sample was estimated by taking 2 g sample with ether or petroleum ether and boiled (initial boiling temperature of 35-38°C and final temperature of 52 °C). Then 200 ml of sulphuric acid was added and boiled for 30 min. Filtered through muslin cloth and washed with boiling water until washings were free of acid. Again, boiled the residue with 200 ml of sodium hydroxide for 30 min. Filtered through muslin cloth, again washed with 25 ml of boiling sulphuric acid, three 50 ml portions of water and 25 ml of alcohol. The residue was removed and transferred to pre-weighed ashing crucible (W1, g). The residue was dried for 2 hr at 130°C, cooled in a desiccator and weighed (W2, g), Ignited for 30 mins at 600 °C and then cooled in a desiccator and reweighed (W3, g). The fibre content of sample was calculated by formula (Mertens 2002).

$$\text{Crude Fibre (\%)} = \frac{(\text{W2} - \text{W1}) - (\text{W3} - \text{W1})}{\text{weight of the sample (g)}} \times 100$$

## 3. Results and Discussion

The results and discussion on influence of hydrogel and graded levels of fertigation on soil nutrient status and biochemical compositions of mulberry are revealed as following:

### 3.1 Soil pH, Electrical Conductivity (EC) and Organic Carbon (OC)

Soil pH, electrical conductivity (EC) and organic carbon content did not differ significantly among treatments during crop cycle, indicating that fertigation and hydrogel application had no adverse effect on soil chemical properties (Table. 5). Soil pH remained within a narrow neutral range of 6.68–6.73, with the lowest value recorded in $T_6$ (6.68) and the highest in $T_7$ and $T_8$ (6.73), demonstrating the stability of soil reaction. Similarly, EC values varied only marginally from 0.20 to 0.24 dS m⁻¹, with the highest in $T_4$ (0.24 dS m⁻¹) and the lowest in $T_7$ and $T_8$ (0.21 dS m⁻¹), and all values remained well below the salinity threshold, indicating no risk of salt accumulation due to fertigation. Soil organic carbon ranged from 0.59 to 0.63 per cent and was also statistically non-significant, with numerically higher values observed in hydrogel- and fertigation-treated plots, particularly $T_6$. These results are in agreement with the findings of Kaplan et al. (2022) and Jeevan et al. (2023) for pH and EC and Das and Ghosh (2022) and Kumari et al. (2013) for organic carbon, suggesting that the combined use of fertigation and hydrogel maintains soil chemical stability and supports sustainable mulberry cultivation.

### 3.2 Primary Nutrients Status (N, P and K) in Post-harvest Soil

The available nitrogen, phosphorus and potassium contents in post-harvest soil were significantly influenced by the interaction of fertigation levels and hydrogel application (Table. 6). Available nitrogen ranged from 240.05 kg ha⁻¹ in $T_8$ to 251.82 kg ha⁻¹ in $T_6$, with the highest values recorded in $T_6$ (100 % RDNK through fertigation + Zeba hydrogel @ 6 kg ac⁻¹), followed by $T_4$ (250.76 kg ha⁻¹) and $T_5$ (248.55 kg ha⁻¹), while $T_7$ and $T_8$ recorded the lowest values. Available phosphorus varied significantly from 35.32 kg ha⁻¹ in $T_8$ to 37.53 kg ha⁻¹ in $T_6$, with higher retention under fertigation combined with hydrogel ($T_4$ and $T_6$) and lower values under conventional practices ($T_7$ and $T_8$). Similarly, available potassium ranged from 221.12 kg ha⁻¹ in $T_8$ to 229.76 kg ha⁻¹ in $T_6$, with higher values in $T_6$ and the lowest in conventional treatments *viz.*, $T_4$ (228.12 kg ha⁻¹) and $T_5$ (227.56 kg ha⁻¹). These results confirm that the significant role of fertigation and hydrogel in improving nutrient retention and minimizing nutrient losses under moisture-optimized conditions. The present findings agree with Khanam et al. (2025) and Mahesh et al. (2022), who reported improved soil fertility, nutrient-use efficiency and residual nutrient status under drip fertigation and hydrogel application in mulberry. Further, Harshitha Mala et al. (2023) also reported enhanced post-harvest N, P and K with Zeba hydrogel @ 6 kg ac⁻¹, supporting the superior performance of $T_6$ in the present study.

### 3.3 Primary Nutrients Status (N, P and K) in Mulberry Leaf

Leaf Nitrogen, Phosphorus and Potassium contents were significantly influenced by fertigation and hydrogel application (Table 7). Leaf nitrogen ranged from 2.92 per cent in $T_7$ to 3.57 per cent in $T_6$, with $T_6$ recording a 21.98 per cent increase over $T_8$ (2.95 %) and 22.26 per cent over $T_7$. Higher nitrogen was also observed in $T_4$ (3.43 %) and $T_5$ (3.36 %), while moderate values were noted in $T_2$ (3.22 %) and $T_3$ (3.10 %). Leaf phosphorus varied from 0.19 per cent in $T_8$ to 0.31 per cent in $T_6$, with $T_6$ showing an increase over $T_8$, followed by $T_4$ (0.29 %) and $T_5$ (0.28 %); the lowest values were observed in $T_7$ (0.21 %) and $T_8$ (0.19 %). Leaf potassium was highest in $T_6$ (1.81 %), followed by $T_4$ (1.72 %) and $T_5$ (1.65 %), while the lowest values were recorded in $T_8$ (1.31 %) and $T_7$ (1.35 %). Overall, fertigation combined

**Table 5. Soil properties as influenced by Zeba hydrogel and graded levels of fertigation**

| Treatments | Soil pH (1:2.5) | Electrical Conductivity (dS m⁻¹) | Organic Carbon (%) |
|---|---|---|---|
| $T_1$ | 6.72 | 0.21 | 0.61 |
| $T_2$ | 6.72 | 0.23 | 0.62 |
| $T_3$ | 6.71 | 0.22 | 0.63 |
| $T_4$ | 6.69 | 0.24 | 0.63 |
| $T_5$ | 6.69 | 0.23 | 0.61 |
| $T_6$ | 6.68 | 0.23 | 0.63 |
| $T_7$ | 6.73 | 0.21 | 0.59 |
| $T_8$ | 6.73 | 0.21 | 0.60 |
| F test | NS | NS | NS |
| S.Em± | 0.05 | 0.01 | 0.01 |
| CD @ 5 % | - | - | - |
| CV | - | - | - |

*NS- non significant*

**Table 6. Major nutrient status in post-harvest soil as influenced by Zeba hydrogel and graded levels of fertigation**

| Treatments | Available Nitrogen (kg ha⁻¹) | Available Phosphorus (kg ha⁻¹) | Available Potassium (kg ha⁻¹) |
|---|---|---|---|
| $T_1$ | 244.12 | 36.05 | 223.5 |
| $T_2$ | 246.51 | 36.76 | 225.05 |
| $T_3$ | 248.32 | 36.82 | 226.45 |
| $T_4$ | 250.76 | 37.15 | 228.12 |
| $T_5$ | 248.55 | 36.92 | 227.56 |
| $T_6$ | 251.82 | 37.53 | 229.76 |
| $T_7$ | 241.43 | 35.71 | 222.18 |
| $T_8$ | 240.05 | 35.32 | 221.12 |
| F test | * | * | * |
| S.Em± | 0.25 | 0.12 | 0.14 |
| CD @ 5 % | 0.75 | 0.37 | 0.42 |
| CV | 0.18 | 0.58 | 0.11 |

**Significant @ 5 %*

**Table 7. Major nutrient content in mulberry leaves as influenced by Zeba hydrogel and graded levels of fertigation**

| Treatments | Nitrogen (%) | Phosphorus (%) | Potassium (%) |
|---|---|---|---|
| $T_1$ | 2.99 | 0.22 | 1.41 |
| $T_2$ | 3.22 | 0.26 | 1.55 |
| $T_3$ | 3.10 | 0.24 | 1.48 |
| $T_4$ | 3.43 | 0.29 | 1.72 |
| $T_5$ | 3.36 | 0.28 | 1.65 |
| $T_6$ | 3.57 | 0.31 | 1.81 |
| $T_7$ | 2.92 | 0.21 | 1.35 |
| $T_8$ | 2.95 | 0.19 | 1.31 |
| F test | * | * | * |
| S.Em± | 0.08 | 0.01 | 0.01 |
| CD @ 5 % | 0.23 | 0.03 | 0.04 |
| CV | 4.58 | 3.03 | 1.33 |

**Significant @ 5 %*

with hydrogel significantly improved N, P and K uptake in mulberry leaves due to precise nutrient delivery and improved moisture retention, resulting in enhanced nutrient absorption efficiency. These findings are in agreement with Motamedi et al. (2023), Mahesh et al. (2022) and Harshitha Mala et al. (2023), who have also reported improved leaf nutrient status under fertigation and hydrogel application.

### 3.4 Total Chlorophyll, Chlorophyll (*a, b*) and Leaf Moisture

Fertigation integrated with hydrogel significantly enhanced both chlorophyll content and leaf moisture status in mulberry (Table 8; Fig. 1). The highest total chlorophyll (2.56 mg g⁻¹), chlorophyll-a (1.58 mg g⁻¹) and chlorophyll-b (0.98 mg g⁻¹) were recorded in $T_6$, followed by $T_4$ and $T_5$, while the lowest values occurred in $T_7$ and $T_8$. Similarly, leaf moisture content at 60 days after pruning (DAP) varied significantly among treatments and ranged from 69.48 per cent in $T_8$ to 75.47 per cent in $T_6$, with higher values in $T_6$, $T_4$ (74.12 %) and $T_5$ (73.23 %), moderate levels in $T_2$ and $T_3$, and the lowest in $T_7$ and $T_8$. The enhancement in chlorophyll and leaf moisture is attributed to improved nitrogen availability through fertigation and sustained soil moisture through the slow-release, water-retentive properties of Zeba hydrogel, which together maintain leaf turgor, reduce water stress and promote efficient chlorophyll biosynthesis. These results are in agreement with the findings of Kargar et al. (2017), and Seenappa et al. (2015) for chlorophyll, and Sudhakar et al. (2018) Padmanabha et al. (2018), for leaf moisture, all of which reported superior pigment concentration and leaf hydration under drip fertigation. Overall, the integration of fertigation with hydrogel proved highly effective in improving photosynthetic efficiency, leaf hydration and overall leaf quality in mulberry.

**Table 8. Effect of Zeba hydrogel and graded levels of fertigation on chlorophyll and leaf moisture content of mulberry leaves**

| Treatments | Chlorophyll-*a* (mg g⁻¹) | Chlorophyll-*b* (mg g⁻¹) | Total Chlorophyll (mg g⁻¹) | Leaf moisture (%) |
|---|---|---|---|---|
| $T_1$ | 1.25 | 0.67 | 1.92 | 71.53 |
| $T_2$ | 1.36 | 0.82 | 2.18 | 73.18 |
| $T_3$ | 1.31 | 0.74 | 2.05 | 72.27 |
| $T_4$ | 1.48 | 0.92 | 2.41 | 74.12 |
| $T_5$ | 1.44 | 0.88 | 2.32 | 73.23 |
| $T_6$ | 1.58 | 0.98 | 2.56 | 75.47 |
| $T_7$ | 1.22 | 0.63 | 1.85 | 70.36 |
| $T_8$ | 1.21 | 0.60 | 1.81 | 69.48 |
| F test | * | * | * | * |
| S.Em± | 0.01 | 0.02 | 0.07 | 0.23 |
| CD @ 5 % | 0.04 | 0.06 | 0.23 | 0.68 |
| CV | 1.59 | 3.43 | 5.31 | 0.54 |

**Significant @ 5 %*

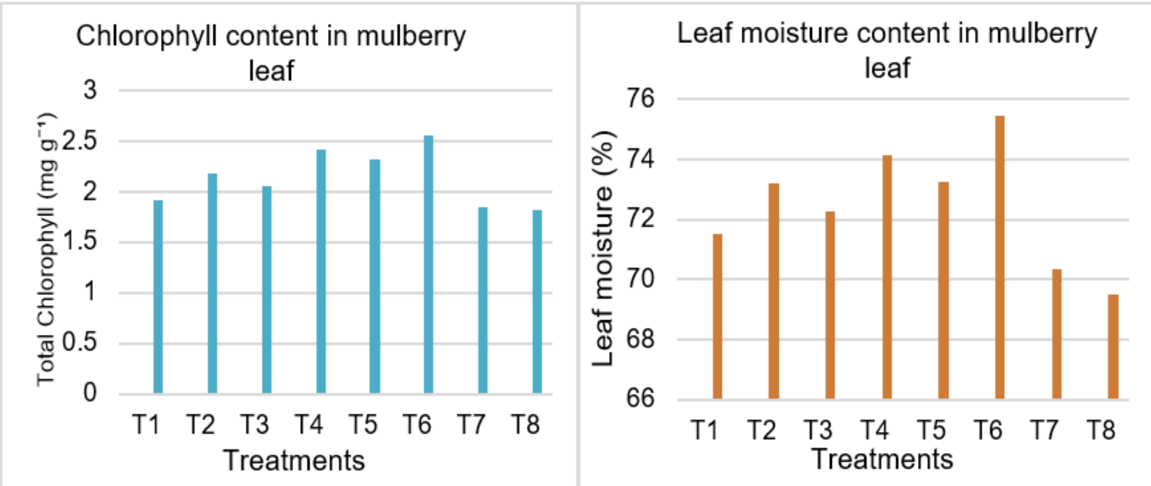


**Fig. 1. Effect of Zeba hydrogel and graded levels of fertigation on chlorophyll and leaf moisture content of mulberry leaves**

**Table 9. Influence of Zeba hydrogel and graded levels of fertigation on carbohydrate, protein and crude fibre content in mulberry leaves**

| Treatments | Carbohydrate (%) | Crude protein (%) | Crude fibre (%) |
|---|---|---|---|
| $T_1$ | 15.32 | 18.72 | 9.85 |
| $T_2$ | 17.08 | 20.12 | 10.56 |
| $T_3$ | 16.24 | 19.36 | 10.12 |
| $T_4$ | 18.56 | 21.45 | 11.24 |
| $T_5$ | 18.12 | 21.02 | 11.05 |
| $T_6$ | 20.15 | 22.34 | 12.18 |
| $T_7$ | 15.05 | 18.25 | 9.42 |
| $T_8$ | 15.24 | 18.45 | 9.68 |
| F test | * | * | * |
| S.Em± | 0.12 | 0.14 | 0.13 |
| CD @ 5 % | 0.36 | 0.41 | 0.40 |
| CV | 1.21 | 1.18 | 2.20 |

**Significant @ 5 %*

### 3.5 Carbohydrate, Crude Protein and Crude Fibre (%)

Carbohydrate, crude protein and crude fibre contents in mulberry leaves varied significantly among treatments and were consistently highest under fertigation integrated with hydrogel (Table 9). Leaf carbohydrate content ranged from 15.05 per cent in $T_7$ to 20.15 per cent in $T_6$, with higher values in $T_4$ (18.56 %) and $T_5$ (18.12 %), while conventional RDF and lower fertigation treatments ($T_1$-15.32 %, $T_7$-15.05 % and $T_8$-15.24 %) recorded lower values. Similarly, crude protein content was highest in $T_6$ (22.34 %), followed by $T_4$ (21.45 %) and $T_5$ (21.02 %), whereas $T_1$ (18.72 %), $T_7$ (18.25 %) and $T_8$ (18.45 %) recorded the lowest values. Crude fibre content also exhibited the similar trend, with the highest value in $T_6$ (12.18 %), followed by $T_4$ (11.24 %) and $T_5$ (11.05 %), while $T_1$ (9.85 %), $T_7$ (9.42 %) and $T_8$ (9.68 %) recorded lower fibre content. The enhanced biochemical quality under $T_6$ attributed due to improved soil moisture retention by hydrogel, which helps in maintaining leaf turgor and supports uninterrupted photosynthesis, while fertigation ensures uniform and timely nutrient supply, particularly nitrogen, thereby promoting carbohydrate synthesis, protein formation and fibre deposition. Improved water availability also facilitates better nitrogen assimilation and amino acid synthesis, while efficient nutrient uptake enhances cellulose and hemicellulose accumulation in cell walls, resulting in higher crude fibre. These results are in close agreement with earlier findings of Padmanabha et al. (2018), Vivien and Claude, (2017), Shankarappa et al. (2020), and Yadav et al. (2025), who reported enhanced carbohydrate, protein and fibre contents under optimized NPK fertilization and drip fertigation. Overall, hydrogel-assisted fertigation and optimized nutrient management synergistically improved the biochemical quality of mulberry leaves.

## 4. Conclusion

It is concluded that the fertigation integrated with Zeba hydrogel significantly improved soil nutrient availability, leaf nutrient content, chlorophyll concentration, leaf moisture and overall biochemical quality of mulberry without adversely affecting soil pH, EC and organic carbon. Among the treatments, $T_6$ (100 % RDNK through fertigation + Zeba hydrogel @ 6 kg $ac^{-1}$) consistently recorded superior performance in soil fertility and leaf quality parameters. The combined application enhanced nutrient availability, improved photosynthetic efficiency and sustained higher leaf moisture under optimized moisture conditions. Hence, hydrogel-assisted fertigation can be recommended as a sustainable nutrient and water management strategy for enhancing soil fertility and leaf quality.

## Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

## Competing Interests

Authors have declared that no competing interests exist.

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