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EFFECT OF MULBERRY LEAVES AS INFLUENCED BY HYDROGEL AND GRADED LEVELS OF FERTIGATION ON PERFORMANCE OF SILKWORM HYBRID (FC2 × FC1)

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ABSTRACT

An experiment was conducted to evaluate the influence of hydrogel and graded levels of fertigation on larval, cocoon and silk filament characteristics of the bivoltine silkworm hybrid $FC_2 \times FC_1$. Mulberry (V-1) leaves produced under eight fertigation–hydrogel treatment combinations were used for silkworm rearing. The results revealed that silkworms fed on leaves obtained from 75 per cent recommended dose of nitrogen and potassium through fertigation combined with starch-based hydrogel @ 6 kg ac^{-1} exhibited significantly superior larval performance, cocoon yield and silk filament quality compared to conventional practices. This treatment also recorded shorter fifth instar duration, maximum grownup larval weight, lower larval mortality, improved cocoon yield by number and weight and enhanced silk filament characteristics. Higher fertigation levels improved mulberry growth, but did not proportionately enhance silkworm performance, indicating an inverse relationship between excess nutrient accumulation in mulberry leaves and silkworm productivity. The study demonstrates that fertigation at 75 per cent recommended dose of nitrogen and potassium integrated with hydrogel is the most efficient and sustainable practice by saving 25 per cent of nitrogen and potassium fertilizer input without compromising cocoon yield.
***Keywords*:** Mulberry, Hydrogel, Fertigation, Silkworm.

Introduction

The silkworm (*Bombyx mori* L.) is a monophagous insect that feeds exclusively on mulberry (*Morus* spp.) leaves, making leaf quality a critical determinant of silkworm growth, cocoon yield and silk quality. The nutritional and physiological quality of mulberry leaves is therefore an important criterion in sericulture, as it directly influences larval development, cocoon characteristics and silk filament production (Bongale *et al.*, 1997). In fact, more than 60 per cent of the total cost of cocoon production in sericulture is attributed to mulberry cultivation alone, emphasizing the need to enhance both the quality and quantity of mulberry leaves through efficient crop management practices.

Among the various agronomic inputs, water is one of the most critical factors in mulberry production and is also the most limiting resource in Indian agriculture which demand its judicious usage. The micro irrigation *viz*., drip and sprinklers, helps in targeted application of water to the root zone of the crop. The drip system of irrigation is suitable for fruits, vegetables and plantation crops, and this system increases water-use efficiency to extent of 50-90 per cent (Suresh *et al.*, 2020). Since irrigation water has the greatest influence on mulberry leaf yield and quality, there is an urgent need to maximize productivity per unit of water by adopting efficient irrigation and nutrient management strategies.

Fertigation, the application of fertilizers through irrigation water, has emerged as an effective technique to enhance water and nutrient use efficiency by supplying nutrients directly to the crop root zone in synchrony with plant demand. Several studies have reported that fertigation improves mulberry growth, leaf yield and nutrient uptake compared to conventional soil application of fertilizers (Arunadevi and Selvaraj, 2007).

In recent years, hydrogels or superabsorbent polymers have gained attention as soil conditioners capable of improving soil moisture retention and nutrient availability under water-limited conditions. Hydrogels can absorb and retain 332–465 times their weight in water and gradually release nearly 95 per cent of the stored moisture for plant uptake, thereby reducing moisture stress during dry periods (Dehkordi, 2016). These polymers remain effective in the soil for two to five years and ultimately degrade into environmentally benign products such as carbon dioxide, water and mineral ions, making them eco-friendly (Trenkel, 1997). In addition, hydrogels improve soil physical properties such as porosity, bulk density, infiltration rate and permeability, which collectively enhance root growth and nutrient absorption.

Harshita Mala *et al.* (2023) reported that maximum plant growth and yield parameters in mulberry plots treated with starch-based hydrogel @ 6 kg per acre compared to cellulose based hydrogel. The integration of hydrogels with fertigation offers a promising approach to improving mulberry leaf quality by ensuring a sustained supply of water and nutrients to the root zone which enables "spoon-feeding" of crops, thereby minimizing water losses due to evaporation and deep percolation while enhancing nutrient uptake efficiency. Improved mulberry leaf moisture content has been shown to enhance silkworm digestion, nutrient assimilation and conversion efficiency, which ultimately leads to better larval growth, cocoon yield and silk quality (Machii and Katagiri, 1991).

In this context, the present investigation was undertaken to evaluate the effect of starch-based hydrogel (Zeba hydrogel) integrating with graded levels of fertigation on mulberry leaf quality and its subsequent influence on larval performance, cocoon yield and silk filament characteristics of the bivoltine silkworm hybrid $FC_2 \times FC_1$, with the objective of identifying an efficient and sustainable strategy for enhancing silk productivity.

Material and Methods

The experiment was conducted during 2025 in well-established V1 mulberry garden at L-block, Agroforestry based Integrated Farming System 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.*,

T_1 -50 % RDNK through fertigation
T_2 - 50 % RDNK through fertigation + hydrogel® @ 6 kg ac^{-1}
T_3 - 75 % RDNK through fertigation
T_4 - 75 % RDNK through fertigation + hydrogel® @ 6 kg ac^{-1}
T_5 - 100 % RDNK through fertigation
T_6 - 100 % RDNK through fertigation + hydrogel® @ 6 kg ac^{-1}
T_7 - RDNK as per Package of Practice and
T_8 - Control (RDF as per Package of Practice)
Note: ® Starch-based Zeba hydrogel

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

Hydrogel application was carried out only once for first crop after the pruning (Harshita Mala *et al.*, 2023) Fertigation (T_1 to T_6) application was carried out in three equal splits at weekly intervals (15^{th} to 29^{th} 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. N (Urea) and K (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 (Table 1) (https://sugarcane.icar.gov.in/index.php/soil-moisture-indicator/).

Table 1 : 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

Plate 1: Hydrogel granules

Plate 2: Fertigation

The rearing was conducted by using the different treatment leaves at Department of Sericulture, UAS, GKVK, Bengaluru. The experiment was laid out in a Complete Randomized Design (CRD) with three replications and eight treatments, comprising of different proportions of hydrogels. Prior to commencement of rearing, the rearing room with rearing stands were cleaned, washed thoroughly and properly disinfected and, the bivoltine double hybrid (FC2 × FC1), third instar silkworms procured from Registered Chawki Rearing Centre and reared as per the protocol (Dandin and Giridhar, 2014). After the fourth moult the samples were drawn randomly for the silkworm parameters *viz.,* grownup larval weight, fifth instar larval duration, larval mortality, larval progression, single cocoon weight, cocoon shell weight, single pupal weight, cocoon shell ratio, average filament length, non-breakable filament length, filament weight and denier were recorded as per the standard procedure.

The data recorded on various parameters were subjected to Fisher's method of Analysis of Variance (ANOVA) and interpreted according to and interpreted according to Sundararaj *et al.* (1972). The level of significance used in F and t-tests was P = 0.05. The critical difference (CD) values were computed where the F test was found significant.

Results and Discussion

The results and discussion on influence of hydrogel and graded levels of fertigation on larval, cocoon and silk filament characteristics of silkworm (FC2 × FC1) are revealed as following:

Table 2 : Effect of V-1 mulberry leaves as influenced by hydrogel and graded levels of fertigation on performance of late-age silkworm (FC2 × FC1)

Treatments	Fifth instar larval duration (days)	Grown-up larval weight (g/10 larvae)	Larval mortality (%)
T_1: 50 % RDNK through fertigation	8.73	34.29	3.18
T_2: 50 % RDNK through fertigation + hydrogel @ 6 kg ac^{-1}	7.82	40.36	2.35
T_3: 75 % RDNK through fertigation	7.96	38.47	2.58
T_4: 75 % RDNK through fertigation + hydrogel @ 6 kg ac^{-1}	7.21	45.73	1.32
T_5: 100 % RDNK through fertigation	7.63	42.91	2.08
T_6: 100 % RDNK through fertigation + hydrogel @ 6 kg ac^{-1}	7.48	44.19	1.52
T_7: RDNK as per Package of Practice	8.75	33.61	3.48
T_8: Control (RDF as per Package of Practice)	8.77	33.38	3.78
F test	*	*	*
S.Em±	0.09	0.16	0.12
CD @ 5 %	0.27	0.48	0.37
CV	1.86	0.70	4.13

*significant @ 5 %

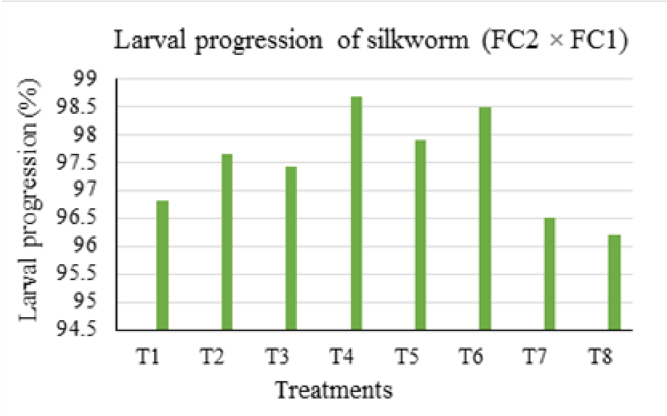

Fig. 1: Effect of V-1 mulberry leaves as influenced by hydrogel and graded levels of fertigation on larval progression of silkworm (FC2 × FC1)

Larval parameters

Feeding late-age silkworms ($FC_2 \times FC_1$) with mulberry leaves obtained from plots receiving hydrogel in combination with graded levels of fertigation significantly improved rearing performance and economic traits compared to conventional practices (Table 2). Among the treatments, hydrogel-integrated fertigation markedly reduced the fifth instar larval duration, with the shortest larval duration recorded in T_4 (75 % RDNK through fertigation + hydrogel @ 6 kg ac^{-1}; 7.21 days), followed by T_6 and T_5, whereas prolonged larval duration was observed in the control treatments (T_7 and T_8) and T_1 (8.73–8.77 days). Grown-up larval weight was significantly higher under integrated treatments, attaining a maximum in T_4 (45.73 g per 10 larvae), followed by T_6 (44.19 g) and T_5 (42.91 g), while the lowest weights were recorded in T_8, T_7 and T_1 (33.38–34.29 g per 10 larvae). Larval mortality was minimized by hydrogel-fertigation, with the lowest mortality in T_4 (1.32 %), followed by T_6 (1.52 %) and T_5 (2.08 %), in contrast to higher mortality in the control treatments (3.18–3.78 %). Consequently, larval progression was highest in T_4 (98.68 %), closely followed by T_6 (98.48 %) and T_5 (97.92 %), whereas lower progression was observed in T_7, T_8 and T_1 (96.22–96.82 %) (Fig. 1). The results clearly demonstrate that fertigation integrated with hydrogel, particularly at 75 per cent RDNK, enhances mulberry leaf quality and significantly improves growth, survival and rearing efficiency of late-age silkworms.

Table 3 : Effect of V-1 mulberry leaves as influenced by hydrogel and graded levels of fertigation on cocoon yield of silkworm (FC2 × FC1)

Treatments	Cocoon yield by number (No./10,000 larvae)	Cocoon yield by weight (kg/10,000 larvae)
T_1: 50 % RDNK through fertigation	9368	21.42
T_2: 50 % RDNK through fertigation + hydrogel @ 6 kg ac^{-1}	9463	22.05
T_3: 75 % RDNK through fertigation	9409	21.82
T_4: 75 % RDNK through fertigation + hydrogel @ 6 kg ac^{-1}	9751	23.48
T_5: 100 % RDNK through fertigation	9631	22.95
T_6: 100 % RDNK through fertigation + hydrogel @ 6 kg ac^{-1}	9694	22.72
T_7: RDNK as per Package of Practice	9111	19.24
T_8: Control (RDF as per Package of Practice)	9088	18.63
F test	*	*
S.Em±	49	0.29
CD @ 5 %	147	0.88
CV	0.91	2.37

*significant @ 5 %

Cocoon yield

Cocoon yield, both in terms of number and weight, was significantly influenced by fertigation levels and hydrogel application (Table 3). The maximum cocoon yield by number was recorded in T_4 (75 % RDNK through fertigation + hydrogel @ 6 kg ac⁻¹) with 9,751 cocoons per 10,000 larvae, followed by T_6 (9,694) and T_5 (9,631), while intermediate yields were observed in T_2 (9,463) and T_3 (9,409); in contrast, the lowest cocoon numbers were recorded in the control treatments T_8 (9,088), T_7 (9,111) and T_1 (9,368). A similar trend was evident for cocoon yield by weight, with the highest yield obtained in T_4 (23.48 kg per 10,000 larvae), followed by T_5 (22.95 kg) and T_6 (22.72 kg), whereas T_2 (22.05 kg) and T_3 (21.82 kg) showed moderate performance and the lowest yields were recorded in T_8 (18.63 kg) and T_7 (19.24 kg). The superior cocoon productivity under hydrogel-integrated fertigation clearly demonstrates its effectiveness in enhancing mulberry leaf quality and translating improved larval growth into higher cocoon yield compared to conventional practices.

Table 4 : Effect of V-1 mulberry leaves as influenced by hydrogel and graded levels of fertigation on cocoon parameters of silkworm (FC2 × FC1)

Treatments	Single cocoon weight (g)	Single pupal weight (g)	Cocoon shell weight (g)
T_1: 50 % RDNK through fertigation	2.18	1.74	0.44
T_2: 50 % RDNK through fertigation + hydrogel @ 6 kg ac-1	2.26	1.79	0.47
T_3: 75 % RDNK through fertigation	2.22	1.76	0.46
T_4: 75 % RDNK through fertigation + hydrogel @ 6 kg ac-1	2.38	1.85	0.53
T_5: 100 % RDNK through fertigation	2.31	1.82	0.49
T_6: 100 % RDNK through fertigation + hydrogel @ 6 kg ac-1	2.35	1.84	0.51
T_7: RDNK as per Package of Practice	2.09	1.67	0.42
T_8: Control (RDF as per Package of Practice)	2.05	1.64	0.41
F test	*	*	*
S.Em±	0.06	0.01	0.01
CD @ 5 %	0.17	0.04	0.04
CV	4.43	1.46	4.93

*significant @ 5 %

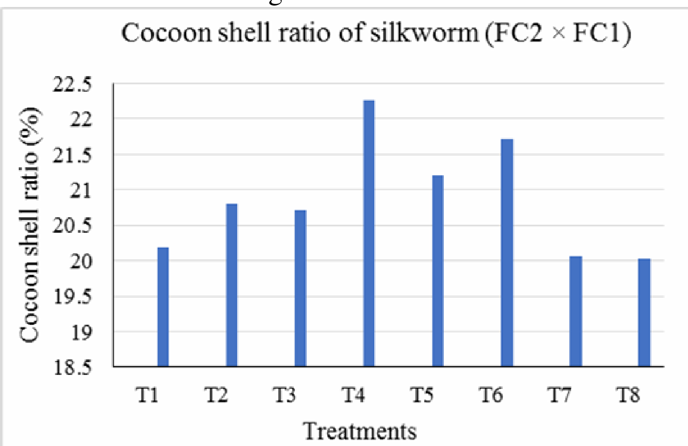

Fig. 2: Effect of V-1 mulberry leaves as influenced by hydrogel and graded levels of fertigation on cocoon shell ratio of silkworm (FC2 × FC1)

Cocoon parameters

Cocoon parameters such as single cocoon weight, single pupal weight, cocoon shell weight and cocoon shell ratio were all significantly influenced by fertigation levels and hydrogel application (Table 4). The maximum single cocoon weight was recorded in T_4 (2.38 g) and T_6 (2.35 g), followed by T_5 (2.31 g), while treatments T_2 (2.26 g) and T_3 (2.22 g) also performed better than the control; the lowest cocoon weights were observed in T_8 (2.05 g), T_7 (2.09 g) and T_1 (2.18 g). A similar response was evident for single pupal weight, with maximum values in T_4 (1.85 g) and T_6 (1.84 g), followed by T_5 (1.82 g), whereas the minimum pupal weights were recorded in T_7 (1.67 g), T_8 (1.64 g) and T_1 (1.74 g). Cocoon shell weight also increased markedly under hydrogel-integrated fertigation, attaining the highest value in T_4 (0.53 g), followed by T_6 (0.51 g) and T_5 (0.49 g), compared to the lowest values in T_8 (0.41 g), T_7 (0.42 g) and T_1 (0.44 g). Consequently, the cocoon shell ratio was highest in T_4 (22.27 %), followed by T_6 (21.71 %) and T_5 (21.21 %), while moderate ratios were observed in T_2 and T_3 and the lowest ratios occurred in the control treatments T_7, T_8 and T_1 (20.02–20.18 %) (Fig. 2). The consistent improvement in cocoon and pupal traits under hydrogel–fertigation treatments clearly indicates that enhanced mulberry leaf quality and nutrient availability translated into superior cocoon quality compared to conventional practices.

Table 5 : Silk filament characteristics of silkworm (FC2 × FC1) as influenced by V1 mulberry with hydrogel and graded levels of fertigation

Treatment	Average filament length (m)	Non-breakable filament length (m)	Filament weight (g)	Denier
T_1: 50 % RDNK through fertigation	1241	1063	0.36	2.58
T_2: 50 % RDNK through fertigation + hydrogel @ 6 kg ac-1	1281	1091	0.38	2.71
T_3: 75 % RDNK through fertigation	1265	1081	0.37	2.69
T_4: 75 % RDNK through fertigation + hydrogel @ 6 kg ac-1	1344	1151	0.43	2.91
T_5: 100 % RDNK through fertigation	1295	1105	0.39	2.81
T_6: 100 % RDNK through fertigation + hydrogel @ 6 kg ac-1	1301	1122	0.41	2.84
T_7: RDNK as per Package of Practice	1211	1042	0.35	2.56
T_8: Control (RDF as per Package of Practice)	1179	1017	0.33	2.53
F test	*	NS	*	*
S.Em±	30	-	0.01	0.08
CD @ 5 %	92	-	0.04	0.24
CV	4.20	-	5.81	5.07

*significant @ 5 %, NS-non significant

Silk filament characteristics

Fertigation levels in combination with hydrogel had a pronounced effect on silk filament characteristics, including average filament length, non-breakable filament length, filament weight and denier (Table 5). The longest average filament length was recorded in T_4 (75 % RDNK through fertigation + hydrogel @ 6 kg ac^{-1}) with 1344 m, followed by T_6 (1301 m) and T_5 (1295 m), whereas moderate filament length values were observed in T_2 and T_3 and the shortest filament lengths occurred in the control treatments T_8, T_7 and T_1 (1179–1241 m). A similar trend was noted for non-breakable filament length, which was maximum in T_4 (1151 m), followed by T_6 (1122 m) and T_5 (1105 m), although differences among treatments were statistically non-significant. Filament weight was maximum under hydrogel-integrated fertigation, with T_4 recording the maximum value (0.43 g), followed by T_6 (0.41 g) and T_5 (0.39 g), while the minimum filament weights were obtained in T_8, T_7 and T_1 (0.33–0.36 g). The cocoon filament denier also showed improvement under integrated treatments, with the maximum denier in T_4 (2.91), followed by T_6 (2.84) and T_5 (2.81), compared to minimum denier values in T_2, T_3 and the control treatments (2.53–2.58). The results clearly indicate that fertigation combined with hydrogel enhanced silk filament quality by improving filament length, weight and denier compared to conventional management practices.

The present study revealed an inverse relationship between fertilizer concentration and silkworm rearing performance, wherein higher fertilizer levels adversely affected larval and cocoon parameters such as larval weight, larval progression, cocoon weight, cocoon shell weight and cocoon shell ratio. This indicates that excessive fertilizer application may alter the functional and biochemical composition of mulberry leaves, disturbing the optimal nutrient balance required for efficient silkworm growth and cocoon formation. Similar observations were reported by Arunadevi and Selvaraj (2007), who demonstrated that drip fertigation improved leaf quality and silkworm performance compared to soil-applied fertilizers. The superior performance of silkworms fed on leaves produced under moderate fertigation, particularly at 75 per cent water-soluble NPK combined with organic amendments, has also been reported by Naveen *et al.* (2019), corroborating the findings of the present investigation. Although higher fertigation levels enhanced mulberry growth and yield, silkworm performance declined, suggesting that excess nitrogen accumulation in leaves may reduce beneficial compounds such as chlorogenic acid and flavanols while increasing 1-deoxynojirimycin (1-DNJ), thereby lowering leaf nutritive value. Improvements in cocoon weight, cocoon shell ratio and filament traits observed under optimal fertigation and hydrogel application can be attributed to enhanced silk protein synthesis through increased aminotransferase activity and efficient nitrogen assimilation in the silk gland, as reported by Machii and Katagiri (1991).

Previous studies have also emphasized that nutrient-rich and physiologically balanced mulberry leaves with higher crude protein, soluble sugars and starch content promote better larval growth, pupal weight and cocoon quality by improving digestive efficiency and metabolic activity (Shivashankar and Shivakumar, 1997; Mahmoud, 2000; Shankar *et al*., 2000). Feeding of nutritionally enriched leaves with ascorbic acid, folic acids and elements like Selenium and metal, nano-particles have showed better growth and development of silkworms which also improved the economic characters of cocoons (Banuprakash *et al*., 2024). Effective water management further enhances these responses by improving soil moisture conservation and nutrient uptake, leading to superior leaf quality and silkworm performance (Rajaram and Qadri, 2014; Seenappa *et al*., 2015). Overall, the present results, in agreement with earlier findings (Naveen *et al*., 2019; Pooja *et al*., 2022; Harshita Mala *et al*., 2024) clearly demonstrate that the combined use of moderate fertigation and hydrogel ensures optimal mulberry leaf quality, supports silk protein synthesis and maximizes silkworm rearing performance and silk quality.

It is concluded that the silkworms fed on mulberry leaves produced under 75 per cent RDNK through fertigation combined with starch-based hydrogel @ 6 kg ac^{-1} exhibited superior larval, cocoon and silk filament characteristics, reflected in improved rearing efficiency and overall productivity. This treatment recorded the maximum cocoon yield by number and weight, followed by 100 per cent RDNK with starch-based hydrogel application. Overall, the findings clearly confirm that fertigation at 75 per cent RDNK integrated with starch-based hydrogel (Zeba hydrogel) as most efficient, also the treatment indicates the saving of 25 per cent nitrogen and potassium fertilizer input without compromising cocoon yield.

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