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Influence of *Salix* Planting Density and Clonal Variation on Aphid Infestation

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Abstract: This study assessed the effects of planting density and clonal variation on growth traits and aphid (*Tuberolachnus salignus*) infestation in four *Salix* clones under short rotation forestry. Clones were planted at three spacings (1×1, 1×2, 2×2 m) in a factorial randomized block design. Growth parameters and aphid incidence were significantly influenced by spacing, clone, and their interaction. UHFS 141 showed the highest volume index (37,803.86 cm^3) at 2×2 m spacing. Aphid infestation was highest under dense planting (1×1 m), with NZ 1140 recording the most colonies (6.2/tree), while UHFS 119 at 2×2 m had the least (0.4 colonies/tree). Imidacloprid 17.8 SL @ 0.3 ml/L effectively reduced aphid populations, followed by Neem oil @ 30 ml/L. Results highlight the importance of integrating optimal spacing, clone selection, and pest management for improved *Salix* productivity.

Keywords: *Salix*, Clones, Spacing, Growth, Volume, Aphid infestation

As the climate crisis intensifies, there is an urgent need to transition toward cleaner and more sustainable energy sources. Biomass from fast-growing perennial woody species, especially those managed under Short Rotation Coppice (SRC) systems, offers a promising route (Luna et al., 2016). These systems provide renewable energy and help reduce atmospheric carbon, with forest-based mitigation potentially cutting global CO_2 emissions by up to 5.5 Gt yr^{-1} by 2040 (IPCC 2002, FAO 2016). In addition, SRC systems-characterized by dense planting and short harvest cycles-deliver ecological benefits such as soil improvement, erosion control, and enhanced biodiversity.

Willow (*Salix* spp.) is particularly suited for SRC systems because of its rapid growth, high biomass yield, and ability to thrive in degraded or nutrient-poor soils, making it valuable both for bioenergy production and ecological restoration (Kuzovkina and Quigley 2005, Jama and Nowak 2012). Globally, the genus comprises about 330–500 species and in India, 31 native and 4 exotic species have been recorded (Sharma et al., 2015). Beyond bioenergy, willows play multiple agroforestry roles, contributing to fodder, fuelwood, and timber production, while also supporting phytoremediation (Bhat 2004, Rawat et al., 2006, Ronald et al., 2007).

In SRC systems, the productivity of *Salix* is influenced primarily by planting density and clonal variation. Closer spacing encourages vertical growth due to competition for light, whereas wider spacing promotes diameter growth and biomass accumulation by reducing root competition (Benomar et al., 2012, Thakur et al., 2023b). Genotypic variation further affects growth vigor, stress tolerance, and adaptability, and the interaction of clone with spacing can alter yield and resilience (Larsson et al., 2001, Karp et al., 2011, Thakur et al., 2023a). High planting densities may exacerbate intraspecific competition, reducing survival and growth (Akers et al., 2013). Thus, assessment of clone performance across spacing regimes is crucial for optimizing survival and biomass yield (Singh et al., 2019).

The growing challenge in *Salix* cultivation is infestation by the willow aphid *Tuberolachnus salignus*, a phloem feeder that colonizes stems and branches. The aphid excretes honeydew, leading to sooty mold formation and attracting ants which interfere with natural aphid predators . While the biology and spread of *T. salignus* are well studied in Europe and other temperate regions (Collins et al., 2001), there is limited information on its behavior, host preference, and management in Indian settings. Understanding how planting density and clonal variation influence aphid infestation is important for integrated pest management and sustainable willow productivity. Denser plantings may facilitate pest spread via close canopy contact, whereas some clones may exhibit inherent resistance or tolerance. In view of the above hypothesis, this study aimed to evaluate the growth performance of selected *Salix* clones under different planting densities, to assess *T. salignus* infestation across clone–density combinations, and to test the efficacy of selected biopesticidal and chemical control measures.

MATERIAL AND METHODS

Location and climate of experiment site: The study was conducted at the research fields of the Department of Forestry and Natural Resources, Punjab Agricultural

University, Ludhiana, India (30°54'26'' N, 75°47'38'' E; 247 m a.m.s.l.), located in Punjab's central agro-climatic zone. The region has a semi-arid, subtropical to tropical climate with three main seasons: hot and dry summer (April-June), humid monsoon (July-September), and cold winter (December-February). Annual rainfall averages 704 mm, primarily during the monsoon months.

Plant material and experimental design: The Department of Tree Improvement and Genetic Resources, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan (Himachal Pradesh), has introduced over 200 *Salix* clones/hybrids from various countries and developed heterotic hybrids using native species. This diverse germplasm has been maintained and evaluated through nursery and multi-location field trials. From this collection, 28 promising clones were tested under Punjab conditions, and four (NZ 1140, UHFS 141 ,UHFS 85 and UHFS 119)were selected for evaluation under different planting densities. One-year-old plants were established in February 2020 using a factorial randomized block design with three spacing as treatments (1 x 1, 1 x 2, 2 x 2m). Irrigation was applied weekly in summer and fortnightly in winter.

Growth Parameters: Observations on growth parameters *viz*., plant height and basal diameter was recorded initially at the time of transplanting and after two years. Volume index was calculated on the basis of D^2H (square of diameter x height) relationship.

Aphid monitoring: Aphid population was monitored visually at weekly intervals from February to March (2021) by counting the number of aphid colonies present on the stems and branches of five randomly selected trees per plot. The mean aphid population per treatment was calculated and subjected to statistical analysis to determine the influence of clone, spacing, and their interaction.

Aphid management: To evaluate the effectiveness of different control measures against *T. salignus*, a separate experiment was conducted under completely randomized design with four treatments: Imidacloprid 17.8 SL at 0.3 ml/L, Neem oil (Azadirachtin 300 ppm) at 30 ml/L, water spray (as a mechanical removal method), and an untreated control. Each treatment was replicated thrice, and five plants per treatment were selected for observation. The treatments were applied using a tractor operated sprayer during early morning hours to minimize evaporation losses. Aphid colony counts were recorded before treatment and subsequently at 3, 7, and 10 days after spraying by visually counting the colonies on the stems and main branches.

Statistical analysis: The mean data recorded on various growth parameters and aphid monitoring were subjected to statistical analysis) using OPSTAT software developed by CCS Haryana Agricultural University, Hisar (Sheoran et al., 1998).

RESULTS AND DISCUSSION

Effect of spacing and clones on growth characters: The spacing, clone type, and their interaction significantly influenced the growth attributes *i.e.*, plant height, basal diameter, and volume index (Table 1, 2, 3). Among the clones, UHFS 119 recorded the highest mean volume index (28,150.92 cm³), closely followed by UHFS 141. Under spacing treatments, 1 × 2 m achieved the greatest mean plant height (5.96 m), whereas 2 × 2 m produced the highest mean basal diameter (6.77 cm) and volume index (27,267.46 cm³). The interaction between clone and spacing was significant, with UHFS 141 at 2 × 2 m recording the highest volume index (37,803.86 cm³). These findings are consistent with earlier research indicating that both genetic makeup (clone) and silvicultural practices (like spacing) can substantially affect tree growth and biomass accumulation (Dvorak et al., 2000). Among the evaluated clones, UHFS

Table 1. Effect of different spacings on plant height (m) of *Salix* clones

Spacings Clones	1x1 m	1x2 m	2x2 m	Mean	1x1 m	1x2 m	2x2 m	Mean
Plant height (m)								
	Initial				2nd year			
NZ 1140	3.80	4.00	3.76	3.85b	4.10	4.33	4.63	4.35d
UHFS 141	4.04	3.63	3.70	3.78b	5.76	5.80	6.52	6.02c
UHFS 85	4.39	3.75	4.20	4.11a	7.20	6.72	6.56	6.83a
UHFS 119	4.57	3.48	4.07	4.04a	6.36	7.02	5.55	6.31b
Mean	4.20a	3.72c	3.93b		5.85b	5.96a	5.81b	
CD (p=0.05)	Clone		0.09		Clone		0.11	
	Spacing		0.08		Spacing		0.10	
	Clone*Spacing		0.16		Clone*Spacing		0.20	

119 recorded the highest overall mean volume index (28150.92 cm³), followed closely by UHFS 141, suggesting that both clones possess superior genetic potential for volume accumulation. The significant variation observed among *Salix* clones in growth parameters such as height and basal diameter aligns with Sharma et al. (2011), who reported considerable genetic diversity in willow clones introduced in Himachal Pradesh, emphasizing the importance of clonal selection for improved growth performance in SRC systems. Similarly, White et al. (2007), emphasized the role of clone selection in maximizing growth and yield under optimal management conditions.

Spacing of 1 × 2 m resulted in the tallest plants (5.96 m). The closer spacing likely enhanced vertical growth due to increased competition for light, which is a known adaptive response in densely planted trees (Pretzsch 2005, Thakur et al., 2023b). On the other hand, 2 × 2 m spacing favoured better basal diameter growth (6.77 cm) and the highest volume index (27267.46 cm³). This wider spacing may have reduced competition for below-ground resources such as water and nutrients, facilitating increased radial growth (Forrester et al., 2006). The findings of this study are consistent with Kumar (2004) in *Populus deltoides* and Patil et al. (2017) and Thakur et al. (2023b) in *Melia dubia*, where wider planting spacing significantly enhances stem diameter. The clone × spacing interaction was significant, demonstrating the importance of matching genetic material to site conditions and silvicultural regimes. The maximum volume index (37,803.86cm³) was observed in UHFS 141 at a spacing of 2 × 2 m. These findings suggest that clone UHFS 141 performs better in wider spacing likely due to its ability to capitalize on resource availability for diameter and height growth. Jayawickrama and Carlson (2000) also emphasized that the optimal performance of clones depends on appropriate spacing, as clones exhibit distinct physiological and morphological responses to planting density.

Effect of planting density and clone on aphid population: The population of *T. salignus* was significantly influenced by

Table 2. Effect of different spacings on basal diameter (cm) of *Salix* clones

Spacings Clones	1x1 m	1x2 m	2x2 m	Mean	1x1 m	1x2 m	2x2 m	Mean
Basal diameter (cm)								
	Initial				2nd year			
NZ 1140	3.02	3.16	3.14	3.10a	5.16	5.87	6.18	5.73c
UHFS 141	3.72	3.08	3.36	3.38a	6.36	6.33	7.61	6.77a
UHFS 85	3.57	3.18	3.11	3.29a	6.24	6.09	6.56	6.29b
UHFS 119	3.66	3.02	3.41	3.36a	6.15	7.06	6.74	6.65a
Mean	3.49a	3.11b	3.25ab		5.97c	6.34b	6.77a	
CD (p=0.05)	Clone		NS		Clone		0.21	
	Spacing		0.26		Spacing		0.18	
	Clone*Spacing		NS		Clone*Spacing		0.36	

Table 3. Effect of different spacings on volume index (cm³) of *Salix* clones

Spacings Clones	1x1 m	1x2 m	2x2 m	Mean	1x1 m	1x2 m	2x2 m	Mean
Volume index (cm³) of								
	Initial				2nd year			
NZ 1140	3499.14	4017.61	3742.36	3753.04b	10933.37	14978.64	17736.76	14549.59b
UHFS 141	5592.02	3475.55	4236.93	4434.90ab	23337.44	23307.79	37803.86	28149.70a
UHFS 85	5697.70	3867.04	4170.29	4578.33ab	28062.46	24966.46	28241.74	27090.22a
UHFS 119	6186.64	3185.10	4759.80	4710.50a	24143.31	35021.95	25287.49	28150.92a
Mean	5243.91a	3636.32b	4227.34b		21619.14c	24568.71b	27267.46a	
CD (p=0.05)	Clone		NS		Clone		1603.13	
	Spacing		719.23		Spacing		1388.35	
	Clone*Spacing		NS		Clone*Spacing		2776.31	

planting density and *Salix* clones, as well as their interaction (Table 4). Among the three spacings, the highest mean aphid population was recorded under 1×1 m spacing (4.6 aphid colonies/tree), followed by 1×2 m spacing (3.5 aphid colonies /tree) and the lowest under 2×2 m spacing (2.2 aphid colonies /tree). The denser spacing likely created a favorable microclimate for aphid multiplication. Among the four willow clones, NZ 1140 recorded the highest overall aphid (4.6 aphid colonies /tree), followed by UHFS 85, UHFS 141 , and the lowest was on UHFS 119 (1.8 aphid colonies /tree). The interaction between spacing and clone was also significant (C.D. = 0.89). The highest aphid incidence was observed in NZ 1140 at 1×1 m spacing (6.2 aphid colonies /tree), while the lowest incidence was found on UHFS 119 at 2×2 m spacing (0.4 aphid colonies /tree). These results suggest that both clone selection and planting geometry play a crucial role in modulating aphid infestation.

Management of aphid: Prior to the spray, aphid populations were statistically at par across all treatments, indicating uniform initial infestation levels (Table 5). At 3 days after spray (DAS), both neem oil (3.8 colonies/plant) and imidacloprid (3.0 colonies/plant) significantly reduced aphid populations compared to the water spray (4.0) and control (4.4). Imidacloprid showed a more pronounced reduction resulted in a significant decline in aphid colonies to 1.4 colonies/plant on 7DAS followed by neem oil, both were statistically superior to water spray and control. Similar trend was observed 10 DAS.

Table 4. Effect of planting density and clones on aphid population during 2021-22

Spacings/Clones	1x1 m	1x2 m	2x2 m	Mean
Spring 2021-22				
NZ 1140	6.20	4.60	3.00	4.60
UHFS 141	3.80	3.80	2.20	3.27
UHFS 85	5.00	4.00	3.20	4.07
UHFS 119	3.40	1.60	0.40	1.80
Mean	4.60	3.50	2.20	
	Clone		0.45	
	Spacing		0.515	
	Clone*Spacing		0.89	

Table 5. Effect of different treatments on aphid management during 2021-22

Treatment	Before spray	3DAS	7 DAS	10 DAS
Neem oil@ 30 ml/L	4.40	3.8	2.40	1.60
Imidacloprid @0.3 ml/L	4.20	3.0	1.40	0.40
Water spray	4.40	4.0	4.20	4.00
Control	4.60	4.4	4.80	5.00
CD (p=0.05)	NS	0.67	0.88	0.68

The present investigation demonstrated that planting density and willow clone significantly influenced the population of *T. salignus*, commonly referred to as the giant willow aphid. High aphid infestation under 1×1 m spacing could be attributed to a more favorable microenvironment for aphid survival and reproduction, including increased humidity, limited sunlight penetration, and reduced air circulation. This is consistent with earlier reports in poplar and apple plantations, where dense plantings were associated with enhanced aphid colonization due to microclimatic effects and host plant accessibility (Wang et al., 2024). Clone-wise variation in aphid incidence suggests that host genotype plays a significant role in pest susceptibility. The highest aphid density on NZ 1140 and the lowest on UHFS 119 across all spacings highlight underlying differences in morphological or biochemical resistance factors. Similar clonal resistance has been reported in poplar against *Chaitophorus* spp. (Ramirez et al., 2004) and in rose cultivars against *Macrosiphum rosae* (Dong et al., 2024). These differences are often linked to variation in trichome density, leaf toughness, or secondary metabolites. Imidacloprid 17.8 SL @ 0.3 ml/L provided the most consistent and significant reduction in *T. salignus* population over time and is consistent with the findings of Khursheed (2015) and Tak et al. (2017) in apple and mustard, respectively

CONCLUSION

The study demonstrated that both planting density and clonal variation significantly affected the growth and aphid infestation in *Salix* clones. Clones UHFS 119 and 141 showed superior growth, while NZ 1140 had the highest aphid infestation and UHFS 119 the least. Denser spacing (1×1 m) promoted aphid build-up, whereas wider spacing (2×2 m) improved biomass. Among control measures, Imidacloprid was most effective, followed by Neem oil. The results highlight the importance of selecting suitable clones, optimizing spacing, and integrating eco-friendly pest management for sustainable *Salix* cultivation.

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AUTHOR'S CONTRIBUTIONS

All authors have made substantial contributions: the conception and design of the study (ST), acquisition of data or analysis (MK, AK) and interpretation of data (MK, ST, AK), drafting the article (MK, AK), revising the final manuscript (ST, AK) and approved.

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