Assessment of Three Fast Growing Populus Deltoides Species in Various Soil Profiles Under Nursery Conditions

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Populus plants, known for their rapid growth, adaptability, and short rotation period, play a crucial role in carbon sequestration, which aids in combating climate change and supporting livelihoods. In Pakistan, where there is a shortage of firewood and timber, hybrid fast-growing Populus species offer a viable solution to meet wood demand. This study aims to evaluate and compare the growth patterns and carbon stocks of different Populus deltoides varieties under nursery conditions. The study utilized three hybrid species: Italian Populus (euramerciana), Clone A-Y48, and local Populus. To conduct the study, three healthy mother plants, aged one to two years, were selected from the Rangeland Research Institute, NARC. These plants were propagated through cuttings and planted in 90 pots, each filled with different soil media. Over a period of three months, plant growth was monitored by recording parameters such as the number of leaves, height, diameter, and irrigation frequency for each pot. The data were collected and analyzed using a randomized complete block design (RCBD). Upon harvesting, the plants were analyzed for total biomass and carbon stocks, with soil samples taken for further examination in the RRI laboratory. The findings revealed that Clone A-Y48 exhibited the highest growth in height and stored the most carbon compared to Italian and local Populus varieties. Additionally, farmyard manure positively impacted the growth of the different Populus varieties, with Clone A-Y48 and Italian Populus demonstrating the most rapid growth. This study highlights the suitability of Clone A-Y48 and Italian Populus for enhanced growth and carbon sequestration, supporting their potential as effective solutions to balance wood demand and supply in Pakistan.

Keywords: Soil Carbon, Biofuel Plants, Agroforestry, Rangeland Management.

Introduction:

There is a severe lack of firewood and timber in Pakistan. The domestic supply of wood is currently far insufficient compared to the overall demand. In 2009, the total wood demand was 43.7 million m^3, with 12 million m^3 used for fuel and 32 million m^3 for timber. However, only 14.4 million m^3 of sustainable wood resources were available annually, resulting in a 29.3 million m^3 gap between supply and demand. This shortfall was often addressed through imports and the overexploitation of existing resources (FAO, 2009) [1]. Projections for 2020 suggested that this gap would significantly widen (PES, 2011) [2]. With a population of 170.5 million, the annual wood consumption was calculated at 48.52 million m^3. Future projections estimate wood usage to rise to 51.72 million m^3 by 2015, 55.64 million m^3 by 2020, and 59.44 million m^3 by 2025 [3]. The increasing consumption of firewood and timber is depleting Pakistan's wood supply and forestland. As energy demands and population grow, the situation is expected to worsen, with no immediate replacements for wood.

To address this challenge, the cultivation of fast-growing tree species has been promoted to boost biomass for renewable energy. By 2018, such plantations covered 2.5% of the world's forest area [4]. Poplar trees (Populus deltoides), which occupy 1.5 million hectares globally, have become a popular choice for agroforestry [5]. Planting poplars on marginal agricultural lands is expected to significantly increase the area under cultivation, helping meet the fuel and timber needs of developing nations [6]. Poplar cultivation not only mitigates land use competition for biomass and food production but also provides numerous ecological benefits, including improved soil quality, reduced water erosion, and enhanced biodiversity [7][8]. Their rapid growth, high productivity, and sustainable wood output make them valuable for industrial plantations and community forestry [9].

In Pakistan, the exotic Populus deltoides was introduced in the late 1950s and has since become a key species for afforestation [10]. Over the past two decades, poplar has gained popularity among Pakistani farmers, particularly in Punjab, due to its rapid growth, crop compatibility, and strong market demand. Local populations use various parts of the tree as fuelwood, while its wood is utilized in plywood manufacturing. The rapid growth and adaptability of poplars offer significant potential for carbon storage and CO2 sequestration [12]. Despite its widespread use, most poplar trees are grown on private farms, with only a small portion (approximately 0.029 million m^3) coming from state-run irrigated plantations in Punjab (PES, 2011) [2]. The poplar-based agroforestry strategy has considerably increased tree numbers outside natural forests and shown potential for socioeconomic growth, ecological restoration, and agricultural diversification [7]. The development of poplar woodlots, expansion of wood-based industries, job creation, and government tax revenue have positively impacted rural economies [13]. Populus species, with their history of research and simple vegetative propagation, remain a major candidate for bioenergy production. They are capable of maintaining growth under moderate stress by adjusting osmotic pressure and accumulating solutes [14][15].

Objectives:

- To introduce three poplar varieties for propagation under nursery condition
- To estimate the growth of three hybrid varieties under three media
- To estimate the Biomass of three hybrid plants

Novelty Statement:

This study presents a novel comparative analysis of three hybrid Populus deltoides species, assessing their growth and carbon sequestration potential in various soil media under nursery conditions in Pakistan. By employing different soil compositions and manures, the research highlights the superior growth performance and carbon storage capacity of the Clone AY-48 and Italian poplar varieties. This offers a promising solution to Pakistan's critical shortage of timber and firewood. The findings contribute significantly to agroforestry and sustainable

land use practices, emphasizing the importance of selecting optimal hybrids to enhance biomass production and support climate change mitigation efforts.

Materials and Methods:

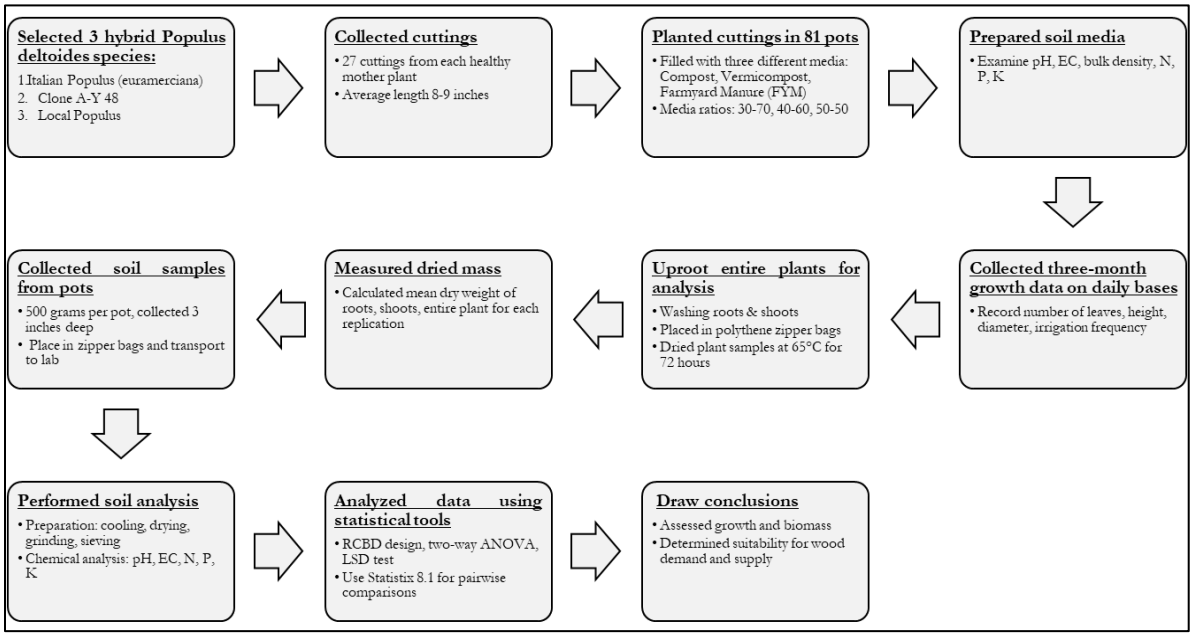

Figure 1: Flow diagram of research methodology

Experimental Site:

The pot experiment was conducted in 2023 at the greenhouse of the Rangeland Research Institute, National Agricultural Research Centre (NARC), Islamabad, Pakistan. The site, located at 33°43'N and 73°04'E, sits at an altitude of 540 meters above sea level on the Potohar Plateau in the northeastern region of the country. This area features a humid subtropical climate with an average annual rainfall of 790 mm.

Experimental Treatments:

In this study, three different soil composites were prepared for pot cultivation, adhering to general recommendations for balanced fertile soil. The selected tree species for this investigation included three varieties of Populus deltoides: local poplar, Italian poplar, and clone AY-48. A total of 81 plants were used, with 27 plants of each species transplanted into the prepared pots, divided into three different soil compositions. The aim was to evaluate the growth and biomass of these fast-growing hybrid species under various soil profiles to address the imbalance between wood demand and supply due to their short rotation and rapid growth characteristics.

Three healthy maternal plants, aged one to two years, were selected from the field area of Rangeland Research Institute (RRI), NARC. Thirty cuttings, each averaging 8-9 inches in length, were taken from each plant. These cuttings were stored in bags to maintain moisture and transported to the nursery site for planting. The cuttings were then planted in 90 pots arranged on a nursery bed, with each pot filled with one of three different soil media: compost, vermicompost, and farmyard manure (FYM). These media were mixed in three different ratios (30-70, 40-60, and 50-50). Soil media were analyzed for pH, electrical conductivity (EC), bulk density, and nutrient content (N, P, and K). The cuttings were planted horizontally in the pots at temperatures of 80–85°C.

Data Collection:

Growth data were recorded daily until plant emergence. Subsequent observations were made after seven days, focusing on the number of leaves, height, diameter, and irrigation frequency

for each pot. Data were collected over a three-month period. All growth metrics were documented and analyzed using a randomized complete block design (RCBD). At the end of the experiment, the plants were harvested, and soil samples were taken from the pots and transported to the RRI laboratory. Total biomass and carbon stock were estimated, with total carbon stock calculated by multiplying biomass by a factor of 0.50. Statistical analysis was performed to evaluate the results and support the study's objectives.

Table 1: Study design and details of manure treatment at different ratios and replicates in this study

Study Design for three different plant varieties one			
Plant varieties	**Ratio$_1$ 30:70**	**Ratio$_2$ 40:60**	**Ratio$_3$ 50:50**
	Replications	**Replications**	**Replications**
V_1	r_1 r_2 r_3	r_1 r_2 r_3	r_1 r_2 r_3
V_2	r_1 r_2 r_3	r_1 r_2 r_3	r_1 r_2 r_3
V_3	r_1 r_2 r_3	r_1 r_2 r_3	r_1 r_2 r_3

Statistical Analysis:

The data collected on various parameters were subjected to statistical analysis using analysis of variance (ANOVA) under a completely randomized design. Means were compared using the least significant difference (LSD) test.

Results:

This section presents a detailed description of the study results. The data collected from the field were analyzed and are summarized in tables. The primary objective of the study was to assess the growth, height, and biomass—both aboveground and belowground—of three different Populus deltoides varieties (local poplar, Italian poplar, and clone AY-48). Additionally, the study examined the effects of various soil amendments (compost, vermicompost, farmyard manure) and their ratios (r1: 30:70; r2: 40:60; r3: 50:50) on these varieties and the physiochemical health of the soil. The analysis and interpretations of these findings are discussed below.

Growth Parameters:

Plant Height:

The data presented in Figure 2 illustrate the results obtained after one complete growing season. Significant differences ($P \leq 0.05$) were observed in plant height among the different soil manures. The highest mean plant height was recorded for the farm with farmyard manure (33.16 cm), followed by the vermicompost farm (28.75 cm), with the lowest mean height observed at the compost farm (26.23 cm).

The effect of soil manure on the height of the different Populus deltoides varieties is shown in Figure 3. Significant differences ($P \leq 0.05$) in plant height were noted among the varieties. The maximum mean height was achieved by Clone AY-48 (35.56 cm), followed by Italian poplar (33.30 cm). The minimum mean height was recorded for local poplar (19.28 cm).

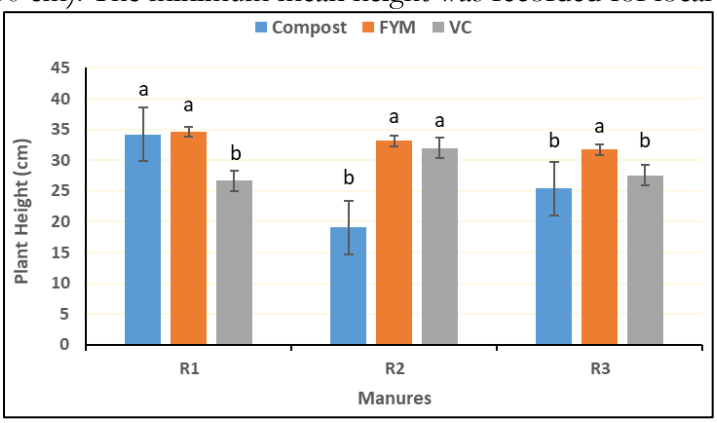

Figure 2: Effect of different manures on plant height (cm).

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD Value (0.05) for Manures = 1.9274
- LSD value (0.05) for manures × ratio = 3.3383

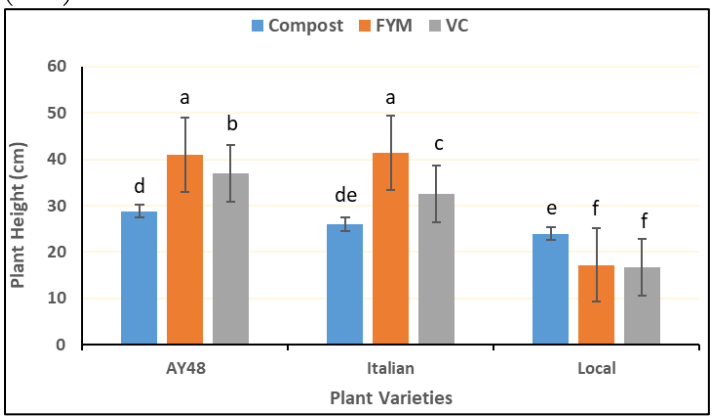

Figure 3: Effect of different manures on the plant height (cm) of different Populus deltoides varieties

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for varieties =1.9277
- LSD value (0.05) for Manures × Variants =3.3388

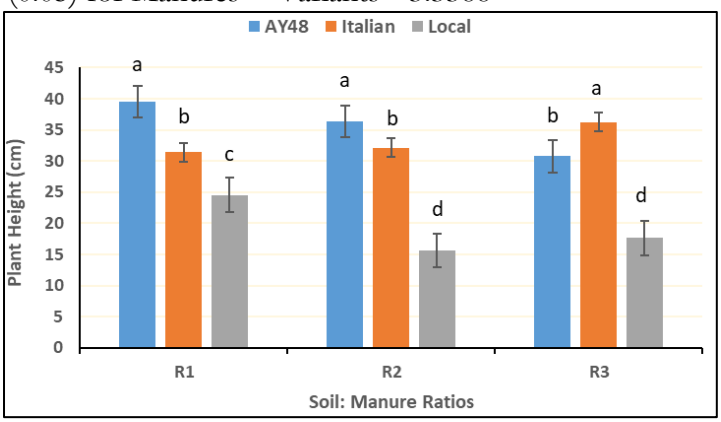

Figure 4: Effect of different soil ratios on the plant height (cm) of different Populus deltoides varieties

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for the ratio =1.9148
- LSD value (0.05) for varieties × ratios =3.3166

The effect of manure ratios on the height of different Populus deltoides varieties is illustrated in Figure 4. Significant differences ($P \leq 0.05$) were observed between the plant heights in R1 and those in R2 and R3. The maximum mean height was achieved in R1 (31.85 cm), while the minimum mean heights were observed in R2 (28.07 cm) and R3 (28.22 cm). Among the various interactions of soil manure, plant variety, and soil ratio, the maximum mean heights were associated with R1, while R2 and R3 showed comparatively smaller mean heights. The results indicate that differences carrying the same superscript letters were considered significantly different ($P \leq 0.05$).

Total Biomass:

The effects of soil manures and their ratios on total biomass are presented in Figure 5. Significant differences ($P \leq 0.05$) were observed among the different soil manures. The highest mean biomass was recorded in the farmyard manure (FYM) treatment (14.51 g), followed by the

compost treatment (13.25 g), with the lowest mean biomass observed in the vermicompost (VC) treatment (12.03 g).

Figure 6 shows the effect of soil manure on the total biomass of the Populus deltoides varieties. There was a significant (P≤0.05) difference in the total biomass among the varieties. The maximum mean biomass was recorded for Clone AY-48 (15.64 g), followed by Italian poplar (13.05 g), while the minimum mean biomass was recorded for local poplar (11.06 g).

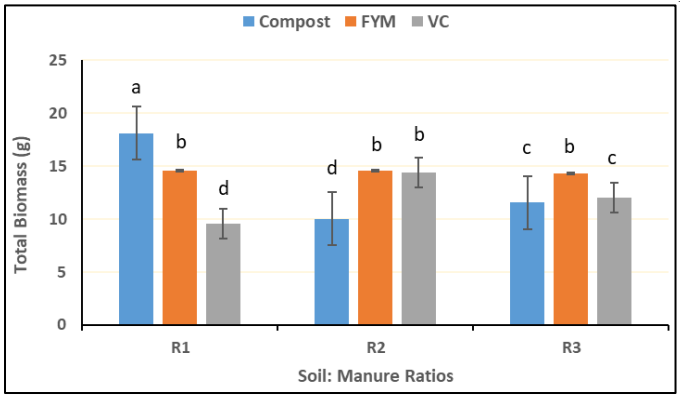

Figure 5: Effect of different manures ratios on total biomass (g).

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD Value (0.05) for Manures = 0.6086
- LSD Value (0.05) for Manures × Ratios = 1.0541

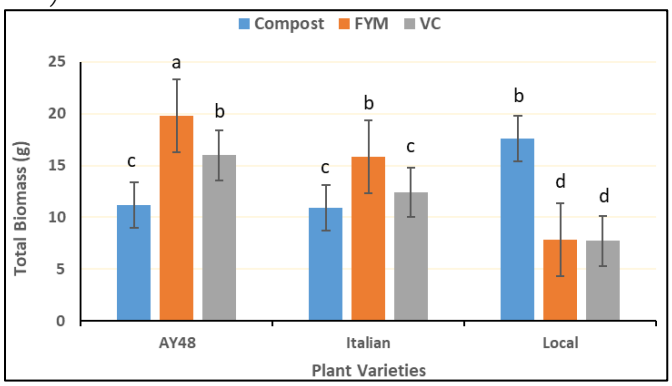

Figure 6: Effect of different manures on the total biomass (g) of different Populus deltoides varieties

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for varieties =1.0220
- LSD value (0.05) for Manures × Variants =1.7701

The influence of manure ratio on the total biomass of different Populus deltoides varieties is shown in Figure 7. The total biomass of the plants in R_1 was significantly (P≤0.05) different from that in R_2 and R_3. The maximum mean was recorded in R_1 (14.12 g), whereas the minimum mean was recorded in R_2 (13.03 g) and R_3 (12.64 g). Among the interactions between soil manure, plant variety, and soil ratio, the significant maximum mean in the entire bar series was followed by later scripts for smaller means. Digits carrying the same scripts were considered to be significantly different (P≤0.05).

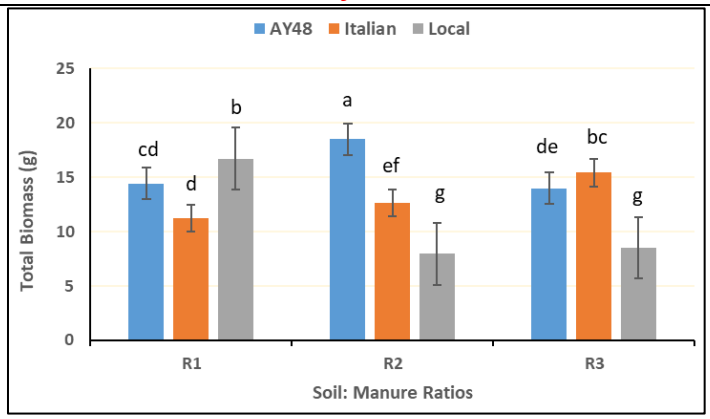

Figure 7: Effect of different soil and manure ratios on the total biomass (g) of different Populus deltoides varieties

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for varieties = 0.8198
- LSD value (0.05) for varieties × ratios =1.4199

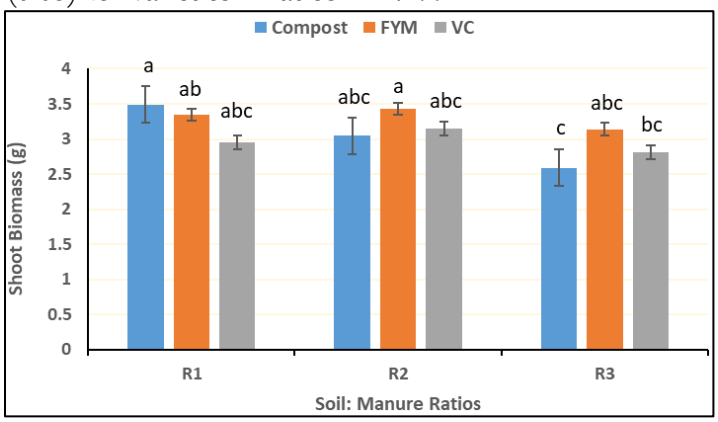

Figure 8: Effect of different manures on shoot biomass (g).

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD Value (0.05) for Manures = 0.3517
- LSD value (0.05) for manures × ratios =0.6091

Aboveground Biomass:

The effects of different soil manures and ratios on the aboveground biomass of plants, including shoots and leaves, are illustrated in Figure 8. No significant differences (P≤0.05) were detected among the soil manures in terms of aboveground biomass. The highest mean biomass was recorded in the farmyard manure (FYM) treatment (3.31 g), followed by the compost treatment (3.04 g), with the lowest mean biomass observed in the vermicompost (VC) treatment (2.97 g). Figure 9 shows the influence of soil manure on the aboveground biomass of the different Populus deltoides varieties. Significant differences (P≤0.05) were observed between AY48 and Italian poplar compared to local poplar. The highest mean biomass was recorded for Italian poplar (3.31 g), followed by AY48 (3.26 g), while the lowest mean biomass was found in local poplar (2.79 g).

The effect of manure ratios on the aboveground biomass of the Populus deltoides varieties is shown in Figure 10. Significant differences (P≤0.05) were observed between the biomass in R1 and those in R2 and R3. The highest mean biomass was recorded in R1 (3.26 g), followed by R2 (3.21 g), while the lowest mean biomass was observed in R3 (2.85 g). In terms of interactions between soil manure, plant variety, and soil ratio, the maximum mean biomass

was associated with R1, and differences carrying the same superscript letters were considered significantly different (P≤0.05).

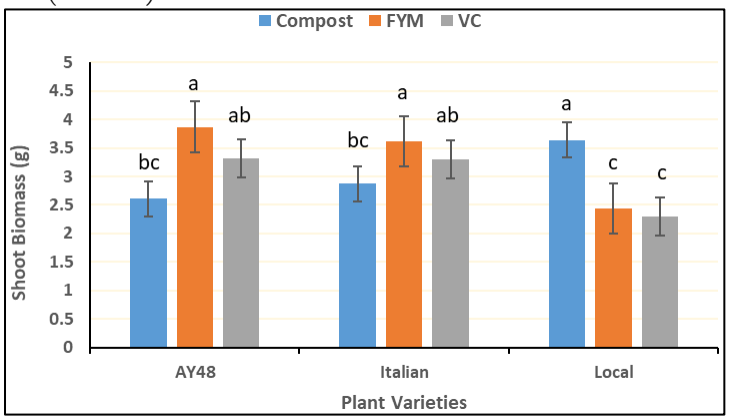

Figure 9: Effect of different manures on the shoot biomass (g) of different Populus deltoides varieties

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for varieties =0.4146
- LSD value (0.05) for Manures × varieties =0.7180

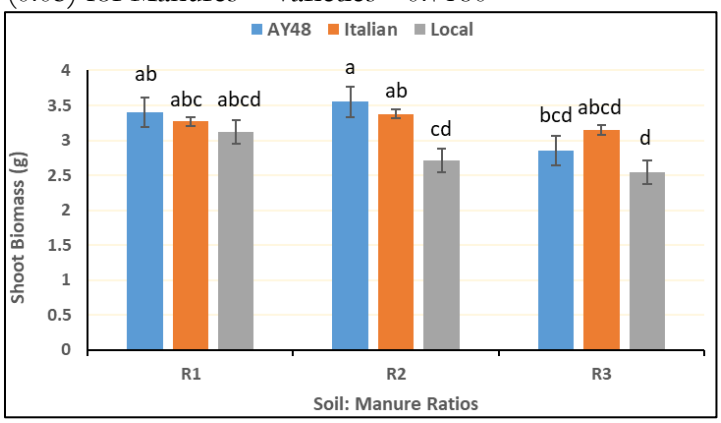

Figure 10: Effect of different soil and manure ratios on the shoot biomass (g) of different Populus deltoides varieties

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for varieties = 0.3704
- LSD value (0.05) for varieties × ratios =0.5415

Belowground Biomass:

The impact of different soil manures and ratios on the belowground biomass of plants is illustrated in Figure 11. Significant differences (P≤0.05) were observed among the soil manures. Compost produced the highest mean biomass (3.35 g), followed by farmyard manure (FYM) with 3.03 g, and vermicompost (VC) with the lowest mean biomass (2.64 g). Figure 12 presents the effects of soil manure on the belowground biomass of different Populus deltoides varieties. Significant differences (P≤0.05) were noted between AY48 and Italian poplar compared to local poplar, though no significant difference was found between AY48 and Italian poplar. The highest mean biomass was recorded for AY48 (3.48 g), followed by Italian poplar (3.20 g), while local poplar had the lowest mean biomass (2.35 g).

Figure 13 shows the effect of manure ratios on the belowground biomass of the Populus deltoides varieties. Significant differences (P≤0.05) were observed between the biomass in R1 and those in R2 and R3. The maximum mean biomass was recorded in R1 (3.46

g), followed by R3 (2.81 g), with the minimum mean in R2 (2.75 g). In terms of interactions among soil manure, plant variety, and soil ratio, the significant maximum mean in the bar series was followed by scripts indicating smaller means. Digits with the same superscripts were considered significantly different (P≤0.05).

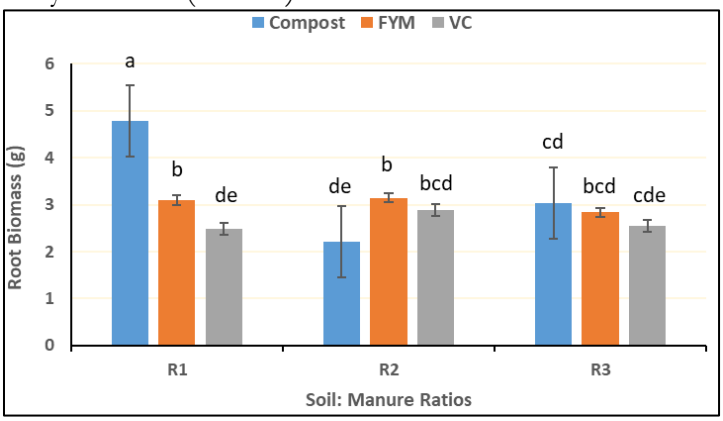

Figure 11: Effect of different manures on the root biomass (g).

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD Value (0.05) for Manures = 0.3083
- LSD value (0.05) for menures × ratios =0.5340

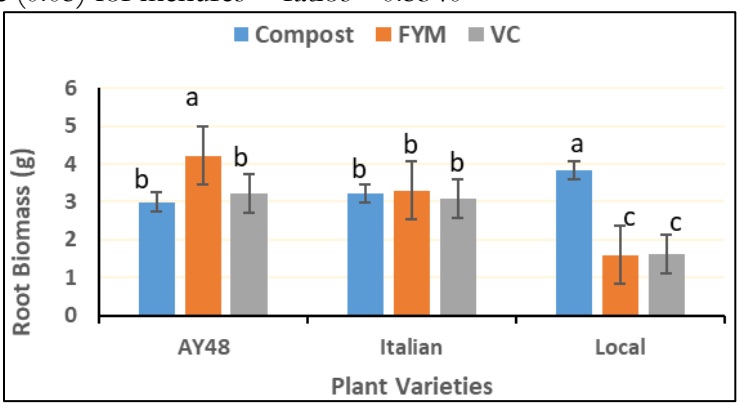

Figure 12: Effect of different manures on the root biomass (g) of different Populus deltoides varieties

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for varieties =0.3069
- LSD value (0.05) for Manures × Variants =0.5316

Soil Analysis:

Table 2 indicates that the soil in all the manures was alkaline. The highest pH was observed in the FYM (8.75), followed by that in the compost (8.23), and the lowest pH was observed in the VC (7.72%). As shown in Table 2, the maximum EC was obtained from VC 690.22, followed by FYM 622.1, and the minimum EC was obtained from compost 600.33. Total N was significantly (P≤0.05) greater in the FYM than in the VC and compost, and total P was significantly (P≤0.05) greater in both the VC and FYM than in the compost. P was significantly greatest in FYM 719.22, followed by VC 689.11, and the total p was minimal in compost 618.3. (Table 2).

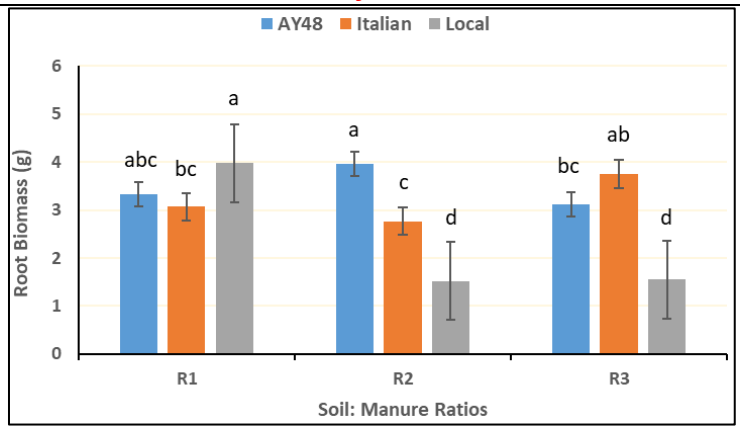

Figure 13: Effect of different soil and manure ratios on the root biomass (g) of different Populus deltoides species

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for varieties = 0.4107
- LSD value (0.05) for varieties × ratios =0.7113

Table 2: Chemical properties of the soil compost, vermicompost, and farmyard manure

Soil property	Compost	VC	FYM
pH	8.23a	7.72b	8.75b
EC (ms/m)	600.33c	790.22a	685.1b
N	0.814c	0.94b	1.32a
P (mg/kg)	1.37c	2.18a	2.35a
K (ppm)	618.3c	689.11b	719.22a

- At the 0.05 probability level, means denoted by different letters vary significantly.
- LSD value (0.05) for compost = 1.6421
- LSD value (0.05) for VC = 3.2261
- LSD value (0.05) for FYM = 3.7445

Discussion:

Growth Parameters:

Plant Height:

The application of manures at various ratios significantly influenced plant height. According to [6], among different plant varieties tested with FYM and canal silt, the highest plant height was achieved with FYM, which aligns with the present study's findings. Additionally, [16] observed that the poplar clone AY48 exhibited superior diameter at breast height (DBH) and height compared to other clones, which corroborates the results of this study.

Total Biomass:

The total biomass, encompassing both aboveground and belowground components, was notably affected by manure treatments. [17] found significant differences in total biomass when comparing FYM+NPK treatment with NPK+control in soybean production, which is consistent with the results of the current study. Similarly, [16] reported that Clone AY48 produced the highest biomass and annual total biomass among various poplar and willow clones, supporting the findings of the present research.

Aboveground Biomass:

[18] investigated the effects of different soil organic amendments on okra (Abelmoschus esculentus L.) and found that vermicompost resulted in higher aboveground biomass compared to other treatments, including FYM and biochar. This is consistent with the present study's results. Furthermore, [19] compared Populus deltoides and Tamarix ramosissima, finding that

Populus deltoides exhibited superior growth in height and aboveground biomass. This reinforces the findings of the current study regarding Populus deltoides.

Belowground Biomass: [20] explored the impact of fertilizers and compost on wheat plants and found that belowground biomass was greater with fertilizer alone compared to a combination with 1% compost, which aligns with the present study's findings. Additionally, [12] reported that belowground biomass of Populus deltoides increased significantly with age, a finding that supports the results of the current study.

Soil Analysis:

[21] examined the effects of various organic manures (compost, VC, FYM) and micronutrients (NPK) on cotton yield, with results that are consistent with those of the present study.

Conclusions:

The study's results indicate that farmyard manure positively and significantly affects the height of different Populus deltoides varieties. Clone AY-48 and Italian poplar are identified as suitable species for rapid growth and short rotation, making them valuable for improving livelihoods through agroforestry and farmlands. Clone AY-48 is particularly noteworthy for its superior carbon sequestration capacity, making it an effective tool for combating climate change compared to Italian poplar and local poplar, which exhibit slower growth and less carbon storage potential.

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