

Optimizing Propagule Type and Harvesting Timing for Accelerated Multiplication of Aloe Vera (L.)

Media Ezzaddin M.Amin¹ and Shabaq M. Nafea Hawezy²

¹and ²Department of Horticulture and Landscape Design, College of Agricultural Engineering Sciences, Salahaddin University, Erbil, Iraq

E-mail: media.mohammedamin@su.edu.krd

E-mail: shabaq.hawezy@su.edu.krd

Abstract

Efficient vegetative multiplication of *Aloe Vera* under semi-arid conditions depends on propagule vigor, planting season, and harvest timing. Three propagule sizes (large, medium, small), two planting dates (July, August 2024), and two harvest times (11 or 12 months after planting) were evaluated in a factorial RCBD (with three replications) in Erbil, northern Iraq. Many plant characteristics like: plant fresh weight, number of leaves per plant, leaf length (cm), leaf width (mm), leaf thickness (mm) leaf fresh weight (g), number of propagules per plant and and gel yield: leaf gel weight (g) and gel ratio were analyzed by ANOVA and the means were compared with Duncan's multiple range test DMRT ($p < 0.05$). The results revealed that, July planting improved vegetative performance relative to August. Large propagules outperformed smaller sizes for nearly all traits, achieving the greatest total plant weight ($1005.72 \text{ g plant}^{-1}$), gel yield (45.42 g), and propagule production (2.50 plant^{-1}) across main-effect means. The superlative combined treatment for overall productivity was July \times 11 months harvest \times large propagule D1H11L that gave highest plant weight: $1390.03 \text{ g plant}^{-1}$; longest leaf: 37.47 cm ; Propagules number: $5.33 \text{ propagule plant}^{-1}$ which did not differ significantly with the treatment July \times 12 months \times medium propagule D1H12M that gave the highest propagule count ($6.33 \text{ propagule plant}^{-1}$) while suggests a trade-off between maximum multiplication rate and biomass. It shows that commercially, July establishment with an 11-month harvest and large propagule D1H11L focus is optimal for semi-arid systems. A 12-month harvest works for medium propagule cases for maximizing planting material.

Keywords: *Aloe vera*, propagule size, harvesting time, propagation efficiency, gel yield.

1. Introduction

Aloe Vera (L.) is a multiuse plant with economic value, and a major component of the cosmetic, pharmaceutical, and nutraceutical industries [1, 2]. To satisfy the ever-increasing market demand for aloe-based products, sustainable aloe raw material propagation techniques must be developed [3]. Still, most aloe vegetative propagation relies on plant clones for asexual reproduction; however, the efficiency of the technique

is adversely affected by the size of the plant, the time of planting, and the length of time between subsequent harvests [4-6].

Harvesting time is also critical. Harvesting interval length and season combined greatly determine the rate of renovative regrowth for harvest, but also determine the quantity of leaf and gel output [7, 8]. Therefore, to maximize the sustainable multiplication rates within a field, combined vigorous planting of aloe with optimal regrowth and

harvesting schedules must be employed.

With reference to improved irrigation [6], nutrient management [9-11], and micropropagation techniques [12-15], improvements in micropropagation and general Aloe agronomy also provide various methodologies for scaling gentle cultivation.

Propagule size is essential to the success of the establishment and the ensuing productivity. In general, larger propagules outperform smaller ones in terms of survival, canopy development speed, and gel yield [4, 16, 17]. However, with the right management, medium and small propagules can also aid in large-scale propagation. Since environmental factors like temperature, radiation, and soil moisture affect biomass accumulation and gel concentration, planting season further influences establishment and yield [18, 19].

In the semi-arid climate of northern Iraq (Erbil-Iraq), the current study examined the combined effects of harvesting interval and propagule size under two planting dates (July and August 2024). Finding propagation techniques that maximize *Aloe vera*'s vegetative growth, gel yield, and propagule multiplication was the goal in order to support both commercial-scale cultivation and sustainable supply.

2. Materials and Methods

2.1 Experimental site

This experiment was conducted during the 2024 growing season in Zanco village, Kurdistan Region of Iraq, in the area of Erbil. The Erbil region experiences moderately cold winters along with hot and dry summer months. The region seems to have a semi-arid

Mediterranean climate. The soil described as sandy loam which is well-drained was leveled, plowed, and harrowed. Aloe thrives in the climatic and soil conditions of the area [18, 19].

2.2 Planting material and propagule selection.

Disease free mother plants kept in the university's collection of medicinal plants served as the source of the obtained propagules. They were grouped as follows:

- Large (L): 25 to 30 cm in height and 6 to 8 leaves with well-developed roots
- Medium (M): 15 to 20 cm and 4 to 6 leaves with moderate developed roots
- Small (S): 8 to 12 cm tall with 2 to 3 leaves, and under developed roots

To reduce the chances of infection, a 48 hours curative period in a shade was observed after propagule detachment. It is well established that larger propagules establish faster and have a better survival rate [4, 5, 17].

2.3 Research Design and Treatments

This experiment was set up using three replicates of a factorial RCBD. The treatments included were:

1. Planting date x Harvesting time: D1H12, D1H11, D2H12 and D2H11.
2. The propagule size was classified as Large (L), Medium (M), and Small (S).

All plots of the experiment that were set up as 150 × 150 cm contained five plants that were 50 × 50 cm apart within the plot. Standard practices of pest control, weeding, and irrigation were upheld. In the Aloe agronomy literature, RCBD factorial designs have been used

for evaluating the impact of irrigation, fertilizer, and spacing [20-22].

2.4 Research Design and Treatments

At 11- and 12-months after planting, plants were harvested, at which time they were assessed for the following measurements:

1. Plant fresh weight (g): *Aloe Vera* fresh plants were harvested and, for the purpose of the study, electronic balances had been used.
2. Number of leaves: Count of the total number of expanded leaves per plant harvested.
3. Leaf length (cm): With a measuring tape, the length of the longest leaf for each plant was assessed, measuring it from the tip all the way down to its base which is a soil level.
4. Leaf width (mm): The width of the longest leaf was determined using digital calipers at the mid-central region of the leaf.
5. Leaf thickness (mm): At the midrib of the longest leaf, thickness was determined with a caliper.
6. Leaf fresh weight (g): The longest leaf of each plant was plucked and then measured using an electronic balance.
7. Gel weight (g): The longest leaf was longitudinally cut and the transparent parenchymatous gel was removed with a sterilized spoon. The spoon was to avoid any contamination from the rind. The weight was subsequently measured using an electronic balance
8. Gel ratio (%): For calculating gel

ratio, the following formula had been used:

$$\text{Gel Ratio (\%)} = \frac{\text{Gel weight}}{\text{Leaf fresh weight}} \times 100$$

Where:

Gel weight (g) = the weight of gel extracted from the longest leaf of the plant.

Leaf fresh weight (g) = total fresh weight of the longest leaf of the plant which includes the peel and the gel.

9. Number of propagules per plant: At the time of harvest, a count of the new propagules that had emerged from the soil, growing around the base of each mother plant.

The parameters (1 - 9) were recorded and regrouped into three conceptions:

1. Growth parameters: leaf weight, number of leaves, and leaf depth length, width, and thickness.
2. Yield traits: the weight of the longest leaf, weight of the gel, gel weight ratio.
3. Propagation traits: number of propagules.

2.5 Statistical Analysis

The data were analyzed for variance (ANOVA) based on the factorial RCBD design. SAS software version 9.4 (2013) was used for computing the variance. Duncan's multiple range test was used for the treatment means comparison and set at the 5% significant level ($p < 0.05$).

3. Results and Discussion

3.1. Influence of planting date and harvesting time on growth, yield and propagation traits of *Aloe vera*

Dates for planting and harvesting intervals greatly affected the parameters of *Aloe Vera* growth, which are shown in Table (1). The treatment (D1H11) which is July planting and harvesting after 11 months, shows the maximum plant fresh weight (888.77 g) and the broadest leaf (43.07 mm). Instead (D2H11) which is August planting and harvested after 11 months of planting shows the longest leaf (36.62 cm) and the broadest leaf (41.12 mm), the thickest leaf (16.13 mm), and the heaviest leaf (83.11 g). In contrast, the greatest number of propagules per plant was recorded for treatment (D1H12) where the *Aloe Vera* was planted in July and harvested after 12 months. In contrast (D2H12) which is August planting with 12 months harvest shows the least values for most of the parameters with the most leaf weight (370.28 g plant⁻¹) and propagules produced (0.00). These results confirm Table 1. Influence of planting date and harvesting time on growth, yield and propagation traits of *Aloe vera*

previous studies which suggest that planting in the summer improves establishment due to favorable soil temperatures and longer photoperiods [18].

It is also counter intuitive that July planting and harvesting at 12 months later (D1H12) distributed easily, even cheese and bed, for July after 12 months permits more biomass, reproduce easily with the rest of the plant.

The findings are consistent with those of [6] highlighting the positive impact of extending the *Aloe vera* harvesting cycle on vegetative propagation and leaf biomass. Temperature and sunlight during the months of July creates an optimal environment with the capacity for strong canopy cover, as noted by [18, 19]. July 12 months as an interval between the July harvests was determined to progress vegetative regeneration, supporting the conclusion that increasing growth period vegetative propagation [7, 8].

Planting date	Harvesting time	plant parameters						
		plant fresh weight (g)	Number of leaves per plant	Leaf length (cm)	Leaf width (mm)	Leaf thickness (mm)	Leaf fresh weight (g)	Number of propagules (plant ⁻¹)
D1	H12	601.14 c	9.56 c	28.29 c	36.67 b	12.73 b	60.41 c	4.22 a
	H11	888.77 a	10.77 b	32.68 b	43.07 a	12.17 b	71.03 b	2.56 b
D2	H12	370.28 d	9.33 c	24.77 b	29.93 c	10.01 c	43.70 d	0.00 c

	H11	843.0 0 b	12.11 a	36.62 a	41.12 a	16.13 a	83.11 a	0.01 c
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*Different letters within a column indicate significant differences according to DMRT at $p < .05$.

**Planting Date (D1=July; D2=August); Harvesting time (H11 = Harvested after 11 months, H12= Harvested after 12 months)

3.2. Influence of planting date and harvesting time on gel traits of *Aloe vera* leaves

The variation in amounts of gel accumulated per treatment suggests that both the date of planting and the interval of harvesting are critical parameters in *Aloe vera* gel yield and concentration (Figure 1). The maximum gel weight noted from the treatment D2H11 (40.36 g) indicates that longer growth periods associated with the August planting schedule are beneficial for accumulation of leaf biomass which in turn augments gel mass [6, 8]. On the other hand, the 56.02% gel ratio for the treatment D1H12 suggests that planting in July fostered greater physiological efficiency which could be a result of favorable light and temperature conditions during

the establishment phase [18, 19]. These results are similar to the ones reported by [7] who indicated that the time of a season, as well as the time of harvest, determines the ratio of the leaf fresh mass that consists of parenchymatous gel. Also, [1] pointed out that under good climate conditions, the leaves of *Aloe* plants possess and maintain higher concentrations of water and mucilage, and as a result, greater gel is formed. All of these results demonstrate that there is a time interval between the planting of the *Aloe vera* and the time of harvesting that is most effective in optimizing the gel mass and concentration, which is consistent with previous findings about the relationship between climatic conditions and *Aloe vera* production [16, 22].

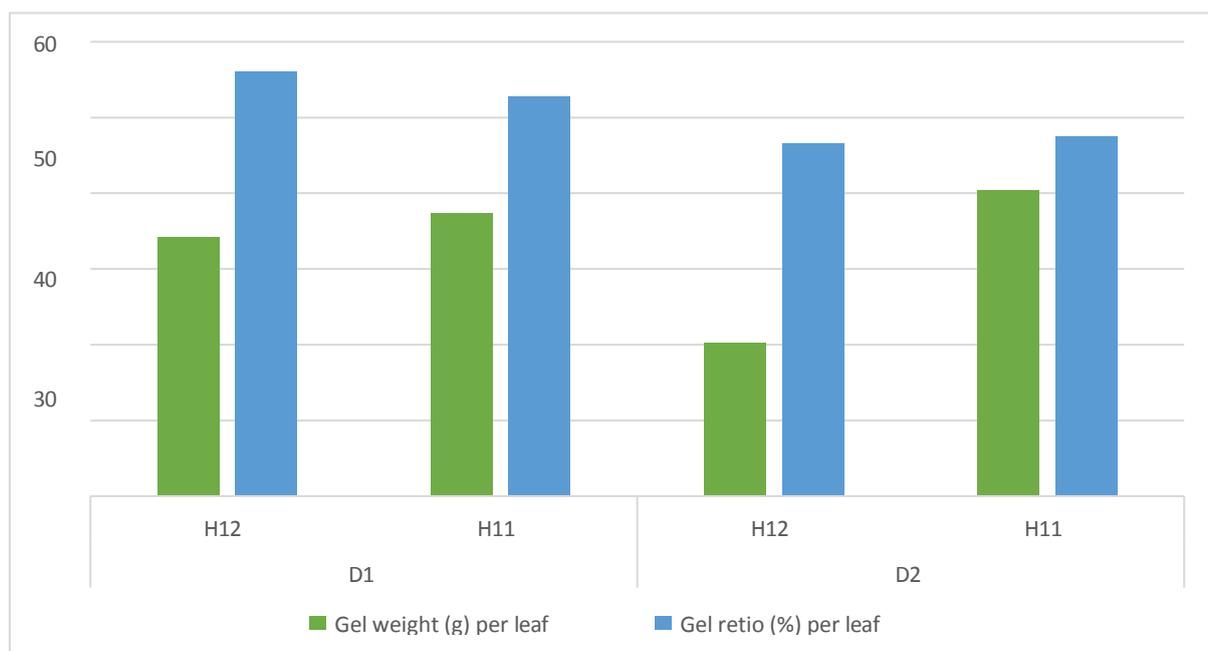


Figure 1. Influence of planting date and harvesting time on gel traits of *Aloe vera* leaves

*Planting Date (D1=July; D2=August); Harvesting time (H11 = Harvested after 11 months, H12= Harvested after 12 months)

3.3. Influence of propagule size on growth, yield and propagation traits of *Aloe vera*

Vegetative growth and propagation were clearly impacted by propagule size (table 2). In almost every parameter, including plant weight ($1005.72 \text{ g plant}^{-1}$), longest leaf (34.06 cm), widest leaf diameter (43.83 mm), thickest leaf (15.06 mm), leaf fresh weight (85.69 g), and propagule production (2.50 plant^{-1}), large propagules (L) had the

highest values. Small propagules produced only $0.75 \text{ propagules plant}^{-1}$, while, medium (M) and small (S) propagules performed progressively worse.

These results support previous research showing that larger suckers or explants offer better early vigor, improved rooting, and improved survival, all of which lead to increased productivity [4, 5, 16, 17].

Table 2. Influence of propagule size on growth, yield and propagation traits of *Aloe vera*

Propagule size	Plant Parameters						
	Plant fresh weight (g)	Number of leaves per plant	Leaf length (cm)	Leaf width (mm)	Leaf thickness (mm)	Leaf fresh weight (g)	Number of propagules (propagules/plant ⁻¹)
L	1005.72 a	11.92 a	34.06 a	43.83 a	15.06 a	85.69 a	2.50 a
M	639.71 b	10.83 b	31.19 b	37.88 b	12.34 b	61.07 b	1.92 a
S	381.97 c	8.58 c	26.52 c	31.38 c	10.89 c	46.93 c	0.75 b

*Different letters within a column indicate significant differences according to DMRT at $p < .05$.

**Large size of Propagules: L; Medium size of propagules: M; Small size of propagules: S

3.4. Influence of propagule size on gel traits of *Aloe vera* leaves

Figure (2) indicates that propagule size has an influence on gel weight but not on the gel ratio. This means that there is an increase in biomass accumulation with increase in propagule size unlike gel concentration which remain constant. The largest propagule's gel weight (45.42 g) indicates that greater initial weight and root vigor improves the water uptake and metabolism which in turn enhances the gel accumulation [4-6, 16]. This is in contrast to gel ratio concentration when propagule size becomes static suggesting gel concentration is genetically or physiologically set [1, 17]. The findings of [16] corroborate this, wherein an increase in size of suckers resulted in an increase in the absolute yield but the gel proportion within the leaf remained static. This constant gel ratio is in support of the findings of [18] and [19], which indicates that propagule size has no effect on the changes in environmental and physiological gel

stability.

Consequently, as with any benefits derived from increased propagule size, with respect to overall gel yield, rather than changes in gel concentration efficiency, are pertinent to the gel yield from derived from Aloe Vera under semi-arid conditions [7, 22].

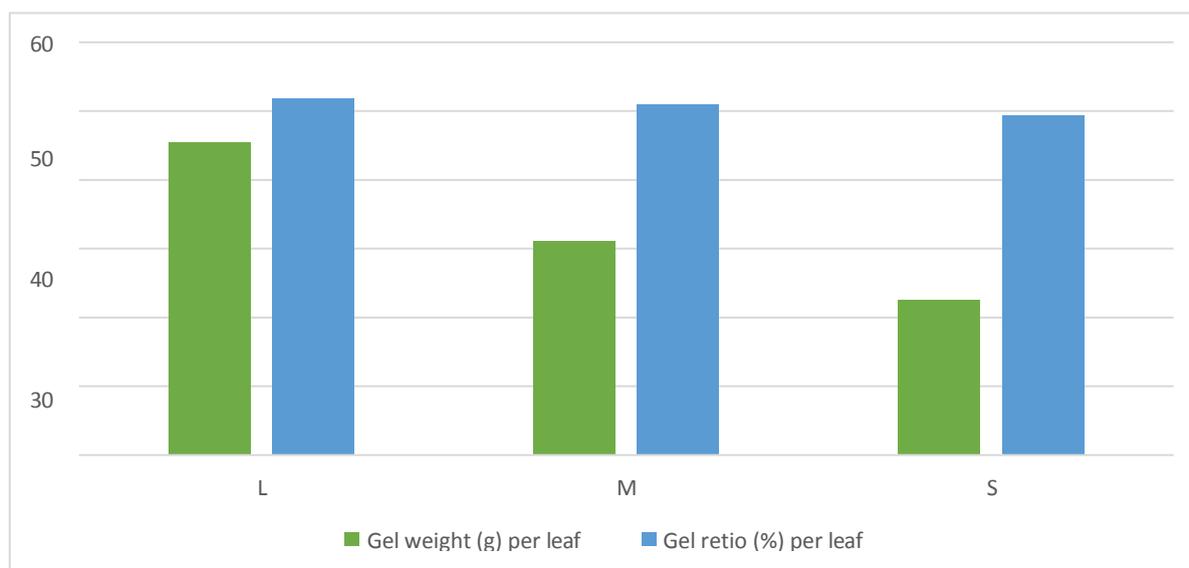


Figure 2. Influence of propagule size on gel traits of *Aloe vera* leaves.

*Large size of Propagules: L; Medium size of propagules: M; Small size of propagules: S

3.5. Combined influences between planting date, harvesting time, and propagule size on growth, yield and propagation traits of *Aloe vera*

As demonstrated in table (3), there appeared to be relationships between size of the propagules and the date the propagules were planted to the date they were harvested. In treatment D1H11L, the heaviest plant (1390.03 g), widest leaves (55.73 mm), and highest number of leaves per plant (13.33), along with the thickest leaves (18.87 mm), and leaves fresh weight (107.50 g) were produced in comparison to treatment D2H11L which there were no significant differences with (D1H11M) treatment. However, the longest leaves (40.47 cm) were produced by (D2H11M). in the other hand, the (D1H12M) treatment produced the greatest number of propagules per plant. Also, D2H11L succeeded with leaf weight (1143.20 g plant⁻¹), still low propagule production (0.33 plant⁻¹).

The treatment D2H12S did markedly worse, yielding no propagules and

lowest leaf weight (240.20 g). This finding illustrates the planting season and the vigor of the propagules work in combination and have a significant effect on the efficiency of multiplication. The authors [5] mention the optimum environment for selecting robust propagules is one of the critical factors for the proven success of aloe propagation. The fact that propagule production during July plantings is greater suggests that the establishment climate for the early part of the season has a residual effect on subsequent vegetative multiplication [1]. This shows the relationship between propagule vigor, and the timing for planting propagules and supports the contention that strong propagules perform best when planted during the most appropriate season [16] Augments the theory that the timing, and size of the planting propagule is essential for maximization of the conversion efficiency of the propagule to plant to productivity per unit area of the best planting date.

The most important factors for irrigation were paired with propagule size and planting time which enhanced productivity even more through complementary agronomic techniques.

The authors claim that irrigation scheduling, organic additions, and nutrient optimization can significantly affect growth, gel yield, and propagule

Table 3. Combined influences between the date of planting, the time of harvesting, and size of propagules on the growth, yield and propagation traits of *Aloe vera*

production [9-11, 20, 22]. In addition, the combination of field-based techniques and tissue-culture techniques provides the most advanced method for satisfying the growing industrial need due to the associated drawbacks of vegetative propagation [12-15].

Planting date	Harvesting time	Propagule size	Plant Parameters						
			plant fresh weight (g)	Number of leaves per plant	Leaf length (cm)	Leaf width (mm)	Leaf thickness (mm)	Leaf fresh weight (g)	Number of propagules (propagules plant ⁻¹)
D1	H12	L	954.27 c	11.00 bcd	34.07 c	43.98 b	15.39 b	93.67 b	4.33 b
		M	576.07 e	10.00 ed	30.40 ef	39.34 c	12.02 c	56.70 e	6.33 a
		S	273.10 g	7.67 f	20.40 i	26.69 e	10.79 cde	30.87 i	2.00 c
	H11	L	1390.03 a	11.67 bc	37.47 b	55.73 a	14.82 b	91.20 b	5.33 ab
		M	941.40 c	12.33 ab	31.40 de	39.93 bc	10.59 cde	65.53 d	1.33 cd

		S	334.8 7 f	8.33 f	29.17 fg	33.5 5 d	11.11 cd	56.3 7 e	1.00 cd
D2	H12	L	535.3 7 e	11.67 bc	28.00 g	32.4 0 d	11.15 cd	50.4 0 f	0.00 d
		M	335.2 7 f	8.67 ef	22.50 h	31.9 4 d	9.75 de	45.6 3 g	0.00 d
		S	240.2 0 g	7.67 f	23.80 h	25.4 4 e	9.14.e	35.0 7 h	0.00 d
	H11	L	1143. 20 b	13.33 a	36.70 b	43.2 0 bc	18.87 a	107. 50 a	0.33 d
		M	706.1 0 d	12.33 ab	40.47 .a	40.3 3 bc	11.20 cd	76.4 0 c	0.00 d
		S	679.7 0 d	10.67 cd	32.70 cd	39.8 4 bc	18.33 a	65.4 3 d	0.00 d

. *Different letters within a column indicate significant differences according to DMRT at $p < .05$.

**Planting Date (D1=July; D2=August); Harvesting time (H11 = Harvested after 11 months, H12= Harvested after 12 months); Large size of Propagules: L; Medium size of propagules: M; Small size of propagules: S

3.6. Combined influences between planting date, harvesting time, and propagule size on gel traits of Aloe

Vera leaves

Figure (3) demonstrates the impact of the planting and harvesting schedule

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along with the size of the propagules and how they correlate with the gel yield and gel ratio. The data collected shows that the most abundant yield of gel produced came from treatment D2H11L (57.50 g) and treatment D1H12L. Hence, treatment D2H11L was not statistically different from treatment D1H12L. These results imply that the larger the propagules, the greater the energy and storability along with added vigorous traits, promoting gel accumulation [4-6]. The treatment D1H12L (59.56%) where a D1H12L (59.56%) gel ratio was recorded suggests the statistical proximity of D1H11M supports the notion that photosynthesis active and gel forming periods improve with greater growth

periods. The results also coincide with [7,8] who claimed that improved harvest intervals allowed for improved gel content and greater gel maturity.

Furthermore, the data obtained from the wide base propagules supports the findings of other authors regarding the propagule size, initial establishment, leaf thickness, and gel yield [6, 16]. It is also supported that the combination of abundant propagules and the appropriate season dictates planting dates optimizes the yield, and also enhances the concentration of the gel, which further multiplies the importance of the timing and technique of cultivation for Aloe Vera gel extraction [1, 22].

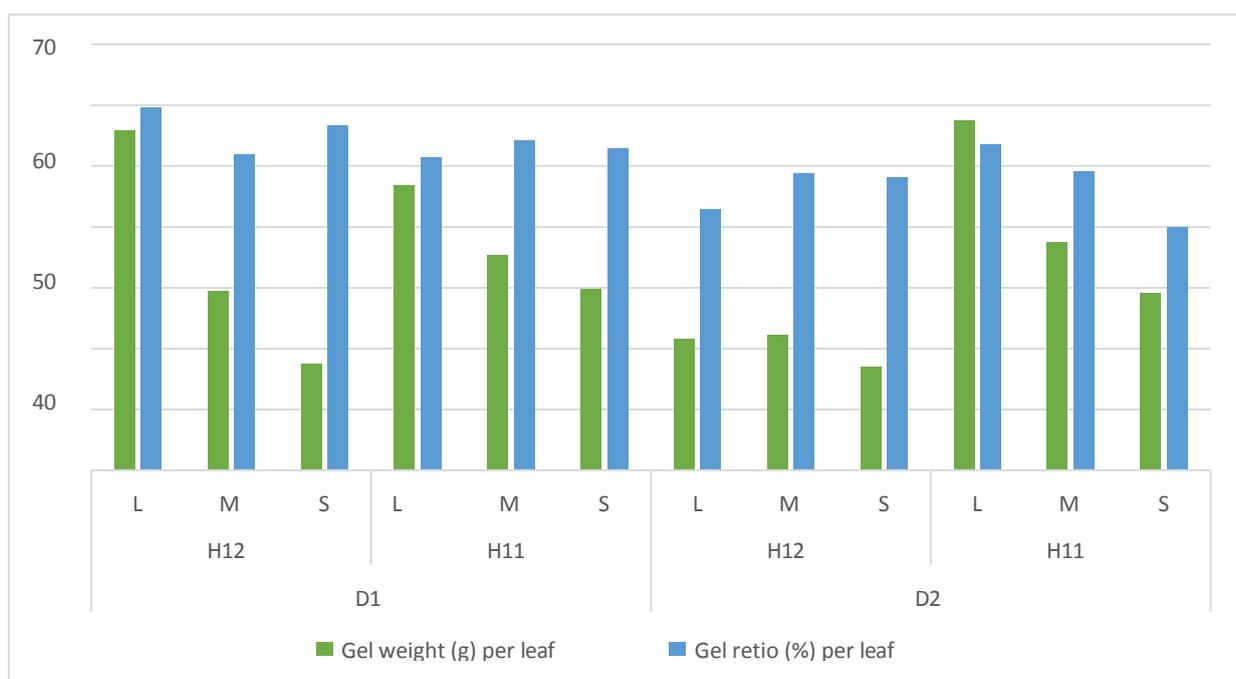


Figure 3. Combined influences between planting date, harvesting time, and propagule size on gel traits of Aloe Vera leaves

*Planting Date (D1=July; D2=August); Harvesting time (H11 = Harvested after 11 months, H12= Harvested after 12 months); Large size of Propagules: L; Medium size of propagules: M; Small size of propagules: S

4. Conclusions

Based on the present study, planting time and interval of harvesting can affect both

vegetative capability and yield attributes in response to *Aloe vera* gel productivity. Means for number of leaves per plant, leaf length (cm), leaf width (mm), leaf thickness (mm), leaf fresh weight (g) and gel ratio (%) for plants grown from August to July (D2H11) were always higher than corresponding means among the other treatments except for plant fresh weight (g) and leaf width (mm) that the treatment D1H11 gave the maximum means. Whereas D1H12 recorded the highest numbers of propagules per plant and greatest gel biomass (g). These conditions seem to offer an ideal combination of light, temperature and seasonality stability that leads to biomass accumulation and vigorous vegetative growth. In contrast, August plantings D2H12 performed more poorly overall and particularly where harvest interval was longer, suggesting a smaller gap of opportunity for establishment success in late summer.

Propagule size influenced growth and gel yield equally. Large propagules showed clear benefits in all characters measured, including all studied parameters as mentioned above owing to their larger initial vigor and more efficient resource capture. Gel yield was promoted by propagule growth but the gel ratio was not appreciably affected, indicating that the concentration is controlled by inherent physiological mechanisms rather than species stature.

The combined effects of propagule size, planting date, and harvesting time were noticeably more pronounced. Large propagules that were planted in July and harvested after 11 months of planting D1H11L produced the highest biomass, the most leaves number, widest leaves, thickest leaves and heaviest leaves fresh weight. While; the highest gel ratio was obtained from (D1H11 L and D2H11L). Conversely, small propagules planted near the end of the season D2H12S performed the worst and produced the least amount of offshoots.

These interactions highlight the necessity to match propagule vigor with ideal seasonal planting periods and sufficient growth duration in order to optimize *Aloe vera* yield. Overall, the findings demonstrate the importance of combining appropriate propagule selection with agronomic scheduling to enhance gel formation and vegetative multiplication in semi-arid conditions. Properly coordinating planting season, propagule size, and harvest time provides a helpful basis for improving commercial *Aloe vera* culture and ensuring consistent, high-quality production.

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