Article

Not peer-reviewed version

Optimizing Planting Methods for Sustainable Pomegranate Cultivation in the Shallow Gravelly Land of Central Deccan Plateau Region, India

Rajagopal Vadivel * , Kotha Sammi Reddy , Yogeshwar Singh , Dhananjay D. Nangare

Posted Date: 5 April 2024

doi: 10.20944/preprints202404.0405.v1

Keywords: planting approach; soil types; pits dimension; shallow gravelly land; pomegranate tree growth; fruit yield; fruit quality; Leaf nutrient content; sustainability

Article

Optimizing Planting Methods for Sustainable Pomegranate Cultivation in the Shallow gravelly land of Central Deccan Plateau Region, India

Rajagopal Vadivel [1,*], Kotha Sammi Reddy [1], Yogeshwar Singh [2] and Dhananjay D Nangare [1]

[1] ICAR-National Institute of Abiotic Stress Management, Baramati Pune-413115 Maharashtra, India
[2] Rani Lakshmi Bai Central Agricultural University, Jhansi- 284003, Utter Pradesh, India
* Correspondence: v.rajagopal@icar.gov.in

Abstract: To enhance pomegranate production on marginal gravelly lands, our study evaluated standardized planting techniques in an 8-year-old orchard. We employed trenching, wider pit excavation, pit digging, and auger digs with dimensions of 1 and 2 meters. Utilizing native soil from barren land, with or without spent wash, and mixing it with black soil up to 1 meter deep, we assessed growth parameters, leaf nutrients, and fruit yield. The trench and wider pit methods outperformed others, yielding greater above-ground biomass (>7.03 t tree^{-1}), root biomass (2.5 t tree^{-1}), and cross-sectional area (3.3 m^2 tree^{-1}). Additionally, trench planting enhanced leaf phosphorus (0.28%) and potassium (1.8%) levels, fruit juice content (48.5%), total soluble solids (16.05°), and fruit yield (>9.3 t ha^{-1}). The trench method also fostered longer roots at 90–150 cm radial distance and deeper roots at 40–60 cm depth. In summary, the trench and wider pit methods, combined with a soil mixture, are recommended for sustainable, high-quality fruit production in shallow gravelly terrains, thereby improving food security and the livelihoods of farmers in arid regions.

Keywords: planting techniques; pit types; soil types; skeletal soil; sustainable fruit production; pomegranate; fruit quality; nutrient concentration

---

1. Introduction

Pomegranate is a significant fruit tree cultivated extensively in India's Deccan plateau region, particularly in Maharashtra, Karnataka, and Andhra Pradesh [1]. The Deccan plateau contributes significantly to India's total pomegranate production, which amounts to nearly 2.85 million tonnes, with Maharashtra alone contributing over 65% ([2]. The cultivation area and production of pomegranates has been steadily increasing over the past two decades, driven by favourable agroclimatic conditions such as adaptability to harsh climates, three-season flower production, short juvenile period, and staggered cultivation ([2]. Notably, districts like Nasik, Solapur, Sangali, Pune, Osmanabad, and Ahmednagar in Maharashtra's Central Deccan plateau region account for a significant portion of pomegranate cultivation, primarily on marginal and sub-marginal lands totalling approximately 0.19 mha [3]. These lands exhibit characteristics such as sloping terrain, high coarse fragments, shallow soil depth, elevated bulk density, low water retention, and poor soil fertility with low organic carbon and nutrient content, posing significant challenges to fruit tree growth and development [4].

Furthermore, the growth and development of fruit trees face substantial limitations in slopping, shallow, and gravelly barren land. These soils typically exhibit poor soil structure, leading to restricted root penetration and hindered absorption of nutrients [5]. Additionally, their low water retention capacity results in frequent drought stress and limited moisture availability for fruit trees [6]. The constrained root space in shallow and gravelly soils further impedes nutrient uptake and overall plant vigour [7]. Furthermore, the erosion susceptibility of slopping soils poses risks to root stability and nutrient cycling. These combined challenges underscore the need for targeted soil management and cultivation practices to improve fruit tree performance in such environments.

 doi:10.20944/preprints202404.0405.v1

Planting techniques significantly influence fruit tree growth and sustainable production [3,8], with pit size, shape, and filler materials being crucial factors. Larger pits with increased soil volume enhance root contact, aeration, and water infiltration [9]. Various planting methods have been devised for arid and semi-arid environments, such as trench planting promoting horizontal root growth [10]. Sunken pit planting conserves subsoil water, crucial for tree growth during dry periods [11]. Pit planting enhances crown growth, stem diameter, and shoot length in fruit trees [12]. As trees mature, adjustments to the pit size become necessary for sufficient water and nutrient supply [12]. Neglecting pit size can cause root coiling, impacting tree health and fruit production negatively [13]. Seedling health directly affects fruit quality and quantity, emphasizing the link between tree vigour and sustainable production. Yet, the growth and development of a tree are equally influenced by the soil and other organic materials used to fill the pits, particularly in stony, marginal lands

Soil is another critical component of planting technique that is required for sustainable pomegranate cultivation under skeletal land situations. The ideal soil for is one should meet specific criteria, including high water retention, nutrient supply capacity, and adequate drainage to support robust tree growth and development [3,14]. Soil composition and nutrient availability directly affect the nutritional content and taste of the fruit [15]. Balanced nutrition can result in higher-quality fruits with better flavour and nutritional value [16]. Limited studies have shown that some soil types, such as loamy soil, clay soil, and clay-sand mixtures at specific ratios, can have a significant influence on fruit yield [3,17]. Additionally, the use of organic sources to supplement nutrient requirements has been suggested by Nadeem Shah et al. [18].

When it comes to optimizing planting procedures for plantation crops under skeletal land conditions and with shallow soil depth, insufficient attention has been given to pomegranate trees. This research seeks to address critical questions related to the sustainable cultivation of pomegranates in shallow skeletal soils, specifically: 1. Which planting techniques, pit sizes (varying in length and depth) and soil types are most effective in promoting robust growth in well-developed pomegranate trees in shallow skeletal soils? 2.To what extent do these planting approaches influence leaf nutrient concentrations, yield, and fruit quality of pomegranate trees in shallow skeletal soils? 3.How does increasing the width or depth of the planting pit affect the growth and development of pomegranate trees under conditions of shallow gravelly land? 4. What is the ideal pit volume required to achieve higher and sustainable fruit production from 8-year-old pomegranate trees under condition of shallow skeletal soil? 5. Does the application of spent wash at the time of planting influence the growth, development, and fruit yield of 8-year-old pomegranate trees in shallow skeletal soils

The research aims to harness the untapped potential of shallow skeletal soils by optimizing planting practices and customizing soil mixtures to these unique soil conditions, thereby enhancing their productivity, resilience, and environmental sustainability. This study strives to set the stage for improved fruit quality, economic growth for farmers, minimized environmental footprints, and a robust agricultural sector, ultimately contributing to a sustainable and secure food future.

2. Material and Methods

2.1. Description of the Study Area

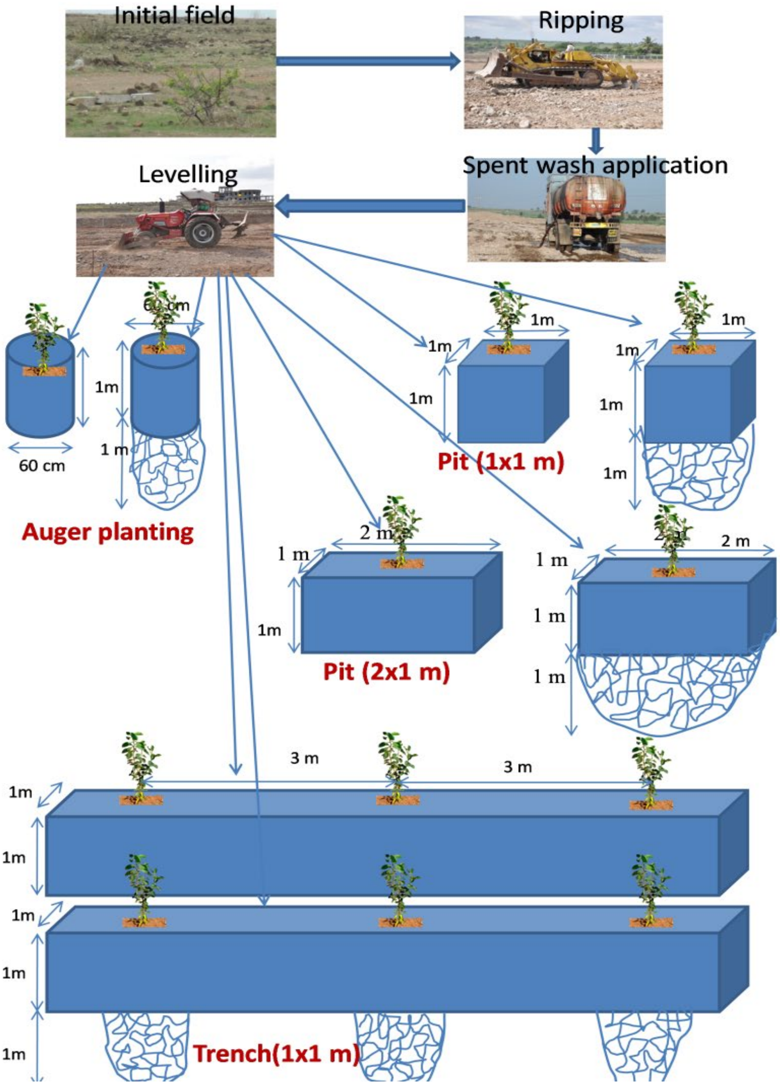
The research field, positioned at 18° 09′ 30.62″N, 74° 30′ 03.08″E and elevated 570 meters above sea level, is nestled in the tropical climate of Baramati, a region within the Pune district of Maharashtra, India. This region experiences an average yearly temperature of 26.3 °C, peaking at 32.5 °C in April and dipping to 23.3 °C in December. The majority of the annual rainfall, constituting over 70%, occurs during the southwest monsoon season from June to September. Given the mean annual precipitation of 572 mm, the research area falls within a rain shadow dryland region, situated behind the western ghat ranges [19].

2.2. Establishment of the Pomegranate Orchard

The study area was characterized by sparse vegetation including native grasses, bushes, and trees, situated within a trapezoidal landscape. To facilitate orchard development, elevation points were utilized to create isoline maps, aiding in the establishment of terraces along a 6% slope. These terraces, varying in dimensions from 90-200 m in length and 33-35 m in width, were organized into three blocks, each comprising six contour terraces. Land preparation involved the use of heavy machinery to break rocky layers, while acidic raw spent wash was applied at a rate of 50,000 L ha-1 to soften the rocks. The site underwent micro blasting, ripping, and chaining multiple times to optimize land conditions. Subsequently, one research plot was used for planting the Bagwa variety pomegranate (Punica granatum L.) trees at intervals of 4.5 x 3.0 m2.

2.3. Planting Techniques

The experiment employed a three-factorial planting method, involving four different pits, three soil types, and two soil depths, alongside two farmer methods currently used by farmers. The treatment details for planting pits (I), soil types, and soil depths are provided below: 1. Trench method: A trench was dug on both sides of trees with a length of 3m, a height of 1m, and a width of 1m, resulting in a soil volume of $3m^3$. 2. Wider pit method: A rectangular pit, 2m in length, 1m in width, and 1m in height, was dug, resulting in a soil volume of $2m^3$. 3. Pit method: A narrow pit in a square shape, 1m in length, 1m in width, and 1m in height, was dug with a soil volume of $1m^3$. 4. Auger: A dug pit with an inner diameter of 0.6m and a height of 1m was created, resulting in a volume of $0.28m^3$. Farmers used a 0.45 m^3 pit volume, with and without sugarcane spent wash, for planting of the pomegranate seedlings.



Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2024 doi:10.20944/preprints202404.0405.v1

Figure 1. Innovative planting techniques for sustainable pomegranate cultivation in the shallow skeletal land.

For soil (II), the following were used for planting: 1. Soil mixture at a 1:1 ratio of black and native soil types. 2. Native soil saturated with sugarcane liquid spent wash of one molar volume (450 ml) and 3. Native soil prepared by separating the murrum with a 2mm sieve. The characteristics of spent wash used for experiments given in Table S1. Two soil depths (III) were utilized for planting tree seedlings: normal depth of 1m and enhanced depth of 2m. In both depths, the soil was filled up to a depth of 1m. The enhanced soil depth to 2m was achieved by loosening native coarse fragments with the help of minor blasting techniques, with no external filler material added beyond 1m soil depth (Figure 1). All pits were gradually filled with their respective soil filler treatments up to a 0.3 m depth. Tree seedlings were planted uniformly at a depth of 0.3m and then carefully filled with the designated soil types, firmly pressed by hand.

2.4. Crop Husbandry

Farmyard manure (FYM) was applied at 20 kg per pit during transplantation of six-month-old pomegranate saplings (cv. Bhagwa) in March 2013, following standard practices for the region (Marathe & Jadhav, 2010). The FYM had nutrient contents including N (0.52%), P (0.28%), K (0.62%), Ca (0.21%), Mg (0.15%), Mn (610 ppm), Zn (73 ppm), Cu (76 ppm), Fe (860 ppm), organic carbon (38.5%), pH (6.4), and electrical conductivity (3.2 dS m-1). Initially, each seedling received 10 kg FYM, 300 g N, 150 g P, and 200 g K for two years. From the third year onwards, Hastha bahar pruning was carried out post-southwest monsoon (September-October). After 45 days, an ethereal (0.25%) and DAP (0.5%) spray was applied for leaf shedding, followed by light pruning and additional nutrient application (20 kg FYM, 500 g N, 200 g P, 200 g K per seedling). Full P and K doses were given in November, with N doses split and applied monthly. Drip irrigation was maintained at 7–10-day intervals at the orchard's periphery.

2.5. Collection, Processing and Analysis of Samples

Soil: Soil was collected at the beginning of the experiment and the distribution of sand, silt, and clay particles of soil used for plantings was assessed with the help of hydrometer [20]. The specific volume of soil was determined through bulk density analysis [21]. The soil available water was determined using the pressure plate apparatus [22]. Soil pH and electrical conductivity (EC) were measured at saturated paste conditions [23]. According to the wet chromic acid oxidation method, the soil organic carbon density was assessed [24]. According to the instruction of Hussain & Malik, [25] instructions, 0.32% potassium permanganate extractant was used for the appraisal of the soil available nitrogen (N) fraction. The Olsen reagent was used to evaluate the soil available phosphorous (P) fraction [26]. The plant available potassium fraction (K) was appraised using the 1N NH4OAC [27].

Above-ground portion of trees: The above-ground biomass of standing trees was evaluated using conventional destructive techniques, which included pruned materials and litter falls collected over the period of 8 years [28]. Tree spread was measured in both the north-south and east-west directions with tape until the last leaf of the tree [29]. The height of the trees was measured from the base to the maximum top of the canopy using a 3m-wooden ruler [29].

Roots: Soil profile method was adopted for root sample collection, where lines were drawn at 30 cm increments surrounding the tree up to 1.5 m away. Three trees from each treatment were harvested and the roots along with the surrounding soil within a 30 cm radius were excavated. Root and soil samples were collected at 20 cm depth intervals up to 1 m depth, separated using wet sieving techniques, and then oven-dried at 65°C for four days to determine root biomass. The lengths of larger roots (> 5mm dia) were measured using a meter scale, the intersection approach was used for smaller roots with diameters up to 5mm for assessing root length and their distribution [30](Habib, 1988). Additionally, composite samples of twenty cores (6 cm height, 5 cm diameter) were collected at the intervals of 30 cm horizontal distances (1.5 m spread) and 20 cm depth (up to 0.6 m depth) for

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2024 doi:10.20944/preprints202404.0405.v1

the assessment of root length density (RLD) [31](Pierret et al., 2000). The RLD value for each planting technique was calculated by averaging the RLD values across the sample width and depth of the pits.

$$RLD\ (m\,m-3)=\frac{Total\ root\ length}{Soil\ core\ volume}$$

Leaf nutrients content: At the pre-flowering stage, composite samples of 50 fully matured leaves were randomly collected from each tree. They were dried and the powdered leaf samples were digested with diacid mixture and the nitrogen content was estimated with distillation system. The phosphorous and potassium from the leaves brought into solution by digestion with a triacid procedure. The solution phosphorus was determined by the vanadomolybdate yellow colour method and the solution potassium was appraised with the flame photometer following the standard procedure given in the textbook by Tandon [32].

Fruit yield and quality: Fruit yield was measured from staggered harvest (t ha^{-1}). A total of 45 fruit samples were used for assessing the fruit length and width using a digital Vernier scale (Mitutoyo, Japan; Least count: 0.1 mm). Total soluble solids (°) in juice were measured with a refractometer (Atago, Tokyo, Japan). After the arils were removed, the juice was extracted with an extractor (Maharaja White line-Smart chef FP-100) and the juice yield was assessed as given below [33].

$$Juice\ yield\ (\%)=\frac{Weight\ of\ juice\ X\ 100}{Weight\ of\ fruit}$$

2.6. Statistical Analysis

The growth parameters of trees, including above-ground biomass, crown spread, root biomass, root length, root length distribution, leaf nutrient content (N, P, K), and fruit quality parameters (length, width, juice content, total soluble solids), were subjected to the Kolmogorov-Smirnov and Shapiro-Wilk tests to assess normal distribution. Furthermore, a three-factorial ANOVA test ($p > 0.05$) was conducted to analyse variance attributed to pit techniques, soil depth, filler soil materials, and their interaction effects. Post hoc analysis using Duncan multiple range test (DMRT) ($p > 0.05$) was employed to identify significant differences between treatments. Multiple regression analysis was performed to identify key variables influencing leaf nutrient content. The liner regression analysis was also carried out to establish functional relationship between pit volume used for planting and fruit yield. Data analysis was conducted using SPSS software version 16.0.

3. Results

3.1. Basic Properties of Soil Types Used for Pomegranate Plantings in the Shallow and Gravelly Barren Land

Table 1 presented herein delineates the foundational soil properties utilized across various planting methodologies for pomegranate cultivation within shallow and gravelly barren land conditions. It is observed that the traditional farmer techniques, represented by barren land, exhibited a significantly elevated coarse fraction content of 73.4% (w/w) as opposed to both the native soil and the black and native soil mixture filled pits. The incorporation of the soil mixture notably transitioned the soil texture from sandy loam, characteristic of the native soil, to loam soil with increased silt and clay particles content. Moreover, the soil mixture showcased augmented soil specific volume and increased plant-available water in comparison to the native soil. The liquid spent wash saturated native soil had a low soil pH of 4.5; conversely, all other soil types maintained a neutral pH range. Furthermore, the soil mixture exhibited a higher soil electrical conductivity (0.41 dS m-1), soil organic carbon content (0.43%), and available nutrients such as N at 155.5 kg ha-1, P at 8.3 kg ha-1, and K at 222.1 kg ha-1 as compared to the remaining soil types (Table 1). Yet, the carbon and available N (< 280 kg ha-1) and P (<10 kg ha-1) of the soil mixture were in low category while K came in medium fertility category (180-350 kg ha-1).

Table 1. Basic physical and chemical properties of soil types that used in the different pomegranate planting pits under the shallow and gravelly barren land situation.

Treat No	Pits	Soil Types	CF (%)	Sand (%)	Silt (%)	Clay (%)	SSV (m^3 Mg^{-1})	PAW (%)	pH (1:2)	EC (1:2) (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T1	Trench	NSBS	15.6	42.5	25.2	32.3	0.73	17.5	7.4	0.45	0.42	154.5	8.5	225.2
T2	Trench	NSSW	20.5	62.5	19.6	17.9	0.63	11.5	4.6	0.27	0.34	135.5	3.8	223.2
T3	Trench	NS	21.2	64.1	19.2	16.7	0.65	12.3	6.7	0.25	0.30	132.5	3.5	216.2
T4	Trench with ED	NSBS	15.2	38.3	26.5	35.2	0.68	18.2	7.2	0.42	0.43	156.0	8.2	220.5
T5	Trench with ED	NSSW	19.8	70.6	15.1	14.3	0.65	12.6	4.7	0.29	0.32	137.5	4.0	217.3
T6	Trench with ED	NS	20.2	71.2	14.3	14.5	0.64	11.8	6.6	0.25	0.28	135.2	3.7	218.5
T7	Wider pit	NSBS	15.1	40.6	26.0	33.4	0.69	17.5	7.3	0.40	0.42	158.0	8.0	219.3
T8	Wider pit	NSSW	21.8	63.1	19.0	17.9	0.66	12.5	5.2	0.27	0.32	132.5	4.1	217.6
T9	Wider pit	NS	20.8	63.8	17.8	18.4	0.65	11.8	6.7	0.29	0.28	134.1	3.9	217.2
T10	Wider Pit with ED	NSBS	21.2	38.5	25.5	36.0	0.70	17.3	7.5	0.43	0.45	155.0	8.3	223.2
T11	Wider Pit with ED	NSSW	20.5	65.2	18.5	16.3	0.65	11.8	4.7	0.35	0.30	136.2	4.2	220.2
T12	Wider Pit with ED	NS	21	66.0	17.2	16.8	0.64	12.4	6.9	0.32	0.27	135.4	3.8	218.2
T13	Pit	NSBS	14.8	34.2	30.2	35.6	0.71	18.5	7.5	0.42	0.43	153.0	8.1	223.5
T14	Pit	NSSW	21.3	64.0	18.2	17.8	0.64	11.5	4.8	0.27	0.30	134.5	4.3	223.2
15	Pit	NS	20.7	70.2	14.5	15.3	0.66	12.6	7.0	0.30	0.26	133.5	3.7	221.5
T16	Pit with ED	NSBS	15.9	39.2	25.8	34.7	0.69	18.2	7.3	0.28	0.44	155.0	8.4	220.5

T17	Pit with ED	NSSW	20.2	65.0	18.6	16.4	0.65	12.3	4.3	0.35	0.32	136.5	4.0	215.6
T18	Pit with ED	NS	20.8	65.4	18.8	15.8	0.64	11.7	6.9	0.25	0.25	132.5	3.6	214.5
T19	Auger	NSBS	16.3	37.2	26.0	36.8	0.70	17.8	7.4	0.42	0.43	157.0	8.3	221.5
T20	Auger	NSSW	19.8	64.5	19.5	16.0	0.63	11.5	4.0	0.27	0.36	135.2	4.1	219.2
T21	Auger	NS	21.2	65.0	19.1	15.9	0.64	12.2	6.9	0.29	0.28	132.2	3.9	218.6
T22	Auger with ED	NSBS	15.5	40.0	25.7	34.3	0.67	17.6	7.7	0.43	0.42	156.0	8.6	223.5
T23	Auger with ED	NSSW	20.5	66.2	17.8	16.0	0.63	12.0	3.8	0.26	0.32	137.5	3.5	220.1
T24	Auger with ED	NS	21	65.1	18.5	15.4	0.65	11.8	6.9	0.35	0.26	134.6	3.7	219.6
T25	Farmer Practice I	NLSW	72.5	75.2	12.5	12.3	0.63	11.0	7.5	0.30	0.27	131.0	3.3	192.5
T26	Farmer Practice II	NL	74.3	76.3	13.8	9.9	0.65	10.9	7.7	0.35	0.25	130.0	3.1	193.6

3.2. Effect of Planting Techniques on Growth Parameters of Pomegranate Trees

Table 2 distinctly illustrates that both the pits and soil types, integral components of planting techniques, exerted significant influence on above-ground biomass production. There were notable differences among all the pits in terms of biomass production, with the trench and wider pit methods demonstrating higher production (>7.03 t ha-1) compared to the other pits. When the width of the pit increased by 1 m, the wider pit method showed a significant increase in biomass production, from 6.57 to 7.03 t ha-1. Similarly, the soil types exhibited variations among themselves, and the soil mixture displayed greater biomass production at 10.03 t ha-1 compared to the other soil types (Table 3).

The crown spread of the tree demonstrated substantial variations contingent upon the types of pits and the soil medium utilized for planting pomegranate seedlings. Among the various tree pits, the trench and wider pit exerted a more pronounced influence on the spread, encompassing an area of 3.3 m2. With every 1 m increase in the width of the pit, there was a significant augmentation in the crown spread. Conversely, the auger and pit exhibited a lesser spread, exceeding 2.2 m2, yet still outperforming the existing planting techniques which typically result in a spread greater than 1.5 m2 (Tables 2 and 3).

The Tables 2 and 3 also indicate that both pit types and soil mediums significantly influenced the production of root biomass and root length in the planting of pomegranate seedlings. Among the pit types, the trench and wider pit methods resulted in a greater biomass production of 2.45 t ha-1 compared to other pit types. The wider pit method, in particular, produced significantly higher biomass than the standard pit method, which in turn was higher than both the auger planting and traditional farming methods. The root length varied significantly across all pit types, with the longest root (1058 m) produced under the trench method. An increase in pit width from 793.2 to 950 m2 also corresponded to an increase in root length. As with pit types, the type of soil used also significantly influenced biomass production and root length. The soil mixture displayed greater biomass and root length (2.1 t ha-1 and 899 m, respectively) compared to the other two soil types. However, the soil's effect on biomass production and root length varied slightly with pit size. For all soil types under the auger method, the biomass and root length remained the same. However, black soil exhibited greater values compared to the other soil types in the remaining pits. Both the native soil with and without spent wash showed lower and almost identical biomass and root lengths in the pit, wider pit, and trench methods (Figure 2).

Table 2. Results of anova for three factorial experiments (Pit types, Soil types and Soil depth) with randomised blocked design.

Source	Pits	Soil	Depth	Pits X Soil	Pits X Depth	Soil X Depth	Pits X Soil X Depth	Adj R2
AGB (t ha-1)	0.00	0.00	0.79	0.81	0.32	0.11	0.58	0.83
Crown spread (m2)	0.00	0.00	0.23	0.55	0.51	0.98	0.90	0.77
Root biomass (t tree-1)	0.00	0.00	0.08	0.000	0.41	0.98	0.30	0.76
Root length (m)	0.00	0.00	0.12	0.000	1.0	0.9	1.00	0.83
RLD (m3 m-3)	0.00	0.00	0.70	0.650	0.99	0.18	1.00	0.74
Nitrogen (%)	0.00	0.00	0.16	0.360	0.72	0.62	1.00	0.84
Phosphorous (%)	0.00	0.00	0.68	0.680	0.97	0.19	0.72	0.72
Potassium (%)	0.00	0.26	0.67	0.741	0.96	0.81	0.97	0.90
Fruit yield (t ha-1)	0.000	0.000	0.080	0.000	0.552	0.311	0.922	0.82
Fruit length (mm)	0.000	0.000	0.810	0.920	1.000	0.550	0.920	0.95
Fruit width (mm)	0.000	0.000	0.054	0.038	0.800	0.933	0.924	0.84
Juice content (%)	0.000	0.000	0.200	0.000	0.129	0.411	0.662	0.96
Total soluble solids (°)	0.000	0.000	0.452	0.000	0.633	0.345	0.281	0.86

Table 3. The tree growth parameters and leaf nutrients content for pit types, soil depth and soil types under the sahllwo and gravelly land situation .

Treatments	Growth parameters					Nutrients content of leaf		
	AGB (t	Crown sprea	Root biomass	Root length (m)	RLD (m m-3)	N (%)	P (%)	K (%)

	tree-1)	d (m2)	(t tree-1)					
Pits								
1.Trench	7.06±0.28a	3.31±0.47a	2.48±0.24a	1057.7±48.2a	0.28±0.08a	1.58±0.07a	0.28±0.05a	1.78±0.08a
2.Wider pit	7.03±0.31a	3.30±0.40a	2.44±0.15a	949.9±47.9b	0.28±0.09a	1.56±0.06a	0.22±0.04b	1.55±0.07b
3.Pit	6.57±0.26b	2.27±0.33b	2.05±0.20b	793.2±39.3c	0.44±0.07b	1.39±0.06b	0.16±0.03c	1.30±0.06c
4. Auger	6.21±0.25c	2.19±0.29b	1.66±0.10c	620.7±20.5d	0.57±0.05c	1.24±0.05c	0.12±0.03d	1.29±0.06d
Soil types								
1.Soil mixture	7.03±0.48a	2.91±0.67a	2.36±0.45a	898.9±185.9a	0.36±0.15a	1.48±0.17a	0.21±0.08a	1.49±0.23a
2.Native soil saturated with liquid vinasse	6.69±0.47b	2.71±0.64b	2.10±0.31b	834.6±157.3b	0.41±0.13b	1.43±0.16b	0.19±0.06b	1.47±0.20a
3.Native soil	6.60±0.43c	2.69±0.62b	2.05±0.32b	828.2±156.1b	0.41±0.14b	1.44±0.15b	0.19±0.05b	1.48±0.19a
Farmers method-I	3.80±0.20	1.50±0.21	1.40±0.20	590.5±30.6	0.70±0.07	1.16±0.10	0.18±0.03	1.20±0.07
Farmers method-II	3.75±0.23	1.70±0.23	1.30±0.23	585.5±41.4	0.72±0.06	1.15±0.09	0.17±0.03	1.23±0.09

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2024 doi:10.20944/preprints202404.0405.v1

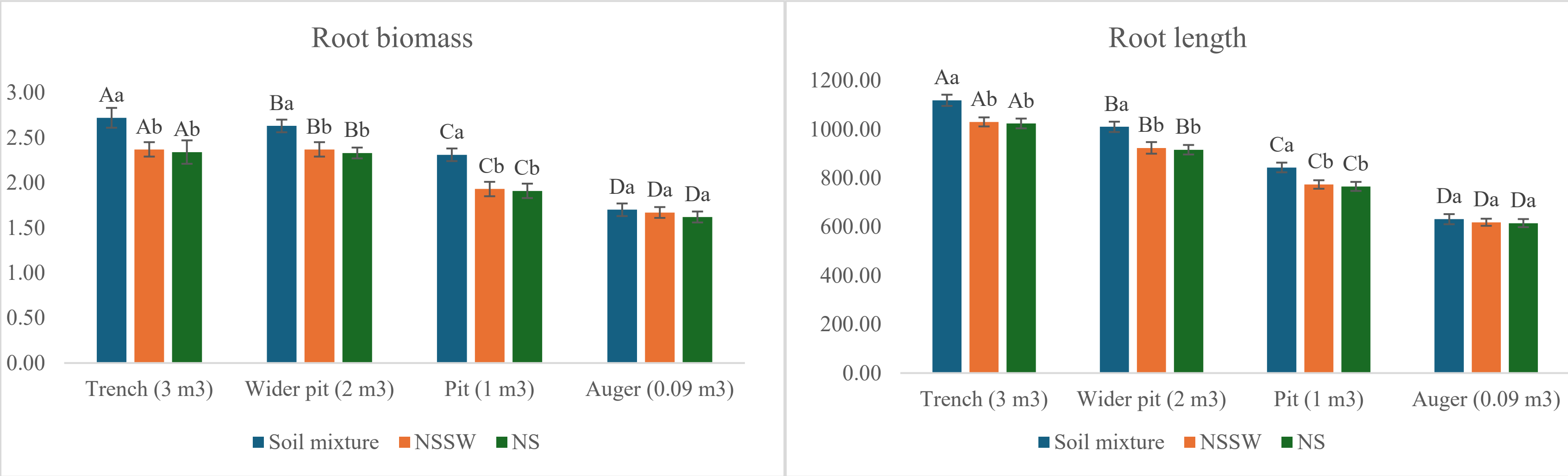
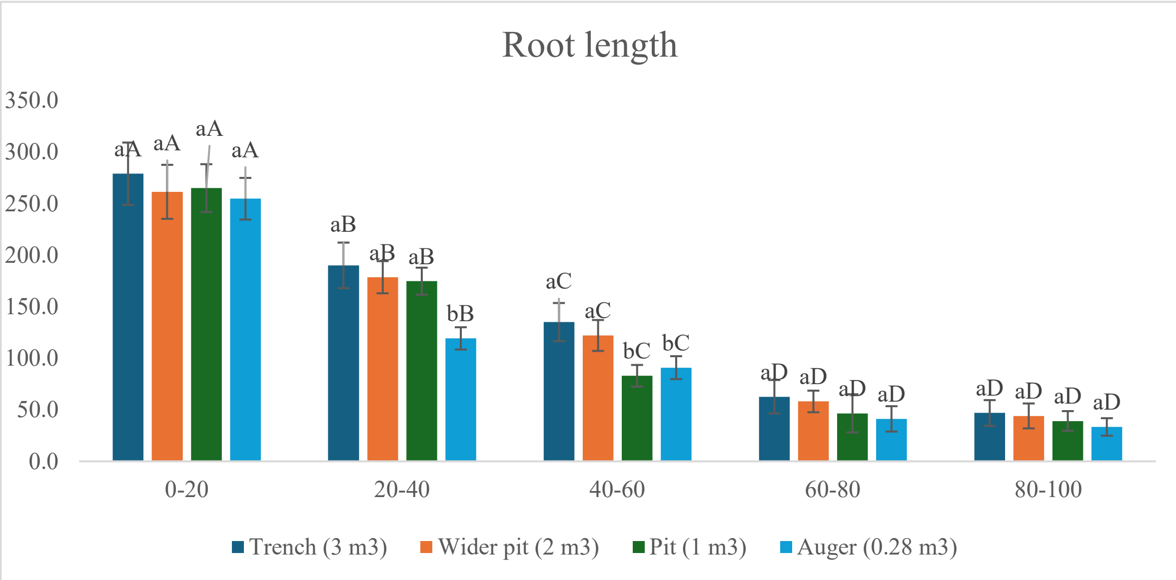


Figure 2. The interaction effect of planting pits and soil types on, root biomass (t tree-1) and root length (m) under the shallow and gravelly land.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2024 doi:10.20944/preprints202404.0405.v1

Figure 3 illustrates the distribution of root length at both vertical intervals and horizontal distances from the tree trunk. The length of the roots declined significantly with increasing soil depths. For vertical distribution, the sum of root length across the lateral distances in all the pits demonstrated that the surface depth (0-20 cm) and subsurface depths (20-40 cm and 40-60 cm) significantly differed from each other and also from the 60-80 cm and 80-100 cm depths. However, there was no clear difference between the latter two depths. The interaction effect of root length and soil depth revealed that planting methods also influenced root length, especially at depths of 20-40 cm. The trench, wider pit, and pit methods resulted in longer roots compared to the auger planting method. At a depth of 40-60 cm, the trench and wider pit methods were similar, but all methods were comparable beyond that depth. In terms of horizontal distribution, the root length near the trunk was consistent across all pits but was significantly higher compared to distances at 30-60 cm, 60-90 cm, 90-120 cm, and 120-150 cm. At 30-60 cm and 60-90 cm, both the trench and wider pit methods showed similar and higher root lengths compared to the pit and auger planting methods. However, at distances of 90-120 cm and 120-150 cm from the trunk, the trench method exhibited significantly higher root lengths, while the wider pit, pit, and auger methods showed similar lengths.



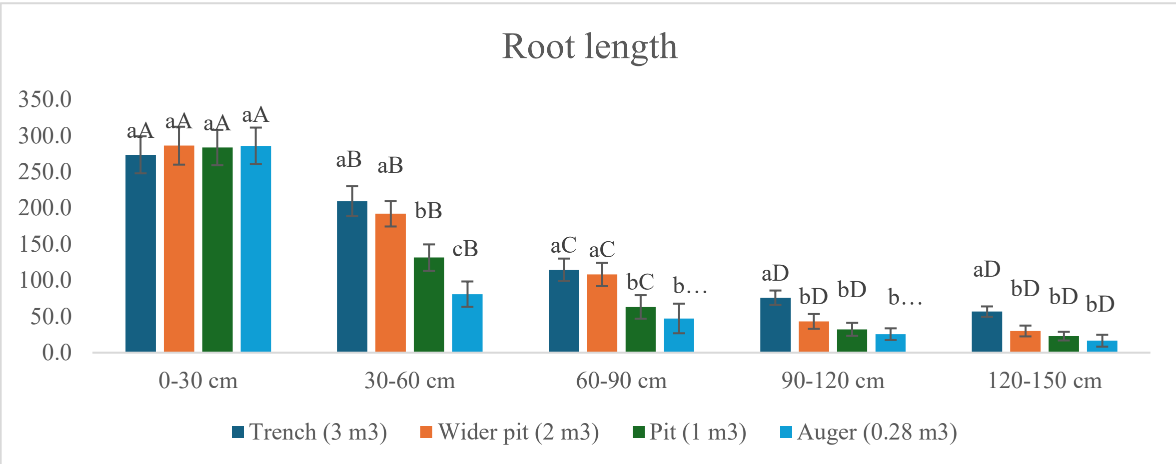


Figure 3. The variations of root length distribution at horizontal and vertical distance under different planting pits followed under the shallow and gravelly land situation .

Root length density, another crucial parameter of root growth, exhibited significant variations across the adapted tree pits and soil types used in the establishment techniques. Both the trench and wider pit methods had the same and lowest root length density (0.28) in comparison to the other pits. Similarly, the soil mixture presented the lowest density (0.36) when compared to other soil types, which had a density value of 0.41. The auger pit method, on the other hand, had a greater density value of 0.57 over the other methods (Table 2).

However, the application of spent wash to the native soil during tree establishment and the increase of soil depth from 1m to 2m without additional soil did not influence any growth parameters of the pomegranate tree (Table 2).

3.3. Effect of Planting Techniques on Nutrients Content of Leaves of Pomegranate Trees

Tables 2 and 3 confirm that the concentrations of nutrients in leaves were significantly influenced by both the types of planting pits and soil. The trench method exhibited higher nutrient contents of P and K, at 0.58% and 1.78% respectively, while the trench and wider pit methods had similar N content, exceeding 1.56%. Similarly, the soil mixture had higher leaf N and P content, at 1.48% and 0.21% respectively, while there was no significant difference among soil types in terms of Potassium content. Moreover, both the native soil with and without spent wash saturation exhibited the same N and P content, at 1.43% and 0.19% respectively.

3.4. Effect of Planting Techniques on Fruit Quality Parameters of Pomegranate

The data presented in Table 4 reveals a significant difference in fruit yield between various planting pits and soil types, specifically adapted for pomegranate cultivation in shallow, gravelly land. The trench method yielded a higher fruit output (9.2 t ha-1) in comparison to other methods. Similarly, the soil mixture demonstrated a superior yield (8.6 t ha-1) relative to other soil types. Moreover, the variation in yield due to soil effect was marginal for different pit types. All pit types exhibited significant differences under black soil conditions, with the trench method recording the highest yield of 9.5 t ha-1. Conversely, under native soil conditions, both with and without spent wash saturation, the pit and wider pit methods produced nearly identical yields (Figure 4).

Table 4. The fruit yield and quality parameters variations for pit types, soil depth and soil types under the shallow and gravelly land situation .

Treatments	Yield (t ha-1)	Fruit length (mm)	Fruit width (mm)	Fruit Juice content (%)	TSS (° Brix)
Pits					
1.Trench	9.16±0.30a	65.0±0.97a	63.52±1.21a	48.5±1.46a	16.05±0.62a
2.Wider pit	8.31±0.46b	64.9±1.04a	63.39±1.35a	45.0±1.07b	15.70±0.45b
3.Pit	7.88±0.22c	59.6±0.91b	60.41±0.77b	42.2±0.75c	14.70±0.33c
4. Auger	7.40±0.12d	56.0±0.70b	50.01±0.75b	38.7±0.76d	13.90±0.41d
Soil types					
1.Soil mixture	8.62±0.85a	61.7±3.90a	61.76±2.71a	44.5±4.25a	15.4±1.18a
2.Native soil saturated with liquid vinasse	8.01±0.65b	61.3±3.94b	61.26±2.43b	43.3±3.42b	15.0±0.78b
3.Native soil	7.94±0.60c	61.1±3.93b	60.98±2.36b	42.9±3.43c	14.9±0.81b

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2024 doi:10.20944/preprints202404.0405.v1

*Farmers method-I	5.70±0.27	53.5±0.62	54.2±1.05	35.0±1.1	12.9±0.20
*Farmers method-II	5.65±0.32	53.8±0.70	53.7±1.02	34.4±1.0	12.7±0.20

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2024 doi:10.20944/preprints202404.0405.v1

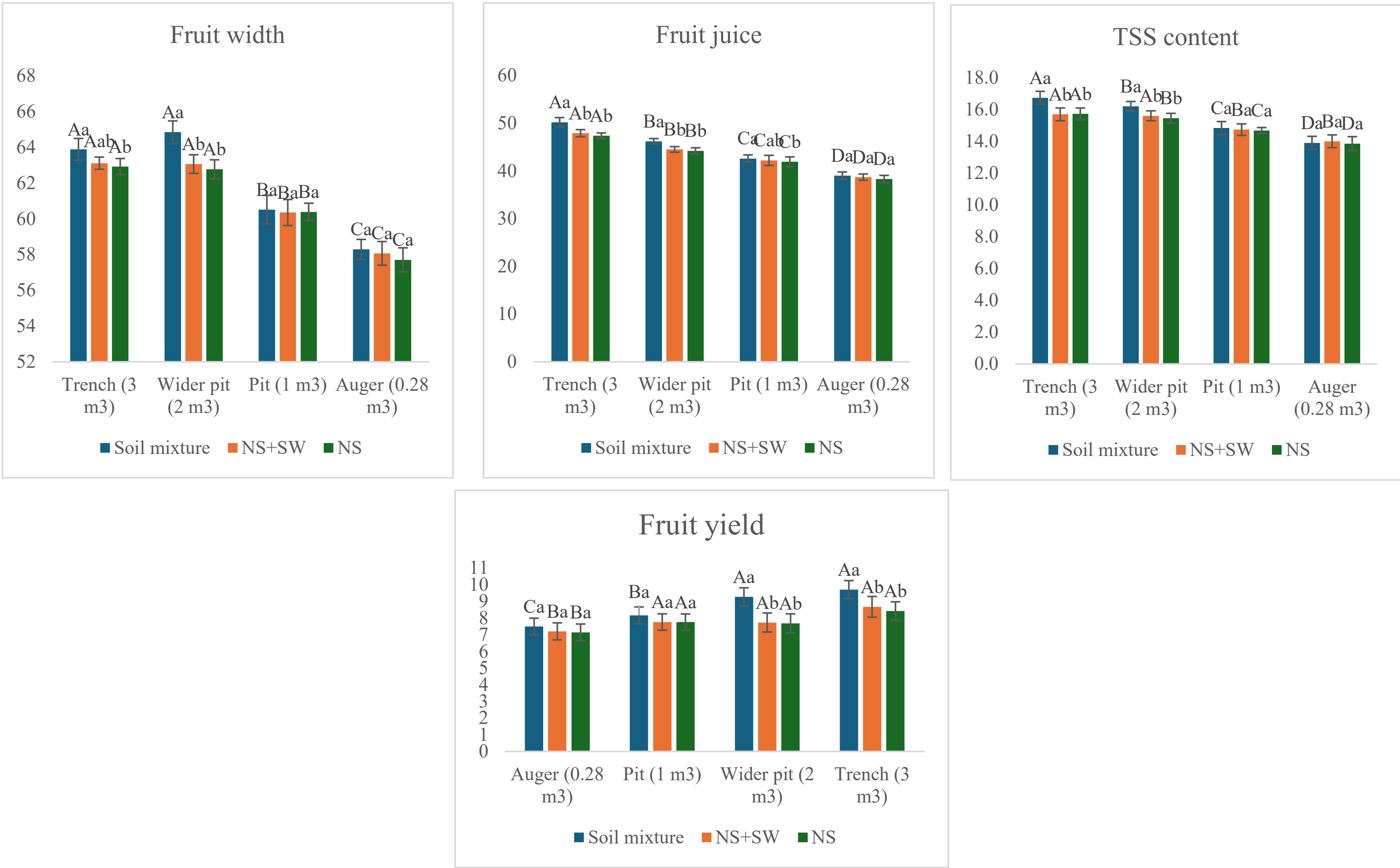


Figure 4. The interaction effect of planting pits and soil types on fruit size (mm), fruit juice (%), total soluble solids (Brix) under the shallow and gravelly land.

An in-depth analysis of fruit quality parameters has revealed that the type of planting pit significantly impacts both fruit length and width. Fruits produced from the trench and wider pits were of equal or greater size, measuring 65 cm in length and 63.5 cm in width. Soil types also had a significant influence on fruit size, with the soil mixture yielding the largest fruit, measuring 62 cm in both dimensions (Tables 2 and 4). The width of the fruit exhibited notable variation among different pit types and soil conditions. Under black soil conditions, the trench and wider pit methods resulted in larger fruit sizes, while other methods yielded similar widths across all soil types. The fruit juice content and TSS content also varied significantly based on the type of planting pit and soil used. The trench method and the soil mixture yielded fruits with higher juice content, 48.5% and 44.5% respectively. Interestingly, the interactive effects of soil types and pits showed varying impacts on juice and TSS contents. The combination of the trench method and soil mixture yielded the highest juice content (50.2%) and TSS (16.1%) (Figure 4).

4. Discussion

4.1. Effectiveness of Planting Techniques on Growth and Development of Pomegranate Trees

The marginal land characterized by shallow and gravelly soil types presents limitations due to a higher proportion of coarser fractions, which replace fertile soil and hinder both above-ground and below-ground biomass growth and development. This is primarily due to severe water and nutrient limitations that restrict root growth and consequently affect above-ground plant parts[4,34,35]. The study revealed that the trench and wider pit methods were most effective in promoting robust growth in pomegranate trees in shallow skeletal soils. Irrespective of soil types, the larger pits with increase of width by 2-3 m could store water and nutrients to the maximum required for 8-year-old pomegranate trees in the case of regular irrigation as well as during high intensity rainfall during the off-season [9]. These methods resulted in production of more than 87.4% above-ground biomass, 94.1% more tree crown spread, 87.6% more root biomass, and 62.3% more root length compared to farmer methods (Table 3). Further, increase of width of the planting pit positively influenced growth parameters, with wider pits leading to higher biomass production and root length [3,8]. This indicates the importance of pit size in tree development under shallow gravelly land conditions.

Soil types used for filling pits also played a significant role, with the soil mixture demonstrating superior growth outcomes compared to other soil types [3]. All pits filled with the soil mixture of loam texture had higher soil volume given unit of land, plant available water, soil available N, P and K content compared to native soils and the farmer method (Table 3) highlights that the soil mixture is more important for achieving success in tree development [36].

4.2. Influence of Planting Approaches on Leaf Nutrients Concentrations, Yield, and Fruit Quality

The study found that planting techniques and soil types had a significant impact on leaf nutrient concentrations, fruit yield, and quality parameters of pomegranate trees [37,38]. The trench method and soil mixture of black and native soil at 1:1 ratio resulted in higher leaf nutrient concentrations of P and K. These soil immobile nutrients showed a 64.7% and 44.7% increase in leaves over farmer method and this is a relatively higher increase compared to the leaf nitrogen (37.3%) content (Table 3) Based on multiple regression analysis, it was confirmed that the leaf nutrients increase was attributed mainly for root growth parameters such as root length, root length density, root biomass and pit volume (Figure S1) [39]. When the pit volume changed from 0.1 m3 to the 3 m3 volume under trench method, the 8-year-old pomegranate tree showed 80.6% and 90.8% increase in root length and root biomass, respectively [40]. Further, the greater root length distribution at 90-150 cm distance away from trees and up to 60 cm soil depth under trench method also displayed the influence of planting method on root length distribution [3,10,41]. As pit volume increased, root length density decreased, which could indicate more spares root development and more root exploration away from the root especially under the larger pit of trench method [7]. These all support the uptake of more soil immobile nutrient uptake under the trench method of planting in the shallow and gravelly barren land situation. Further, the black soil highly favoured for uptake of the N and P by fruit trees since

 doi:10.20944/preprints202404.0405.v1

their content was higher compared to the native soil [17,42](Newman et al., 1973; Marathe et al., 2018). In contrast, the leaf K content was same to all the soil had soil available potassium ranged between 192.5 and 225.2 kg ha-1 [43]. This findings emphasis soil type use for planting with respect to nutrient uptake by aged pomegranate tree.

The planting method also played a crucial role in achieving fruit yield with superior fruit quality under the challenging land situation. The trench method that the 8-year-old pomegranate showed higher productivity with superior fruit quality and the yield increase was 62.1% more compared to currently exist planting practice [17]. Similarly, the loam soil mixture showed greater fruit yield (56.2%) and fruit quality (>15% of fruit dimension, >29% fruit juice and >21% TSS content compared to other soil types [44]. The interaction effect of soil types and pit size indicated that when smaller pits up to 0.3 m3 used for planting of pomegranate seedling in the shallow and gravelly land, the soil type could not affect fruit quality parameters [45]. This finding emphasises the selection of appropriate soil type when different pits used for planting pomegranate tree under the marginal land situation for archiving higher and sustainable fruit production with better fruit quality.

4.3. Impact of Pit Volume and Spent Wash Application on Fruit Production

The investigation delved into determining the optimal pit volume necessary for sustainable fruit production from 8-year-old pomegranate trees in shallow skeletal soils. A linear regression analysis corroborated that each 1 m3 increase in pit volume led to a corresponding increase of 0.69 tons ha-1 in fruit yield production (Figure 5). Notably, the research revealed that larger pit sizes, particularly those with increased width rather than depth, such as trenches and wider pits (ranging from 2-3 m3 in volume), contributed significantly to higher fruit yield and quality when compared to smaller pits within the context of 8-year-old pomegranate trees grown in marginal land showed a shallow soil depth and a higher gravel stone content de [46].

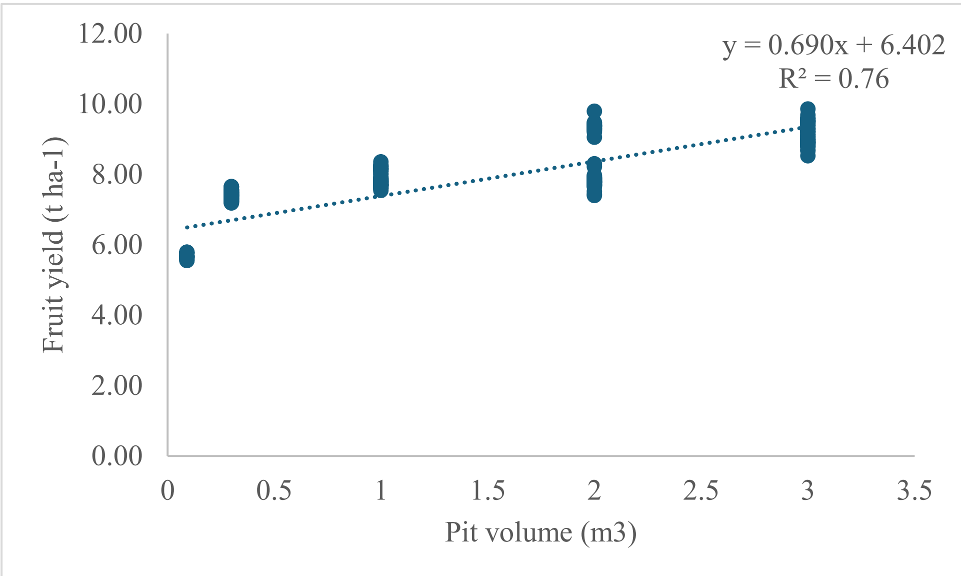


Figure 5. A linear functional relationship between pit volumes and fruit production under the shallow and gravelly barren land situation.

Spent wash is a liquid waste produced from the sugar industry, which is rich in nutrient source and its application brings improvement to soil physical properties and chemical properties. This is the cheapest nutrient source for small and marginal farmers and is widely used in agriculture in the study area ([47]. However, in our study, the application of spent wash during seedling planting could not have contributed to fruit production since effect of spent wash are mostly short term in nature and the effect might have gotten diluted with tree growth over the period [48]. The deepening of pits beyond 1 m without soil filling also did not yield any improvements in fruit production. This lack of improvement can be attributed to the fact that the majority of the roots are concentrated within the upper 0.6 m of soil, indicating that the pomegranate tree is a shallow-rooted tree [3,49].

5. Conclusion

Trench and wider pit methods which involve digging pits of 2-3 meters in width, have been found to promote an 87.4% increase in above-ground biomass, a 94.1% increase in tree crown spread, an 87.6% increase in root biomass, and a 62.3% increase in root length in pomegranate trees grown in shallow gravelly land. These larger pits with increased width play a crucial role in storing water and nutrients, leading to significant improvements in biomass, root length, and tree crown spread. The loam soil mixture with higher soil specific volume, plant-available water, and higher nutrients content has shown optimal tree development and efficient nutrient uptake and fruit production with superior fruit quality. Moreover, the trench method with soil mixtures showed higher uptake of soil immobile nutrients (P & K). These nutrient improvements directly impact the achievement of higher fruit yield and superior quality, emphasizing the critical role of planting strategies in attaining desirable fruit characteristics. However, the adoption of trench or wider pit methods in pomegranate cultivation requires heavy machinery for pit formation, adding to cultivation costs. This aspect may discourage small and marginal farmers from adopting these techniques. Future research should focus on analysing the cost of cultivation for pomegranates using different planting techniques and the corresponding yield benefits. Additionally, assessing carbon sequestration and potential income from trading sequestered carbon resulting from restoring challenging terrains for planting techniques should be explored in future studies.

The planting volume of 2-3 m^3 pit or trench and filling of loam soil to 1 m depth can be recommended for achieving sustainable fruit production from 8-year-old pomegranate trees under the shallow skeletal soil condition. This ensures improving food and nutritional security and enhancing the livelihoods of pomegranate farmers who cultivate rocky barren land.

Author Contributions: Rajagopal Vadivel- Soil and plant analysis, Data collection, Data analysis and writings; Kotha Sammi Reddy- writing—review and editing; Yogeshwar Singh- Experimental design and field monitoring; Dhananjay D Nangare- Field monitoring and Data collection

Acknowledgments: Authors grateful to ICAR NIASM for giving opportunity for conducting field experiment and lab facilities and successful completion of this research work. This research did not receive any specific grant from funding agencies, the public, commercial, or not-for-profit sectors, other than the ICRA NIASM institute.

Conflicts of Interest: The authors declare no conflicts of interest

References

1. Saroj PL, Kumar R. Recent advances in pomegranate production in India-a review. Annals of Horticulture. 2019;12. doi:10.5958/0976-4623.2019.00010.0
2. Narayan P, Chand S. Explaining status and scope of pomegranate production in India: An economic analysis. INTERNATIONAL RESEARCH JOURNAL OF AGRICULTURAL ECONOMICS AND STATISTICS. 2020;11. doi:10.15740/has/irjaes/11.2/157-165
3. Marathe RA, Sharma J, Dhinesh Babu K. Identification of suitable soils for cultivation of pomegranate (Punica granatum) cv Ganesh. Indian Journal of Agricultural Sciences. 2016;86. doi:10.56093/ijas.v86i2.55968
4. Loh FCW, Grabosky JC, Bassuk NL. Growth response of Ficus benjamina to limited soil volume and soil dilution in a skeletal soil container study. Urban For Urban Green. 2003;2. doi:10.1078/1618-8667-00023
5. Kheoruenromne I, Suddhiprakarn A, Watana S. Properties and Agricultural Potential of Skeletal Soils in Southern Thailand. Kasetsart Journal Natural Sciences. 2000;34.
6. Devin SR, Prudencio ÁS, Mahdavi SME, Rubio M, Martínez-García PJ, Martínez-Gómez P. Orchard Management and Incorporation of Biochemical and Molecular Strategies for Improving Drought Tolerance in Fruit Tree Crops. Plants. 2023. doi:10.3390/plants12040773
7. Fulkey G, Nooman HJ. EFFECTS OF SOIL VOLUME ON ROOT GROWTH AND NUTRIENT UPTAKE . Developemnts in Agricultural and Managed Forest Ecology . 1991;24: 446–448.
8. Ojasvi PR, Goyal RK, Gupta JP. The micro-catchment water harvesting technique for the plantation of jujube (Zizyphus mauritiana) in an agroforestry system under arid conditions. Agric Water Manag. 1999;41. doi:10.1016/S0378-3774(99)00023-2

9. Mauki D, Kilonzo M. Planting pit size determines successful tree seedling establishment in arid and semi-arid region of Tanzania. Environmental and Sustainability Indicators. 2022;15. doi:10.1016/j.indic.2022.100197
10. Celma S, Katrina B, Dagnija L, Karlis D, Santa N, Toms A S, et al. Effect of soil preparation method on root development of P. sylvestris and P. abies saplings in commercial forest stands. New For (Dordr). 2019;50: 283–290.
11. Von Carlowitz PG, Wolf G V. Open-pit sunken planting: a tree establishment technique for dry environments. Agroforestry Systems. 1991;15. doi:10.1007/BF00046276
12. Jo HK, Park HM. Effects of pit plantings on tree growth in semi-arid environments. Forest Sci Technol. 2017;13. doi:10.1080/21580103.2017.1312559
13. Mohammad N, Rajkumar M, Singh K, Nain NPS, Singh S, Rao GR, et al. Spacing, PIT size and irrigation influence early growth performances of forest tree species. Journal of Tropical Forest Science. 2021;33. doi:10.26525/jtfs2021.33.1.69
14. Cardoso FCG, Marques R, Botosso PC, Marques MCM. Stem growth and phenology of two tropical trees in contrasting soil conditions. Plant Soil. 2012;354. doi:10.1007/s11104-011-1063-9
15. Sun H, Huang X, Chen T, Zhou P, Huang X, Jin W, et al. Fruit quality prediction based on soil mineral element content in peach orchard. Food Sci Nutr. 2022;10. doi:10.1002/fsn3.2794
16. Kumar G, Sharma DD, Kuchay MA, Kumar R, Singh G, Kaushal B. Effect of Foliar Application of Nutrients on Growth, Yield and Fruit Quality of Pomegranate (Punica granatum L.) Cv. Bhagwa. Current Journal of Applied Science and Technology. 2020. doi:10.9734/cjast/2020/v39i2030807
17. Marathe RA, Sharma J, Murkute AA. Innovative soil management for sustainable pomegranate cultivation on skeletal soils. Soil Use Manag. 2018;34. doi:10.1111/sum.12416
18. Nadeem Shah M, Wright DL, Hussain S, Koutroubas SD, Seepaul R, George S, et al. Organic fertilizer sources improve the yield and quality attributes of maize (Zea mays L.) hybrids by improving soil properties and nutrient uptake under drought stress. J King Saud Univ Sci. 2023;35. doi:10.1016/j.jksus.2023.102570
19. Singh R, Potekar S, Chaudhary A, Das D, Rane J, Pathak H. Climatic Trends in Western Maharashtra, India. Pune; 2020.
20. Bouyoucos GJ. Hydrometer Method Improved for Making Particle Size Analyses of Soils 1 . Agron J. 1962;54. doi:10.2134/agronj1962.00021962005400050028x
21. Vincent KR, Chadwick OA. Synthesizing Bulk Density for Soils with Abundant Rock Fragments. Soil Science Society of American Journal. 1994;58: 455–464. Available: https://doi.org/10.2136/sssaj1994.03615995005800020030x
22. Reichert JM, Albuquerque JA, Kaiser DR, Reinert DJ, Urach FL, Carlesso R. Estimation of water retention and availability in soils of Rio Grande do Sul. Rev Bras Cienc Solo. 2009;33. doi:10.1590/s0100-06832009000600004
23. Corey RB. A Textbook of Soil Chemical Analysis. Soil Science Society of America Journal. 1973;37. doi:10.2136/sssaj1973.03615995003700020003x
24. Walkley AJ, Black IA. Estimation of soil organic carbon by the chromic acid titration method. Soil Sci. 1934;37.
25. Hussain F, Malik KA. Evaluation of alkaline permanganate method and its modification as an index of soil nitrogen availability. Plant Soil. 1985;84. doi:10.1007/BF02143191
26. Olsen SR, Cole CV,, Watanabe FS. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. Washington DC: US Government Printing Office; 1954.
27. Williams CH, Steinbergs A. Soil sulphur fractions as chemical indices of available sulphur in some australian soils. Aust J Agric Res. 1959;10. doi:10.1071/AR9590340
28. McHale MR, Burke IC, Lefsky MA, Peper PJ, McPherson EG. Urban forest biomass estimates: Is it important to use allometric relationships developed specifically for urban trees? Urban Ecosyst. 2009;12. doi:10.1007/s11252-009-0081-3
29. Marini RP, Barden JA, Sowers D. Growth and Fruiting Responses of `Redchief Delicious' Apple Trees to Heading Cuts and Scaffold Limb Removal. Journal of the American Society for Horticultural Science. 2019;118. doi:10.21273/jashs.118.4.446
30. Habib R. Total root length as estimated from small sub-samples. Plant Soil. 1988;108. doi:10.1007/BF02375658
31. Pierret A, Moran CJ, Mclachlan CB, Kirby JM. Measurement of root length density in intact samples using X-radiography and image analysis. Image Analysis and Stereology. 2000;19. doi:10.5566/ias.v19.p145-149
32. Tandon HLS. Methods of analysis of soils, plants, waters, fertilisers & organic manures. Methods of analysis of soils, plants, waters, fertilisers & organic manures. 2005.
33. Fawole OA, Opara UL. Effects of maturity status on biochemical content, polyphenol composition and antioxidant capacity of pomegranate fruit arils (cv. 'Bhagwa'). South African Journal of Botany. 2013;85. doi:10.1016/j.sajb.2012.11.010

34. Boland AM, Mitchell PD, Goodwin I, Jerie PH. The effect of soil volume on young peach tree growth and water use. Journal of the American Society for Horticultural Science. 1994;119. doi:10.21273/jashs.119.6.1157
35. Naseri M, Joshi DC, Iden SC, Durner W. Rock fragments influence the water retention and hydraulic conductivity of soils. Vadose Zone Journal. 2023;22. doi:10.1002/vzj2.20243
36. Ewetola EA, Oyeyiola YB, Owoade FM, Farotimi MF. Influence of soil texture and compost on the early growth and nutrient uptake of Moringa oleifera Lam. Acta Fytotechnica et Zootechnica. 2019;22. doi:10.15414/afz.2019.22.02.26-33
37. Marathe RA, Babu KD, Shinde YR. Soil and leaf nutritional constraints in major pomegranate growing states of India. Agricultural Science Digest - A Research Journal. 2016;35. doi:10.18805/asd.v35i1.9311
38. Doussan C, Pagès L, Pierret A. Soil exploration and resource acquisition by plant roots: An architectural and modelling point of view. Sustainable Agriculture. 2009. doi:10.1007/978-90-481-2666-8_36
39. Isaac ME, Borden KA. Nutrient acquisition strategies in agroforestry systems. Plant and Soil. 2019. doi:10.1007/s11104-019-04232-5
40. Proebsting L, Jerie PH, Irvine J. Water Deficits and Rooting Volume Modify Peach Tree Growth and Water Relations. Journal of the American Society for Horticultural Science. 2022;114. doi:10.21273/jashs.114.3.368
41. Loh FCW, Grabosky JC, Bassuk NL. Growth response of Ficus benjamina to limited soil volume and soil dilution in a skeletal soil container study. Urban For Urban Green. 2003;2. doi:10.1078/1618-8667-00023
42. Newman EI, Andrews RE. Uptake of phosphorus and potassium in relation to root growth and root density. Plant Soil. 1973;38. doi:10.1007/BF00011217
43. Li X, He N, Xu L, Li S, Li M. Spatial variation in leaf potassium concentrations and its role in plant adaptation strategies. Ecol Indic. 2021;130. doi:10.1016/j.ecolind.2021.108063
44. Quaggio JA, Mattos D, Cantarella H. Fruit yield and quality of sweet oranges affected by nitrogen, phosphorus and potassium fertilization in tropical soils. Fruits. 2006;61. doi:10.1051/fruits:2006028
45. Lu J, Shao G, Gao Y, Zhang K, Wei Q, Cheng J. Effects of water deficit combined with soil texture, soil bulk density and tomato variety on tomato fruit quality: A meta-analysis. Agric Water Manag. 2021;243. doi:10.1016/j.agwat.2020.106427
46. de Luna Souto AG, de Melo EN, Cavalcante LF, do Nascimento APP, Cavalcante ÍHL, Geovani Soares, et al. Water-Retaining Polymer and Planting Pit Size on Chlorophyll Index, Gas Exchange and Yield of Sour Passion Fruit with Deficit Irrigation. Plants. 2024;13: 235.
47. Rajagopal V, Paramjit SM, Suresh KP, Yogeswar S, Nageshwar RDVK, Avinash N. Significance of vinasses waste management in agriculture and environmental quality- Review. Afr J Agric Res. 2014;9. doi:10.5897/ajar2014.8819
48. Hassan MU, Aamer M, Chattha MU, Haiying T, Khan I, Seleiman MF, et al. Sugarcane distillery spent wash (Dsw) as a bio-nutrient supplement: A win-win option for sustainable crop production. Agronomy. 2021. doi:10.3390/AGRONOMY11010183
49. Hiwale SS, More TA, Bagle BG. Root distribution pattern in pomegranate "Ganesh" (Punica granatum L.). Acta Hortic. 2011;890.