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Impact of moisture pit planting on growth and yield of upland Taro [Colocasia esculenta (L.) Schott]: A climate-smart strategy

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ABSTRACT

Climate change and unpredictable rainfall patterns pose significant challenges to sustainable agriculture, underscoring the need for climate-smart, innovative technologies that enhance productivity and environmental resilience. Taro [*Colocasia esculenta* (L.) Schott] is a high-value superfood; however, its production in Kenya remains limited due to limited farmland, basic planting techniques, and a severe shortage of propagation materials. Taro [*Colocasia esculenta* (L.) Schott] is a high-value superfood; however, its production in Kenya remains limited due to limited farmland, basic planting techniques, and a severe shortage of propagation materials. Traditionally, taro is grown in wetland ecosystems; as such, the potential of taro is underutilized and ignored, therefore hindering its expansion into upland cropping systems and meeting the increasing demand. This study examines moisture pits as a climate-adaptive strategy to enhance upland taro production by optimizing water harvesting and conservation. This study examines moisture pits as a climate-adaptive strategy to enhance upland taro production by optimizing water harvesting and conservation. Field experiments conducted in 2023 and repeated in 2024 at Egerton University assessed the impact of varying planting depths on taro tuber yield and its components. A randomized complete block design with four replications was used, incorporating pit depths of 20, 30, 45, and 60 cm. Data collected focused on shoot parameters, corm yield, and yield components. Results indicated that planting depths significantly influenced corm weight per plant, with weights of 2.67 kg for 60 cm, 2.02 kg for 45 cm, 1.24 kg for 30 cm, and 0.35 kg for 20 cm. Corm yields also differed significantly: 44.63 t ha^{-1} at 60 cm, 38.43 t ha^{-1} at 45 cm, 29.58 t ha^{-1} at 30 cm, and 7.54 t ha^{-1} at 20 cm. The study concluded that the depth of planting pits significantly impacts the yield of upland taro, with deeper pits yielding better results. It is recommended that farmers adopt 30 cm wide and 30 to 60 cm deep pits for improved yields and high-density planting of suckers.

Key words: Pyrus, Morphology, Quantitative parameters, Kaghan, Pakistan, Quantitative parameters, Kaghan

INTRODUCTION

Taro [*Colocasia esculenta* L.) Schott] is referred to as "Nduma" in Kenya, "Koko" or "Cocoyam" in West Africa, and by many indigenous names in other regions (Anonymous1, 2006-2024). This staple tuber crop is crucial for food security in rural areas (Tajudeen *et al.*, 2019), particularly among small-scale farmers who produce under wetland cropping systems (Muthoni and Shimelis, 2023). The increasing social awareness of utilizing indigenous food sources (Serem *et al.*, 2008), which are healthy and safe, has led to a growing demand for taro tubers (Zulkhairi *et al.*, 2020). Taro is preferred as a staple food because of its significantly higher energy starch and protein than all the other central root and tuber crops (Tshipamba *et al.,* 2021).

The consumption of taro in Kenya has risen due to increased awareness of its nutritional benefits (Ubalua *et al.*, 2016) and its role as an alternative source of carbohydrates (Uwamariya *et al.*, 2023). Additionally, taro's gluten-free nature makes it an excellent option for individuals with gluten intolerance or celiac disease (Lakitan *et al.*, 2022). Its digestibility is generally superior to that of other root and tuber crops, making it a particularly suitable food choice for vulnerable populations, such as infants and the elderly. However, current production systems have not kept pace with the growing demand (Nuani, 2022).

Unlike other root and tuber crops, taro has received little attention in terms of policy support and research (Otekunrin *et al.*, 2021). It is mainly cultivated informally (Oladimeji *et al.*, 2022), with no regard for good agronomic practices such as fertilizer application, plant spacing, and planting depth (Ogbonna *et al.*, 2015). These practices have influenced the growth and yield of taro in other regions (Tumuhimbise, 2015).

Additionally, the area reserved for taro production is typically wetlands and river banks, which are often inadequate and protected for ecological conservation (Mongi and Chove, 2020), Furthermore, these areas face significant challenges of soil and water contamination with toxic substances (Mathews and Ghanem, 2021; Lloyd *et al.*, 2021).

The future production of taro in traditional areas is increasingly threatened by climate change. Prolonged droughts and more frequent floods are making lowland regions unsuitable for cultivating the wetland taro cultivars that are popular in Kenya.

While some efforts have been made to promote upland taro production using various methods (Oladimeji *et al.*, 2022), the adoption remains low due to labor and cost constraints (Eze and Okorji, 2003). Therefore, sustainable agronomic practices are required to transition cultivation of taro from wetland to upland areas (Njuguna *et al.*, 2023), with an effort on enhancing yields. The objectives of the study were to determine the influence of moisture pits on the growth and yield of upland-grown taro and to evaluate the potential of this technique for regenerating planting materials.

MATERIALS AND METHODS

The field experiment was conducted at Egerton University, Department of Crops, Horticulture and Soils, Teaching and Research Field Station. The site is located at 0°22′11.0″S, 35°55′58.0″E at an altitude of 2,267 m above sea level. The soils in this area are well-drained and exhibit a red-brown hue. They are classified as mollic phaeozems within Kenya's Agro-climatic Zone III (AZE) (FAO, 2014), receiving annual rainfall between 950 and 1,500 mm. This rainfall follows a bi-peak season distribution, with the first-peak season from March to August and second-peak season from September to November. The average yearly temperature ranges from 8°C to 23°C (Jaetzold *et al.,* 2010).

The field experiments were laid out in a randomized complete block design (RCBD) with four replications. Each plot measured 4 m by 4 m. A popular dasheen cultivar, referred to as Girigaca, was sourced from a farmer's field in Murang'a County, Central Kenya. The taro headsets, approximately 30 cm long and with a basal diameter of 3-5 cm, were prepared and planted in moisture pits. Four moisture pit depths: 20 cm x 15 cm (control), 30 cm x 30 cm, 45 cm x 30 cm, and 60 cm x 30 cm and a plant spacing of 50 cm by 100 cm were manually dug.

Planting commenced at the onset of the long rainy season. Each headset with a basal diameter of 3-5 cm was placed at the bottom of the pit, which was filled with a mixture of topsoil, organic compost manure (10 t ha^{-1}), biochar (5 t ha^{-1}), and organic fertilizer (500 kg ha^{-1}). The mulch, consisting of chopped dry maize stalks at a rate of 10 t ha^{-1}, was placed inside the pit. The field was maintained weed-free through manual weeding.

Data on shoot parameters were collected at 60, 120, 180, and 240 days after planting for the 2023 and 2024 seasons. Measurements included plant height, leaf length and width, the number of leaves, and suckers per plant. Leaves were counted cumulatively from oldest to newest, and plant height was measured from the crown to the tallest petiole. Suckers were counted cumulatively until harvest, and the distance from the mother plant to the suckers was noted. Harvesting involved sampling six plants per treatment from the middle rows, measuring corm length, diameter, girth, and yield per plant from an area of 9 m^2. After harvesting, corms and cormels were separated from the tops, with corm length measured from the posterior end to where the outer leaf petiole attaches. Corm diameter and girth were taken using a Digital Vernier Caliper (150 mm). Fresh weights of corms and cormels were recorded using a digital balance, and the estimated corm yield was calculated.

The data were analyzed using ANOVA with SAS Software version 9.4. Means related to taro growth were separated using Tukey's HSD method, while Pearson's correlation assessed the relationship strength between response variables at a 95% confidence level.

RESULTS

Table 1 illustrates the impact of pit depth on taro plant height and leaf area across two growing seasons. During the first season, taro exhibited greater mean plant heights and leaf areas when planted at pit depths of 20, 30, and 45 cm compared to the second season. However, at a pit depth of 60 cm, the first season still recorded higher mean plant heights and leaf areas.

Table 1. Taro Plant height and leaf Area in varying moisture pit depths (2023-2024)

Pit depth (cm)	Time days	Plant height		Leaf area	
		Season I	Season II	Season I	Season II
20	60	37.73±1.58^{h}	36.25±3.07^{g}	313.07±32.43^{g}	313.07±34.55^{d}
	120	45.00±2.28^{gh}	48.63±2.84^{efg}	418.67±24.76^{fg}	384.77±31.78^{d}
	180	60.50±2.60^{def}	60.20±3.39^{def}	417.19±28.8^{fg}	394.88±26.52^{d}
	240	67.50±1.32^{cde}	62.25±2.99^{de}	407.00±51.87^{fg}	889.83±470.26^{cd}
30	60	48.37±6.73^{fgh}	42.31±1.06^{g}	566.50±118.07^{efg}	295.49±28.72^{d}
	120	61.98±2.91^{def}	61.22±2.72^{def}	897.88±87.95^{def}	868.86±33.35^{cd}
	180	71.65±2.23^{bcd}	85.58±1.53^{c}	1389.86±134.33^{bcd}	1675.54±183.57^{ab}
	240	83.77±4.14^{ab}	112.45±3.63^{ab}	1733.51±105.01^{ab}	1812.14±115.87^{ab}
45	60	42.62±0.89^{gh}	46.37±1.35^{fg}	521.85±146.62^{efg}	438.78±81.14^{d}
	120	61.93±2.71^{def}	71.23±2.28^{d}	1012.60±104.89^{de}	1358.90±39.19^{bc}
	180	71.56±2.57^{bcd}	84.40±1.88^{c}	1362.38±110.00^{bcd}	1898.57±34.32^{ab}
	240	84.80±2.79^{ab}	120.25±2.95^{a}	1826.30±91.25^{ab}	2314.35±103.73^{a}
60	60	54.97±2.23^{efg}	41.06±1.32^{g}	668.92±67.30^{efg}	237.46±18.39^{d}
	120	67.23±2.08^{de}	57.06±1.63^{efg}	1230.81±84.49^{cd}	511.31±47.75^{d}
	180	81.02±5.29^{bc}	65.75±1.36^{de}	1665.86±37.45^{abc}	877.42±83.04^{cd}
	240	95.17±6.99^{a}	104.46±3.22^{b}	2105.04±157.11^{a}	1776.32±96.91^{ab}

Means followed by the same letter along the column are not significantly different at a $p \le 0.05$ probability level

Fig. 1 shows the effect of pit depth on the leaf area index of taro, revealing no significant differences between the two seasons. In 2023, the highest mean leaf area index was observed at a depth of 45 cm (1.19), followed by 30 cm (0.95), 60 cm (0.72), and the lowest at 20 cm (0.19). A similar pattern emerged in 2024, with leaf area index values of 1.09 for 45 cm, 0.90 for 30 cm, 0.74 for 60 cm, and 0.18 for 20 cm. Overall, plant height and leaf area significantly increased across all pit depths. In the first season, the tallest plants were recorded at a depth of 60 cm (95.17 cm). In the second season, a depth of 45 cm yielded the highest measurements for both height (120 cm) and leaf area (2,314.35 cm²). Although leaf area expanded with growth duration at pit depths of 30, 45, and 60 cm, a decline was noted at the 20 cm depth during the final growth stage. In summary, a pit depth of 45 cm consistently demonstrated the highest mean leaf area index throughout both seasons.

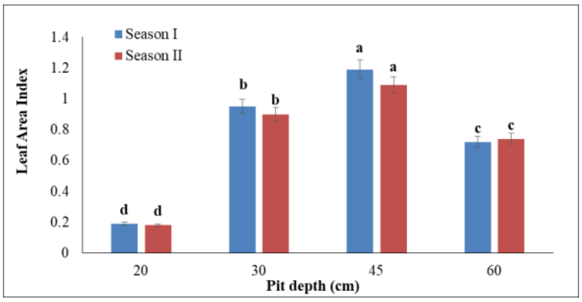

Fig. 1. Effect of moisture pit depth on the leaf area index for the two seasons

Fig. 1 illustrates the impact of pit depth treatment on the leaf area index across two growing seasons, 2023 and 2024. There were no significant differences in the leaf area index of taro grown at the same pit depth between the two seasons. However, during the first season, taro planted at a depth of 45 cm exhibited the highest mean leaf area index (1.19), followed by 30 cm (0.95), 60 cm (0.72), and the lowest recorded at 20 cm (0.19). A similar trend was observed in the second season, with leaf area indices of 45 cm (1.09), 30 cm (0.90), 60 cm (0.74), and 20 cm (0.18). The plant height and leaf area significantly increased over time, regardless of pit depth in both seasons. In the first season, plants in a 60 cm pit depth achieved the tallest height (95.17 cm) and the largest leaf area (2,105.04 cm²) compared to the other treatments: 45 cm (84.80 cm and 1,826.30 cm²), 30 cm (83.77 cm and 1,733.51 cm²), and 20 cm (67.50 cm and 407.00 cm²).

In contrast, during the second season, it was the taro at a 45 cm pit depth that recorded the highest values for plant height (120 cm) and leaf area (2,314.35 cm²), followed by 60 cm (104.46 cm and 1,776.32 cm²), 30 cm (112.45 cm and 1,812.14 cm²), and 20 cm (62.25 cm and 889.83 cm²), as detailed in Table 1. The 60 cm pit depth recorded the most significant height and leaf area at harvesting time compared to other pit depths. However, taro planted at a 45 cm depth during the second season exhibited the highest values for both plant height and leaf area (Table 1). The deeper pit depths yielded a greater number of leaves, with counts of 28 (30 cm), 28.13 (45 cm), and 28.75 (60 cm), compared to 19.5 (20 cm). There were no seasonal variations in leaf counts for the same depths (Table 2).

Table 2. Effects of moisture pit depth, and season on arrowroot shoots parameters

Pit depth (cm)	Season	Mother/ sucker dist. (cm)	Sucker numbers	Stem girth (cm)	No. of leaves
20	I	4.67 ± 0.70^{c}	3.25 ± 0.48^{c}	15.40 ± 1.70^{c}	18.50 ± 0.65^{b}
	II	6.16 ± 0.96^{bc}	3.50 ± 0.29^{c}	17.13 ± 0.58^{bc}	20.50 ± 0.65^{b}
30	1	5.49 ± 0.16^{c}	10.00 ± 1.08^{a}	37.15 ± 1.65^{ab}	27.50 ± 1.04^{a}
	II	6.40 ± 0.65^{bc}	4.25 ± 0.48^{bc}	31.50 ± 0.38	28.50 ± 1.32^{a}
45	1	12.88 ± 1.17^{a}	9.50 ± 1.04^{a}	19.65 ± 8.12^{bc}	26.50 ± 0.65^{a}
	II	13.31 ± 0.54^{a}	9.25 ± 1.38^{ab}	40.78 ± 2.44^{a}	29.75 ± 0.75^{a}
60	1	9.57 ± 0.28^{ab}	10.25 ± 0.25^{a}	33.50 ± 1.44^{abc}	27.75 ± 1.38^{a}
	II	10.62 ± 1.06^{a}	11.75 ± 1.89^{a}	35.85 ± 1.28^{ab}	29.75 ± 1.11^{a}

Means followed by the same letter along the column are not significantly different at a $p \leq 0.05$ probability level.

Deeper pits (30 cm, 45 cm, and 60 cm) resulted in higher sucker counts per plant (Table 2), with averages of 7.13, 9.38, and 11.0, respectively, compared to just 3.38 for the 20 cm depth during the first season. In the second season, only the 45 cm and 60 cm depths yielded significant numbers of suckers (Fig. 2). The 45 cm depth recorded the most significant distance from the mother plant at 13.09 cm, followed by 60 cm at 10.1 cm. In contrast, the shorter depths of 20 cm and 30 cm produced distances of 5.42 cm and 5.94 cm, respectively. There were no significant differences in stem girth across the growing seasons. In summary, pit depth has a considerable impact on sucker production and leaf count, but has a minimal effect on stem girth.

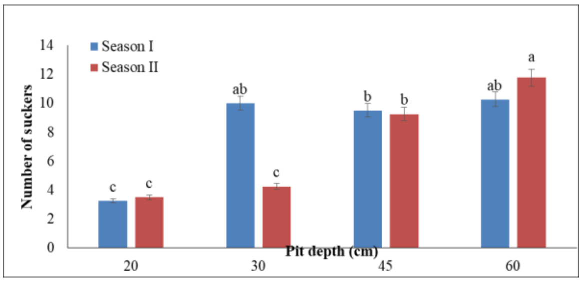

Fig. 2. Effect of moisture pit depth and season on sucker density per plant

Table 3 highlights that seasonal conditions have a significant effect on taro corms, with fresh weights in 2024 exceeding those in 2023. Increasing the pit depth from 20 cm to 60 cm resulted in improved corm length, while girth and diameter showed limited differences (Table 3). The best growth was observed in 60 cm deep pits during the second season. Corm weight increased from 1.43 kg in 2023 to 1.71 kg in 2024, and cormel weight rose from 0.93 kg to 1.18 kg, indicating better growing conditions. However, there were no changes in corm length, girth, or diameter, suggesting an increase in biomass without altering physical dimensions.

The observations from the first season, detailed in Fig. 3, show significant variations in corm yields based on planting depth. The highest mean corm yield of 40.58 tons per hectare was achieved at a depth of 45 cm, which also had the maximum cormel yield of 33.83 tons per hectare. In the second season, the optimal depth for corm yield shifted to 60 cm, resulting in an impressive 50.38 tons per hectare, while the best cormel yield was recorded at 30 cm with 32.32 tons per hectare. The shallowest pits in 2023 yielded 10.12 tons per hectare, slightly lower than the 9.93 tons in 2024, illustrating a significant disparity, as yields from the deepest pits were four to five times greater than those from shallow pits.

There was an insignificant interaction between pit depth and season, suggesting that the high leaf area and leaf area index in 2024 may be due to increased rainfall compared to 2023. The highest mean leaf area index (LAI) of 1.14 was recorded at a 45 cm pit depth, while the lowest was 0.19 at 20 cm (Fig. 1). Most suckers were initiated during the intermediate growth stage (60-120 days after planting), with deeper moisture pits; 30, 45, and 60 cm producing more suckers; 7.13, 9.38, and 11.0, respectively, compared to 20 cm pits, which produced 3.38 suckers (Fig. 2). This supports the findings of Legesse and Bekele (2021). The sucker production followed the trend: 60 cm > 45 cm > 30 cm > 20 cm. The emergence of suckers close to the mother plant makes separation difficult, highlighting the need for practices that create space for easier removal and enhance corm yields. Early removal of suckers may help reduce competition for resources (Lakitan *et al.*, 2021), improving the quality of the corms by reducing cormels.

Table 3. Effects of moisture pit depth and season on the taro corm yield components (2023 and 2024)

Pit depth (cm)	Season	Corm length (cm)	Corm girth (cm)	Corm diameter (cm)	Corm wt./plant (kg)	Cormel wt. /plant (kg)
20	I	16.15±0.46^{d}	23.90±0.10^{d}	2.80±0.22^{ab}	0.37±0.02^{e}	0.20±0.02^{d}
	II	14.85±0.54^{d}	23.30±0.47^{d}	2.75±0.13^{b}	0.33±0.01^{e}	0.15±0.03^{d}
30	I	23.69±1.75^{cd}	32.57±0.98^{c}	15.65±5.72^{a}	0.99±0.05^{de}	1.17±0.10^{bc}
	II	28.95±0.37^{bc}	35.17±0.42^{bc}	10.31±0.55^{ab}	1.50±0.07^{cd}	1.62±0.19^{ab}
45	I	37.83±0.31^{b}	36.08±1.13^{abc}	12.21±0.23^{ab}	2.02±0.18^{bc}	1.02±0.16^{c}
	II	35.25±1.50^{b}	35.70±1.20^{bc}	11.90±0.34^{ab}	2.02±0.01^{bc}	1.04±0.07^{c}
60	I	49.48±4.73^{a}	38.46±1.09^{ab}	10.64±0.19^{ab}	2.35±0.19^{ab}	1.35±0.15^{bc}
	II	57.55±3.27^{a}	40.45±0.86^{a}	11.22±0.20^{ab}	2.99±0.15^{a}	1.91±0.21^{a}

Means with the same letter along the column are not significantly different from each other as per Tukey's test at α= 5%

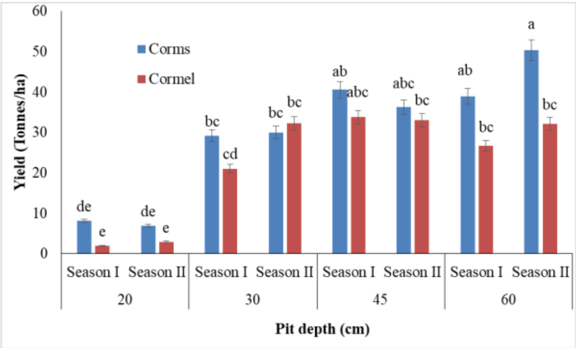

Fig. 3. Effect of moisture pit depth on the corm and cormel yields

While no correlation was found between mother plant and sucker distance, or overall corm yield, it is inferred that suckers can be harvested early as propagation material without negatively impacting corm yield. Overall, moisture pits appear to create optimal conditions for upland taro growth and sucker generation. No significant interaction between pit depth and season was observed; suggesting that the high leaf area and leaf area index in 2024 may be due to increased rainfall received compared to 2023. The highest mean leaf area index (LAI) of 1.14 was recorded at a 45 cm pit depth, while the lowest was 0.19 at 20 cm (Fig. 1). Most suckers were initiated during the intermediate growth stage (60-120 days after planting), with deeper moisture pits (30, 45, and 60 cm) producing more suckers (7.13, 9.38, and 11.0, respectively) than the shallow 20 cm pits, which produced only 3.38 suckers.

DISCUSSION

This observation corroborates the findings reported by Legesse and Bekele (2021). The research indicates that the efficacy of deeper moisture pits (ranging from 30 to 60 cm) markedly enhances both shoot and corm metrics when compared to shallower pits of 20 cm, which is consistent with the conclusions drawn by Tumuhimbise (2015).

Opara-Nadi (1988) highlighted that deeper pits enhance soil coverage, retain moisture and nutrients, and protect roots from drying out. Onwueme (1999) found that deeper planting for upland taro leads to higher yields (Lewu *et al.*, 2017; Oladimeji *et al.*, 2022), and our study supports this by showing that the 60 cm deep pit yielded 50.38 tons per hectare in the second season, compared to 10.12 tons per hectare from the 20 cm pit in the first season (Figure 3). This aligns with Ubalua *et al.* (2016), who recorded yields exceeding 38 tons per hectare under favorable conditions. Under intensive management, yields can reach up to 73 tons per hectare (Goenaga and Chardon, 1995). Earlier studies reported lower yields, for instance, 22.34 tons per hectare (Norman *et al.*, 2022) and 18.26 tons per hectare (Njuguna *et al.*, 2023). Although past reports indicated deep planting resulted in lower yields (Hartman *et al.*, 2005), our findings supported the past results of Talwana *et al.* (2010) that showed taro may thrive in upland conditions and produce high yields if supplemented with water and nutrients, therefore, the moisture pits planting method could be exploited for enhanced productivity of upland taro.

CONCLUSION

Based on the research findings, it was determined that taro of the Dasheen-type has exceptional adaptability to grow in upland and drier conditions, making it a suitable cultivar for production in comparable agroecological zones that receive adequate and well-distributed rainfall. The results have shown that the moisture pit planting technique, with pit dimensions of 30 cm in width and a depth of 30 cm to 60 cm, effectively enables the growth and production of taro in the non-traditional, upland conditions. The planting depth significantly influenced the growth, development, and yield, as well as the yield components, of taro (*Colocasia esculenta* L.); notably, this technique led to high corm and cormel yields. The increased pit depth significantly positively influenced yield parameters, including corm length, diameter, and girth, which was contrary to earlier reported findings from wetland taro production studies. The technique demonstrated that taro planted using pits produced suckers at a further distance from the "mother plant", enabling easy and safe separation, thereby providing suckers for propagation before the crop's maturity. Additionally, non-significant correlations were recorded between the distance of the suckers from the mother plant and both corm yield per plant and stem girth.

These findings suggest that further investigation is needed to understand the dynamics in these specific measurements, as they did not demonstrate a strong correlation with overall yield outcomes.

RECOMMENDATION(S)

According to the findings of the research, the following suggestions are proposed:

1. The innovative moisture retention pit, with a 30 cm width and depths ranging from 30 cm to 60 cm, should be adopted as a planting technique for growing upland arrowroots. It will increase yields more than four times the national average.
2. To facilitate further research, the moisture pit cultivation technique is proposed to be implemented in various agroecological zones (AEZs) at low and medium altitudes. The objective is to determine the optimal planting depth that maximizes taro yield in these distinct environments.
3. To conduct further studies to evaluate the effect of early sucker removal on the growth and productivity of the mother plant. Aimed to improve management strategies for harvesting suckers for propagation before crop maturity. This development aims to establish systems that ensure a consistent supply of suckers to growers.

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