Studies on Agricultural Utilization of Sand Dunes of South Kuwait through Soil Reclamation

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Abstract
Southern part of the Kuwait contains extensive mobile and semi-stabilized sand deposits whose coarse texture, low water retention and weak nutrient reserve constrain agricultural use. low soil organic matter and limited freshwater availability dominated by arid to hyper-arid desert conditions This study assessed the reclamation potential of dune sand amended with mixed cow-camel dung. Where two plant species selected based on their properties of short-duration vegetable crop and Aloe vera (Aloe barbadensis Miller) as a drought-adapted succulent medicinal crop and Three sand: manure mixtures of each plant were tested: 50:50 (T1/A1), 60:40 (T2/A2) and 70:30 (T3/A3). Tomato was monitored first followed by Aloe vera plant due to area constrains for experimental setup. The field experiment set up used replicated plants within three rows per treatment; measurements included shoot/stem height, stem diameter, leaf count, leaf appearance, tomato fruiting, and Aloe vera offsets for leaf count, leaf size, appearance for sap content and baby plant counts offsets production, field observations were analyzed by treatment-level means, changes over time, and comparative performance against controls where available. Soil pH and water-holding capacity were also recorded for the mixture amendments and without Amendment, a lowering in pH from 7.8 to 6.2-7.2, recorded in other hand water-holding capacity raised from 5-7% to 10-30%. Tomato growth improved under all treatments, results indicated the earliest recorded fruit appearance under the 70:30 mixture, while the 60:40 mixture produced the most consistently vigorous early vegetative growth. Aloe vera in the 70:30 mixture showed the strongest mean height (405.0 mm), mean stem diameter (54.0 mm), mean leaf number (15.0) and mean offsets (18.5), exceeding the control. The study recommends a 70:30 dune sand: well-composted cow-camel dung blend for Aloe vera establishment and a 60:40 blend as a more conservative starting medium for tomato, subject to irrigation, salinity and nutrient monitoring. This research results support the feasibility of using locally available organic manure of cow-camel dung to reclaim sandy dune substrates for selected crops, which will be economically feasible too, in future trials salinity monitoring, and long-term soil-quality assessment to be integrated

Keywords: Southern part of Kuwait; sand-dune reclamation; sustainable arid agriculture; organic manure; cow dung; camel dung; sandy soil; tomato; Aloe vera

1. Introduction

Kuwait is an arid country in which wind erosion, sparse vegetation and repeated surface disturbance have made moving sand a persistent environmental and land-use problem. Sand sheets, nebkhas and dunes occur in coastal and inland settings; their movement can affect infrastructure, settlements and agricultural areas. Earlier work on Kuwait links desertification to loss of vegetation, wind erosion and the conversion of relatively stable sandy surfaces into active dunes (Khalaf, 1989). Remote-sensing studies further show that multi-date Landsat imagery can delineate dune fields and identify major changes in dune distribution and formation (Al-Dousari et al., 1997). These findings establish that dune management is not only a hazard-control issue but also a land-restoration question. Agricultural production in Kuwait faces a combination of environmental constraints that are typical of the northern Arabian Peninsula: extreme summer heat, sparse and irregular rainfall, strong winds, highly evaporative conditions, and soils that are generally coarse textured and low in organic matter.. These limitations are especially pronounced in active or semi-active sand-dune areas, where surface materials are loose, poorly aggregated, and commonly unsuitable for direct cultivation without amendment.

Sand dunes in Kuwait are not merely barren landforms. They represent a large and dynamic land resource that intersects with infrastructure protection, dust-storm mitigation, land rehabilitation, and food-security planning. Published work on Kuwait dune geomorphology reports that sand dunes and sand sheets occupy a substantial portion of the country, and that dune mobility can affect agriculture, roads, settlements, and industrial facilities. The South Kuwait setting therefore presents a practical research question: can organic amendment convert sand-dune soil from a physically unstable, nutrient-poor substrate into a root medium capable of supporting useful crops?

Agricultural utilization of dune sand is challenging because the material is dominated by large particles with limited specific surface area. Such substrates commonly drain rapidly, retain little plant-available water, contain little organic carbon and have low capacity to retain nutrients. In south Kuwait, high evaporative demand, saline or limited irrigation water and strong winds further intensify these limitations. A reclamation approach must therefore improve the rooting medium while avoiding excessive salinity, nutrient loss, odor, pathogens and groundwater contamination (Rahil Ayaz, et al., 2026).

Soil reclamation in arid lands usually requires simultaneous improvement of physical, chemical, and biological soil properties. Sandy soils often drain rapidly and retain few nutrients because they contain limited fine particles and organic matter. Organic manure is a practical local amendment because it can add carbon, nutrients and biologically active material while improving pore connectivity and water storage. Recent controlled work confirms that organic fertilizers can increase soil organic carbon, available water and tomato root development in sandy soils (Rahman & Widjajanto, 2024). Yet amendment responses are not automatically positive: manure type, maturity, dose, electrical conductivity and irrigation management determine whether an amendment supports or delays crop growth. The use of locally available cow and camel dung offers a circular option for Kuwait, but the mixture must be evaluated against crop response and basic soil indicators rather than assumed to be beneficial at every proportion. Animal manures and composted organic residues can provide carbon, nitrogen, phosphorus, potassium, micronutrients, and microbial substrates. When incorporated into sandy soil, organic manure may improve aggregation and increase the capacity of the soil matrix to retain water and nutrients in the root zone. The present study focuses on cow-camel dung organic manure as a locally relevant reclamation amendment. Livestock manure is of particular interest in Kuwait and the wider Gulf region because it is available as an organic by-product and can be integrated into circular land-management systems. Cow and camel dung can contribute organic carbon and nutrients while improving the physical condition of sand-dune soil. However, the optimal sand-to-manure ratio may differ by crop. A mixture with too little organic matter may not improve the substrate sufficiently, while a mixture with too much manure may influence salinity, aeration, or nutrient balance. Testing different ratios is therefore essential.

This paper interprets a supplied set of field observations on tomato and Aloe vera grown in dune sand amended with cow-camel dung. It combines those observations with a survey-and-mapping framework appropriate for geomorphologic characterization. The aim is not to claim a regional production standard from a single field experiment; rather, it is to identify a defensible composition for follow-up trials and improved agricultural practice in south Kuwait.

Tomato was selected as a test vegetable crop because it responds strongly to soil fertility, water availability, and root-zone conditions. Its stem growth, leaf production, and fruiting provide useful indicators of amendment response over a relatively short period. Aloe vera was selected as a second test plant because it is drought tolerant, has succulent leaves, uses crassulacean acid metabolism, and is widely recognized as suitable for arid and semi-arid regions when drainage is adequate. Aloe also produces vegetative offsets, making baby-plant production a practical indicator of vigor and reproductive performance.

Literature Review:

Sand dunes, desertification and land-use planning in Kuwait:

Kuwait's aeolian landscape reflects both regional sediment supply and local surface disturbance. Khalaf (1989) described active aeolian processes in Kuwait and recognized degradation through vegetation decline, wind erosion and increasing mobile sand activity. More recent synthesis work reports thousands of dunes distributed across several dune fields and emphasizes the need to distinguish mobile-sand belts in land-use planning (Al-Dousari et al., 2022). The implication for agricultural reclamation is clear: agricultural plots should be selected on stable or controllable dune margins, not placed where active migration or sand encroachment will continuously bury seedlings and irrigation infrastructure.

A practical survey begins with satellite-image interpretation, field verification and a geomorphologic map. Field traverses should then verify landform type, crest and slip-face orientation, vegetation cover, surface crust, erosion features and evidence of sand accumulation. For each prospective plot, slope, access, irrigation source, wind exposure, depth to any restrictive layer and proximity to contamination must be documented. This spatially explicit approach connects the amendment experiment to a scale at which land managers can make safe decisions.

Water scarcity for Agriculture purpose and sand-dune landscapes in Kuwait:

Water scarcity is a central constraint on agriculture in arid regions. FAO describes water scarcity as a major twenty-first-century challenge affecting agricultural and food systems, and its Global Framework on Water Scarcity in Agriculture promotes coordinated and evidence-based responses to improve water use. This context is highly relevant to Kuwait, where crop production must be planned around limited freshwater availability, treated wastewater use, brackish-water management, and efficient irrigation.

Kuwait dune systems are shaped by wind, sediment supply, and sparse vegetation. Published studies describe Kuwait as an arid to hyper-arid desert environment in which Al-Shamal winds contribute to erosion, deposition, and sand-dune migration. A 2025 remote-sensing study of Jal Al-Liyah reported dramatic dune changes and migration rates ranging from 4 to 60 m per year, showing that dune mobility is an active land-management issue. Dune materials in Kuwait are reported to include quartz and carbonate sands, with mineral composition influencing mobility and stability. These conditions make sand-dune reclamation both a land-utilization opportunity and an environmental-management challenge.

Sandy Soils Organic Amendments:

The primary reclamation function of organic matter in coarse sand is physical as well as nutritional. Organic materials improve aggregation, increase water retention and add sites capable of holding nutrients. In a tomato study on sandy loam, organic fertilizer significantly improved organic carbon, bulk density, hydraulic conductivity and soil-water availability, with improved root traits linked to increased organic carbon (Rahman & Widjajanto, 2024). A separate tomato experiment found that manure-derived amendments increased soil porosity and water-holding capacity, though crop vigor varied by amendment type and maturation (Miller et al., 2021). Thus, a field recommendation should use matured, pathogen-managed manure and be coupled with periodic testing.

Cow manure is widely used in arid agriculture, while camel dung is particularly relevant where dromedary husbandry is common. Their nutrient contents differ by feed, bedding, storage and composting method. Fresh manure can contain readily mineralizable nitrogen and soluble salts; poorly matured material can cause ammonia injury, weed introduction and excessive oxygen demand. Composting before application reduces these risks and supports a more predictable release pattern. The manure used in the present field observations was described as a natural fertilizer or organic manure mixture; its exact nutrient, EC and maturity status were not supplied and should be measured before scale-up.

Organic matter as a foundation of sandy-soil reclamation :

The FAO soil organic matter bulletin emphasizes that organic matter affects soil structure, porosity, water infiltration, moisture-holding capacity, biological activity, and plant nutrient availability. This is especially important for sandy substrates because coarse-textured soils have weak nutrient-retention capacity and low water-holding capacity. Organic matter can act as a revolving nutrient fund, retain nutrients in plant-available forms, and support microbial processes that mineralize nitrogen, phosphorus, and sulfur.

Sandy soils are difficult to reclaim because organic additions can decompose rapidly under warm, well-aerated conditions. However, repeated amendment can build active organic matter, increase microbial activity, improve aggregation, and reduce the speed at which water and soluble nutrients move below the root zone. Animal manure and compost are therefore common reclamation inputs. In addition to nutrients, manure contributes organic carbon that can support microbial communities and improve physical properties. For dune soils, these improvements are directly relevant because root systems need a stable and moist zone for establishment.

Aloe vera provides a complementary test because it is a drought-adapted perennial succulent with lower irrigation demand after establishment and propagates through offsets. Its leaf appearance, plant size and number of baby plants are relevant indicators of establishment and multiplication. In amended sand, an Aloe response can reveal whether the substrate remains sufficiently aerated while retaining enough moisture. The contrast between the annual tomato trial and the longer Aloe trial is valuable: a formulation that produces early annual growth may not be the formulation that best supports perennial clonal expansion.

Tomato growth with Organic manure amendments

Tomato is sensitive to soil fertility and water status, making it a useful biological indicator for reclamation trials. Published research on tomato soil amendments has shown that organic and inorganic amendments can increase plant height, stem girth, leaf production, fruit number, yield, and post-cropping soil quality compared with untreated controls. A 2022 study reported that soil amendments increased tomato growth and yield and that organic amendments such as poultry manure and biochar-based products improved physical and chemical soil properties. However, its production in desert soils requires regular irrigation, salinity control and nutrient management. High organic input can improve water retention but can also create nutrient imbalance if amendment quality is inconsistent. Therefore, tomato height and fruit appearance are early performance indicators, not a substitute for marketable yield mass and fruit-quality measurements.

Cow dung and other animal manures can supply nutrients and improve vegetative vigor in tomato. However, Tomato has a high nutrient demand and a short growth cycle, so the timing of nutrient release is important. Manure-based treatments may perform well when decomposition is sufficient to release available nutrients, but excessive or immature manure could produce salinity or nutrient-imbalance effects. For this reason, treatment ratios must be evaluated empirically under local conditions rather than assumed from general fertilizer recommendations.

Aloe vera adaptation to arid reclaimed soils with organic amendments:

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Aloe vera is an economically important succulent plant cultivated in warm climates for medicinal, cosmetic, and food-related uses. A major review in Frontiers in Plant Science notes that Aloe can be cultivated in arid and semi-arid areas because of its drought resistance, succulence, and crassulacean acid metabolism. The same review emphasizes that good drainage is necessary to prevent waterlogging and root diseases, which is important when organic amendments are added to sandy substrates.

Organic manure has specific relevance to Aloe vera. The review cited experimental evidence that a 50% cow dung plus 50% soil treatment increased Aloe leaf number and total leaf weight compared with 100% soil in pot culture, and that compost-based manure increased leaves and gel yield as manure dose increased in an arid-zone study. These findings support the use of organic manure in Aloe production, but they also show that the response depends on substrate, drainage, amendment dose, and water management. Aloe offset production is a particularly useful indicator because vegetative propagation by suckers is a standard production route.

Sustainable desert agriculture and reclamation implications:
Sustainable desert agriculture requires more than plant survival. It requires stable soil cover, efficient irrigation, salinity monitoring, organic-matter maintenance, wind protection, and crop selection suited to arid conditions. The literature on Kuwait dune management highlights the need for sustainable management plans to alleviate dune hazards, while arid agriculture literature emphasizes the role of organic matter, crop residues, and biological activity in building soil resilience. Reclamation trials such as the present experiment are therefore important first steps toward determining which crop-amendment combinations are practical for South Kuwait sand dunes.

A two-crop approach strengthens interpretation. Tomato tests whether amended dune sand can support a nutrient-demanding vegetable crop with fruiting potential, while Aloe vera tests whether the same reclamation concept can support a drought-adapted, longer-duration crop. Together, these species provide evidence for both food-crop and industrial/medicinal-crop possibilities in reclaimed sandy land.

2. Methodology :

The study was designed as a comparative plant-growth experiment using reclaimed sand-dune soil amended with cow-camel dung organic manure. The treatment ratios were defined as sand-dune soil : organic manure. For Tomato, the treatments were T1 = 50:50, T2 = 60:40, and T3 = 70:30. For Aloe vera, equivalent treatments were A1 = 50:50, A2 = 60:40, and A3 = 70:30. Control plants were recorded for Tomato & Aloe vera and were used as an untreated or reference comparison in the analysis.

Each treatment contained repeated observations for individual plants within rows and replicates. Tomato observations were recorded and observation records maintained if forms of readings data. Aloe vera observations were also recorded. The monitoring periods therefore captured early establishment, vegetative development, and reproductive or propagation responses.

Measured Tomato variables included stem height (cm), stem diameter (mm), leaf count, leaf conductivity where recorded, fruit status or count, and remarks. Measured Aloe vera variables included plant height (mm), stem or base diameter (mm), leaf count, plant appearance, remarks, and baby-plant count at the later observations. Conductivity was recorded for Tomato leaves and therefore analyzed for that crop.

The primary data analysis consisted of treatment-level descriptive statistics. For each observation date and treatment, the mean, standard deviation, and relevant totals were calculated. Growth gain was calculated from the first observation to the final observation for height and diameter. Fruit count was summarized for Tomato in the final fruiting table, and baby-plant production was summarized for Aloe vera. Missing numerical values were excluded from means. Where fruit cells were blank in the final Tomato fruit-count table, they were interpreted as zero because the column represented fruit count/status and blank entries indicated no recorded fruit.

The study used descriptive comparison rather than formal inferential statistics because the experiment was based on supplied field notes with limited replication, missing values, and non-uniform measurement frequency. The results are therefore interpreted as treatment-level trends rather than statistically conclusive yield estimates. The conclusions identify promising treatment combinations for further controlled trials.

The experiment evaluated dune sand mixed with cow-camel dung at three volume-based compositions. For tomato, treatments were designated T1 (50:50), T2 (60:40) and T3 (70:30); for Aloe vera, A1, A2 and A3 used the corresponding proportions. In this paper, the notation is interpreted as dune sand:organic manure, consistent with the supplied soil table in which a greater dung fraction corresponded to lower pH and higher water-holding capacity. Each treatment was represented by three row/replicate labels and two plant-level observations per label, giving 18 plants per crop per observation date. Three control Aloe plants were recorded; tomato controls were not reported with complete measurements.

Experimental treatment design :

Table 1.Tomato and Aloe vera Soil: Manure treatment structure

Plant Species	**Treatment Ratio**	**Sand-dune soil : organic manure**	**Soil : Cow-camel dung portion (Kg)**	**Parameters /variables response**
Tomato	T1	50:50	2.5+2.5=5	Height, diameter, leaves, conductivity, fruiting
	T2	60:40	3.0+2.0=5	Height, diameter, leaves, conductivity, fruiting
	T3	70:30	3.5+1.5=5	Height, diameter, leaves,

				conductivity, fruiting
Aloe vera	A1	50:50	2.5+2.5=5	Height, diameter, leaves, appearance, offsets
	A2	60:40	3.0+2.0=5	Height, diameter, leaves, appearance, offsets
	A3	70:30	3.5+1.5=5	Height, diameter, leaves, appearance, offsets
Tomato / Aloe vera	Control	Reference plants	2.5+2.5=5	Height, diameter, leaves, appearance, offsets

3. Results & Discussion :

Tomato growth response:

Tomato plants established successfully in all three reclaimed sand-dune mixtures. At the first observation on beginning of the month, mean height ranged from 11.83 cm in T1 to 14.67 cm in T2, with T3 intermediate at 13.17 cm. By end of the respective month, all treatments showed rapid growth, and mean heights increased to 21.00 cm in T1, 25.67 cm in T2, and 25.00 cm in T3. The early response indicates that incorporation of organic manure created a root environment capable of supporting initial Tomato vegetative development in dune sand.

By next consecutive month, the vegetative differences among treatments became clearer. T2 reached the highest mean stem height (66.00 cm), closely followed by T3 (64.67 cm), while T1 remained lower at 42.67 cm. Stem diameter also increased in all treatments, with T3 showing the highest mean diameter on 7 January (7.53 mm), followed by T2 (6.70 mm) and T1 (6.32 mm). Fruit appearance was first clearly recorded in T3R2 plants on 7 January, where fruit counts of three fruits per plant were noted. This early fruiting in T3 suggests that the 70:30 sand-to-manure mixture supported a favorable balance between vegetative growth and reproductive transition.

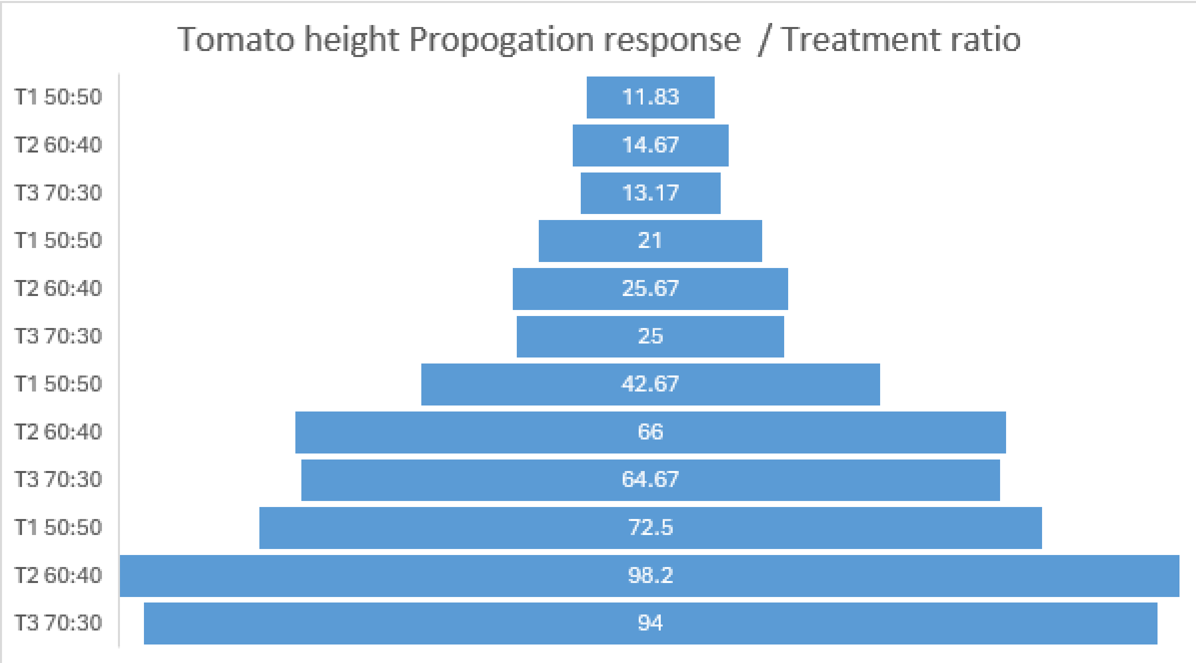
At the final observation, T2 recorded the highest mean height (98.2 cm), followed by T3 (94.0 cm) and T1 (72.5 cm). The ranking shows that the 60:40 treatment was most favorable for vegetative height, while T3 remained close in overall biomass development. The final fruit data showed a different ranking: T3 produced the highest total fruit count (67 fruits; 11.17 fruits per plant), followed by T2 (34 fruits; 5.67 fruits per plant) and T1 (15 fruits; 2.50 fruits per plant). Therefore, the best Tomato treatment depends on the target indicator. T2 was best for vegetative height, but T3 was clearly best for fruiting response.

This divergence between vegetative and reproductive performance is agronomically meaningful. A higher manure proportion may support vegetative growth, but under arid sandy conditions, a slightly sandier mixture may improve aeration and drainage while still retaining enough organic matter to supply nutrients. T3 may therefore have provided a more balanced root-zone environment for reproductive development. This interpretation is consistent with the literature showing that soil amendments improve Tomato growth and yield, while also emphasizing that nutrient release and physical root-zone conditions influence yield components differently.

Table 2. Treatment level summary corresponding observation date

Reading Date	Treatment Ratio	Mean height (cm)	Mean diameter (cm)	Mean leaves	Mean conductivity (µS/cm)	Fruit Counts
2 Dec 2023	T1 50:50	11.83	0.332	21.00	575	0
2 Dec 2023	T2 60:40	14.67	0.402	23.00	475	0
2 Dec 2023	T3 70:30	13.17	0.363	24.00	625	0
13 Dec 2023	T1 50:50	21.00	0.437	26.50	625	0
13 Dec 2023	T2 60:40	25.67	0.500	28.67	575	0
13 Dec 2023	T3 70:30	25.00	0.473	30.17	600	0
7 Jan 2024	T1 50:50	42.67	0.632	-	-	0
7 Jan	T2 60:40	66.00	0.67	-	-	0

2024							
7 Jan 2024	T3 70:30	64.67	0.753	-	-	6
Final date	T1 50:50	72.50	0.854	-	-	15
Final date	T2 60:40	98.20	0.917	-	-	34
Final date	T3 70:30	94.00	0.797	-	-	67



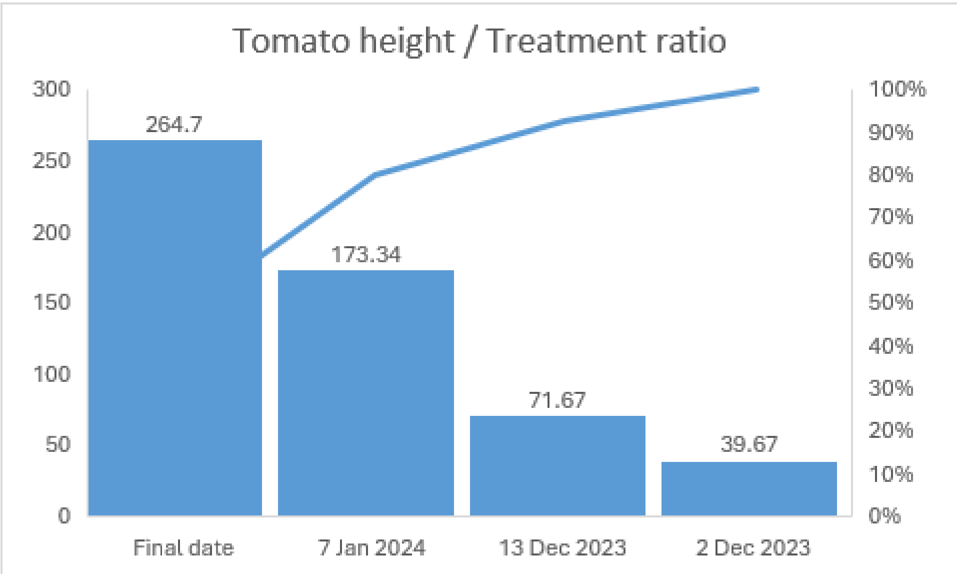


Table 3. Tomato initial-to-final growth propogation.

Treatment Ratio	Initial height (cm)	Final height (cm)	Height gain (cm)	Height gain (%)	Initial diameter (cm)	Final diameter (cm)	Final fruits/plant
T1 50:50	11.83	72.50	60.67	512.68	0.332	0.854	2.50
T2 60:40	14.67	98.20	83.53	569.55	0.402	0.917	5.67
T3 70:30	13.17	94.00	80.83	613.92	0.363	0.797	11.17

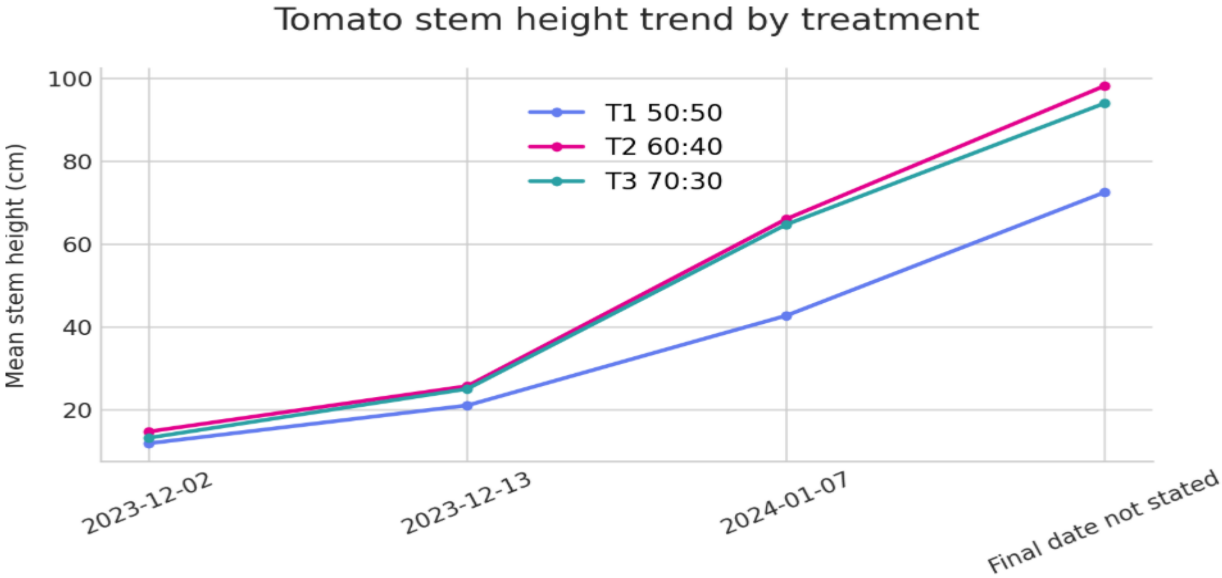


Figure 1. Tomato mean stem-height trend by treatment.

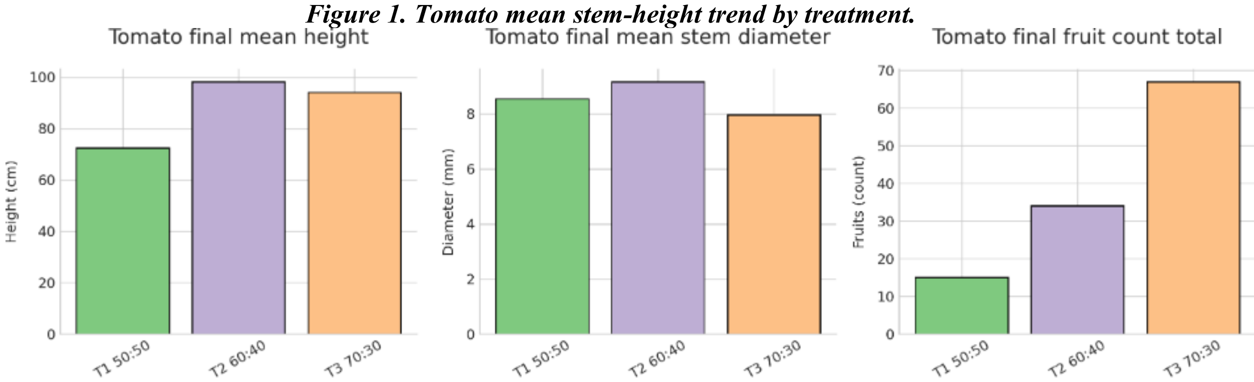


Figure 2. Tomato final treatment performance for height, stem diameter, and fruit count.

Tomato leaf conductivity and environmental remarks :

Tomato conductivity readings were randomly done only for selected from each set of treatment plants (T1/T2/T3) during the plant growth observations, mean recorded conductivity values were 575 µS/cm for T1, 475 µS/cm for T2, and 625 µS/cm for T3. and recorded values were 625 µS/cm for T1, 575 µS/cm for T2, and 600 µS/cm for T3. The data do not show an obvious treatment-specific stress pattern therefore readings were limited to two plants per treatment and not consistently repeated across all sampling dates.

Aloe vera growth response :

Aloe vera responded strongly to organic amendment in all reclaimed dune-soil treatments. At the initial observation, mean plant height was similar among A1, A2, and A3, ranging from 39.0 to 42.17 mm. Control plants averaged 35.0 mm. By 3 month later, all amended treatments greatly exceeded the control in height. A3 had the highest mean height (201.33 mm), followed by A2 (191.33 mm) and A1 (182.50 mm), compared with 129.33 mm in the control. A3 also recorded the highest diameter (22.00 mm) and the highest green-appearance percentage (83.33%) at this stage.

After the 4 months observation showed a temporary shift in height ranking, with A1 recording the highest mean height (249.67 mm), A2 at 217.33 mm, and A3 at 201.33 mm. However, A3 maintained the greatest mean diameter (23.83 mm) and the highest mean leaf count (7.50). This suggests that A3 plants were developing greater structural mass and leaf-bearing capacity even when height alone did not show dominance. The control remained weaker, with only 134.0 mm mean height and a higher dry/dull percentage than the amended treatments.

After the 8 months, A3 became clearly superior across most growth and propagation indicators. Mean height reached 405.83 mm in A3, compared with 360.00 mm in A2, 320.00 mm in A1, and 208.33 mm in the control. Mean diameter was also highest in A3 (51.83 mm), compared with 40.50 mm in A2 and 36.83 mm in A1. A3 plants had 15.0 leaves per plant, 100 total baby plants, 16.67 baby plants per plant, and 100% fleshy appearance. The control produced only 4 total baby plants and showed 66.67% dry or dull appearance.

The final observation confirmed the superiority of A3. Final mean height was 405.0 mm in A3, 373.33 mm in A2, 348.33 mm in A1, and 226.67 mm in the control. Mean diameter was 54.0 mm in A3 compared with 42.0 mm in A2, 40.0 mm in A1, and 30.67 mm in the control. A3 also produced the highest mean leaf count (15.0) and the highest offset production, with 111 total baby plants and 18.50 offsets per plant. All amended treatments were 100% fleshy at final observation, whereas the control remained only 33.33% fleshy. These data indicate that organic manure amendment strongly improved Aloe vigor and that the 70:30 mixture was the best overall Aloe treatment.

Table 4. Summary of Aloe vera treatment-level corresponding observation date.

Date	Treatment R atio	Mean height (mm)	Mean diameter (mm)	Mean leaves	Baby plants / Offset total	Fleshy or green condition
5 May 2025	A1 50:50	39.00	10.17	6.00	-	green
5 May 2025	A2 60:40	41.50	10.33	5.50	-	green
5 May 2025	A3 70:30	42.17	12.00	7.00	-	Light green
5 May 2025	Control	35.00	7.67	10.67	-	Light green
5 Aug 2025	A1 50:50	182.50	18.33	9.67	-	60.0 % green
5 Aug 2025	A2 60:40	191.33	16.67	9.50	-	60.0 % green
5 Aug 2025	A3 70:30	201.33	22.00	8.50	-	80.0% green
5 Aug 2025	Control	129.33	18.00	8.00	-	60.0 % green
17 Sep 2025	A1 50:50	249.67	19.33	5.67	-	80.0% green
17 Sep 2025	A2 60:40	217.33	18.00	6.17	-	80.0% green
17 Sep 2025	A3 70:30	201.33	23.83	7.50	-	60.0 % green
17 Sep 2025	Control	134.00	22.67	5.33	-	30.0% green
11 Feb 2026	A1 50:50	320.00	36.83	8.83	38	60.0 % green fleshy
11 Feb 2026	A2 60:40	360.00	40.50	11.33	59	80% fleshy
11 Feb 2026	A3 70:30	405.83	51.83	15.00	100	100% fleshy
11 Feb 2026	Control	208.33	27.67	8.33	4	30.0% fleshy
24 Mar 2026	A1 50:50	348.33	40.00	9.50	40	100% fleshy
24 Mar 2026	A2 60:40	373.33	42.00	11.33	72	100% fleshy
24 Mar 2026	A3 70:30	405.00	54.00	15.00	111	100% fleshy
24 Mar 2026	Control	226.67	30.67	8.33	7	30.0% fleshy

Table 5. Aloe vera initial-to-final growth Propogation and offset response.

Treatment	Initial height (mm)	Final height (mm)	Height gain (%)	Initial diameter (mm)	Final diameter (mm)	Final leaves/plant	Final baby plants/plant	Final baby / Offset plants total
A1 50:50	39.00	348.33	793.16	10.17	40.00	9.50	6.50	40
A2 60:40	41.50	373.33	799.60	10.33	42.00	11.33	12.00	72
A3 70:30	42.17	405.00	860.47	12.00	54.00	15.00	18.50	111
Control	35.00	226.67	547.62	7.67	30.67	8.33	2.50	7

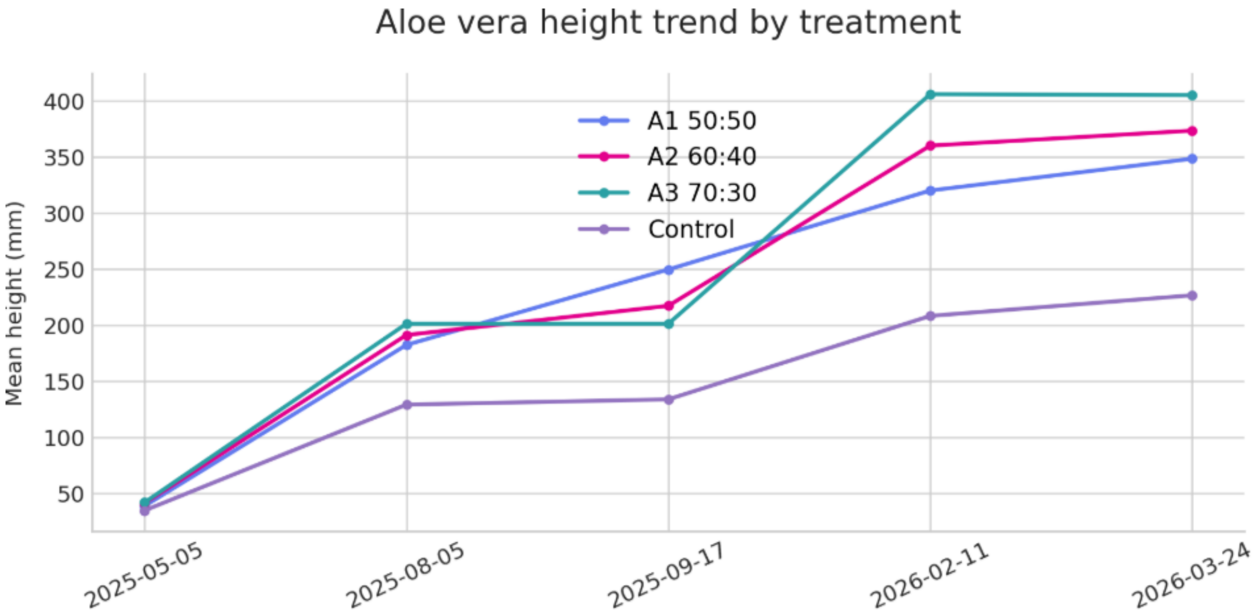


Figure 3. Aloe vera height growth propogation by treatment.

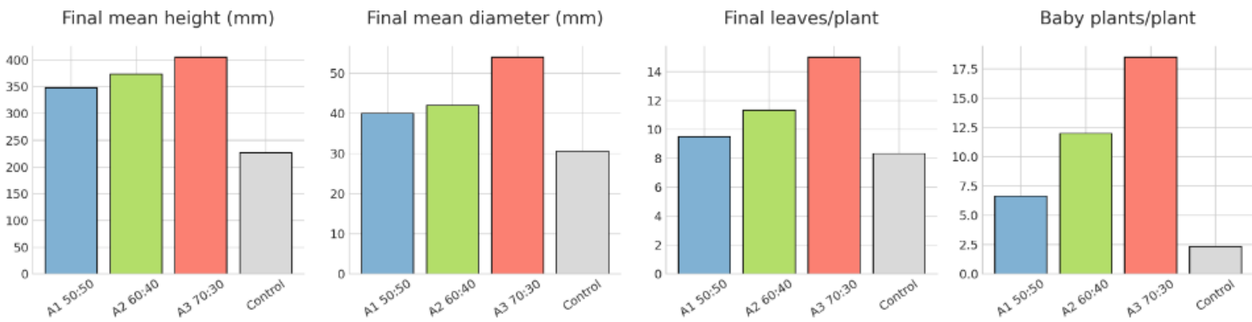
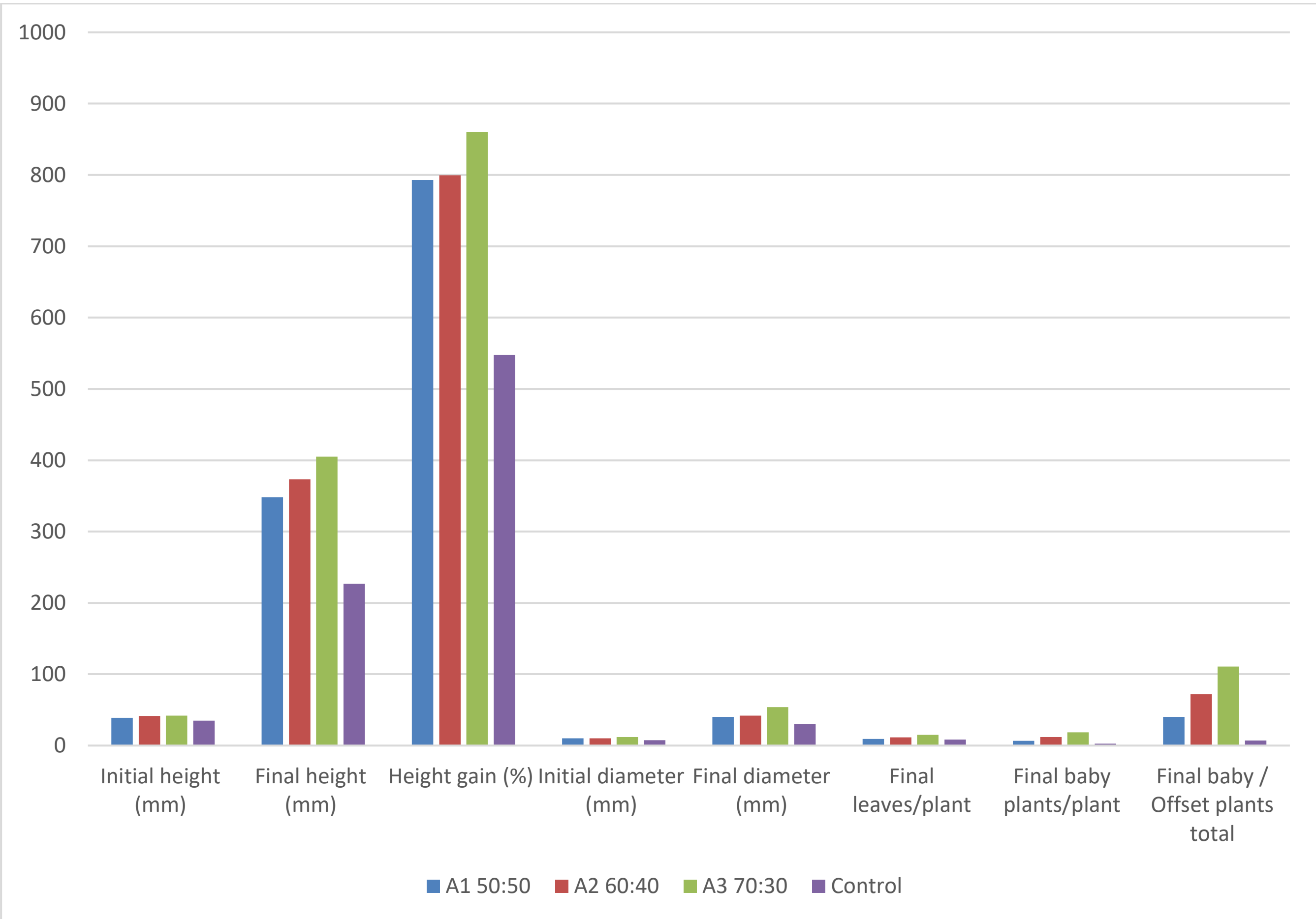


Figure 4. Aloe vera final treatment performance, growth propogation including offset production.



Comparative interpretation of treatment ratios

Across both the crops, the 70:30 sand-dune soil to organic manure mixture emerged as the best reproductive or propagation treatment. Tomato T3 produced the highest total fruit count, and Aloe vera A3 produced the highest number of baby plants. This indicates that the 70:30 mixture provided sufficient organic amendment to overcome the major limitations of dune sand while retaining enough sand fraction to maintain aeration and drainage. This balance is particularly important in arid reclamation because both nutrient retention and root-zone oxygen supply influence productivity.

The 60:40 mixture also performed strongly, especially for Tomato vegetative height and Aloe vera intermediate performance. Tomato T2 achieved the highest final mean height and diameter, indicating that slightly higher manure content may promote vegetative vigor. In crop systems where leafy biomass or plant height is the main target, the 60:40 ratio may therefore be advantageous. However, fruiting performance was better in T3, suggesting that reproductive response may require a different balance of nutrient availability, aeration, and root-zone moisture.

The 50:50 mixture supported plant growth but generally ranked lowest among the amended treatments in Tomato final height, Tomato fruiting, Aloe final height, Aloe diameter, Aloe leaf count, and Aloe baby-plant production. This does not mean that 50:50 is agronomically unsuitable; rather, it may represent an amendment level that is more organic-rich than necessary for these crops under the observed conditions. Higher organic content can improve moisture retention but may also alter drainage, salinity, or nutrient-release patterns. Future trials should measure soil EC, pH, bulk density, moisture retention, and available nutrients to clarify this mechanism.

Aloe control plants provide strong evidence for the importance of amendment. The final control mean height was 226.67 mm, compared with 348.33 to 405.00 mm in amended treatments. Control plants produced only 7 baby plants in total, compared with 40 in A1, 72 in A2, and 111 in A3. The final control appearance was only 30.0% fleshy, while all amended treatments were 100% fleshy. This contrast indicates that organic amendment substantially improved plant vigor, water status, or nutrient availability in the reclaimed substrate.

Tomato: T2 gave the highest final vegetative height, but T3 gave the highest fruit production. Aloe vera: A3 was the best overall treatment across height, diameter, leaf count, fleshy condition, and baby-plant production. Overall reclamation implication: 70:30 sand-dune soil: organic manure appears most promising for balanced productivity, while 60:40 may be useful where Tomato vegetative growth is prioritized.

Mechanistic insights into organic manure effects on dune soils

The results are consistent with a soil-reclamation mechanism based on organic-matter enrichment. Dune sand alone generally has low nutrient-retention capacity, weak aggregation, high permeability, and limited ability to retain plant-available water. Cow-camel dung organic manure likely improved the substrate through several linked pathways: it supplied nutrients, increased organic carbon, improved moisture retention, supported microbial activity, and reduced the rapid leaching of soluble nutrients from the root zone.

For Tomato, these improvements were reflected in rapid stem elongation, thicker stems, increasing leaf counts during early observations, and eventual fruit production. The strong final fruit response in T3 suggests that a physically balanced substrate is important. The 70% sand fraction likely maintained drainage and aeration, while 30% manure provided sufficient nutrients and water retention. For Aloe vera, the manure-amended sand likely supported root expansion and succulent leaf development while avoiding waterlogging. The large number of offsets in A3 indicates that the plants had adequate resources for vegetative propagation.

Organic matter also has a broader relevance to desert agriculture. FAO emphasizes that organic matter improves soil structure, water infiltration, moisture retention, nutrient availability, and biological activity. These properties directly address the limitations of South Kuwait sand dunes. The data therefore support the concept that reclaimed dune sand can become a productive substrate if amendment ratios are optimized and supported by proper irrigation and salinity management.

Future reclamation trials Recommendation's

- Use T3/A3 (70:30 sand-dune soil : organic manure) as the leading treatment for follow-up trials, especially where Tomato fruiting and Aloe offset production are the target outcomes.
- Retain T2/A2 (60:40) as a comparison treatment because it produced the highest Tomato final height and strong Aloe performance.
- Measure soil EC, organic matter, available N-P-K, bulk density , and infiltration
- Measure irrigation water quality and schedule irrigation using soil-moisture monitoring to avoid both drought stress and salt accumulation.
- Record Tomato fruit weight, marketable fruit number, flowering date, fruiting date, and harvest index.
- Record Aloe leaf fresh weight, gel yield, offset survival, and harvestable biomass.
- Consider windbreaks, mulch, or surface stabilization measures where dune mobility and sand abrasion are likely to affect plant establishment.

Integration of results with previous work, discussion in relation to published literature:

The field results agree with the general soil-science literature that organic matter is central to the restoration of sandy and drought-prone soils. Bot and Benites (2005) describe soil organic matter as a key factor affecting soil structure, porosity, water infiltration, moisture-holding capacity, biological activity, and plant nutrient availability. The observed improvement in Tomato height, stem diameter, and fruiting, and the stronger Aloe vera growth and offset production, are consistent with this mechanism because sand-dune soil alone would be expected to have low nutrient and moisture retention.

The Tomato response is also consistent with published evidence that organic amendments improve tomato vigor and yield under low-fertility conditions. Soil amendment studies have reported increases in tomato plant height, stem girth, leaf number, and yield where organic amendments improve soil nutrient supply and physical properties. In the present dataset, this was reflected by height gains of 512.68% in T1, 569.55% in T2, and 613.92% in T3 from the first to final observation. The strongest fruiting in T3 suggests that an amendment rate lower than 40-50% manure may be adequate when the target is fruit production rather than maximum vegetative height.

The Aloe vera findings are strongly aligned with the agronomic review by Cristiano, Murillo-Amador, and De Lucia (2016), which states that Aloe can be cultivated in arid and semi-arid areas because of its drought resistance, succulence, and CAM physiology, while also requiring good drainage to prevent root problems. The same review discusses evidence that cow dung and compost-based manure can increase Aloe leaf growth and yield. In the present trial, A3 gave the best combination of height, diameter, leaf number, fleshy appearance, and baby-plant formation, which supports the suitability of Aloe as a candidate crop for reclaimed sandy substrates in Kuwait.

Kuwait-specific dune studies emphasize that dune mobility and sand encroachment affect agriculture, roads, and infrastructure. The implication for agricultural reclamation is that soil fertility improvement alone is insufficient if plots remain exposed to wind erosion and sand movement. Reclaimed plots should be paired with windbreaks, surface mulch, temporary fencing, or biological stabilization methods. Such measures would protect young plants, reduce sand abrasion, and help retain the organic-amended root zone.

The comparison between Tomato and Aloe vera also shows the value of matching crop choice to reclaimed-soil maturity. Tomato can demonstrate short-term production potential, but it is nutrient and water demanding and may require careful fertility and irrigation management. Aloe vera is slower but more drought-adapted and produced strong propagation outcomes, especially in A3. For early-stage sand-dune reclamation in South Kuwait, Aloe vera may therefore be a lower-risk crop, while Tomato may be suitable in better-managed plots with reliable irrigation and nutrient monitoring.

Agricultural utilization outcomes in South Kuwait:
The results indicate that reclaimed dune sand can be used not only as an experimental planting medium but as a potential component of small-scale arid agriculture systems. In South Kuwait, such systems could support demonstration plots, green belts, nursery production, medicinal-plant cultivation, and selected vegetable production. The key is to treat sand-dune soil as a substrate requiring engineering and biological improvement rather than as a naturally fertile soil.

The 70:30 treatment is particularly important because it uses a higher share of native sand than the 50:50 and 60:40 treatments while still producing excellent biological performance. From a land-reclamation perspective, this means less manure is required per unit volume of substrate, which can reduce amendment cost and improve scalability. If future replicated trials confirm these results, a 70:30 sand-to-organic-manure mixture could be used as a baseline recipe for pilot plots.

However, large-scale implementation must account for salinity. Organic manures can contain soluble salts, and arid irrigation systems can accumulate salts if leaching and drainage are insufficient. The present experiment included only limited conductivity readings for Tomato leaves and no soil EC data. Therefore, any applied reclamation program should include routine monitoring of soil EC, irrigation-water EC, drainage conditions, and plant stress symptoms. Salinity management is likely to determine whether short-term success can become long-term productivity.

Another implication is that reclaimed dune agriculture should be integrated with waste recycling and environmental management. Cow-camel dung manure can be converted from an organic waste stream into a soil-building resource. Proper composting or stabilization before application would reduce odor, pathogens, weed seeds, and ammonia effects while improving handling quality. This would make reclamation more suitable for operational use in Kuwait conditions.

Finally, the findings support a phased development model. Phase 1 should refine treatment ratios in pots or small beds. Phase 2 should test the best treatments under field plots with irrigation, mulch, and wind protection. Phase 3 should evaluate crop yield, water productivity, soil-carbon improvement, salinity change, and economic feasibility. This staged approach would convert the promising findings of the present study into practical guidance for South Kuwait sand-dune utilization.

4. Conclusion:

Sand dunes can be transformed from a very low water-holding, alkaline substrate into a more agriculturally usable rooting medium through cow-camel dung amendment. In the supplied soil measurements, amendment increased water-holding capacity from 5-7% in raw sand to 10-30% and lowered pH from 7.8 to 6.2-7.2. These changes provide the physical basis for reclamation, but they must be verified with EC, nutrient and manure-quality testing before broad application.

The crop data demonstrate that response is composition- and crop-dependent. For tomato, the 60:40 treatment showed the most consistent vegetative advantage, while the 70:30 treatment had the highest observed final fruit count. For Aloe vera, the 70:30 treatment clearly outperformed the other blends and controls in height, stem diameter, leaf count and offset production. The primary recommendation is therefore to use a 70:30 dune sand: composted cow-camel dung blend for Aloe vera and for a tomato fruiting validation strip, while using 60:40 as the conservative starting medium for tomato vegetative establishment.

Agricultural use must be paired with geomorphologic planning. Reclamation should prioritize stable or semi-stabilized dune margins, use GIS-supported survey and field verification, avoid active sand-movement corridors and incorporate wind protection, drip irrigation and soil monitoring. With these safeguards, localized organic amendment can support productive vegetation and contribute to a broader strategy of land stabilization and sustainable desert agriculture in south Kuwait.

The supplied experimental data show that South Kuwait sand-dune soil can support plant growth when reclaimed with cow-camel dung organic manure. Tomato and Aloe vera both responded positively to amendment, demonstrating that organic inputs can partially overcome the physical and fertility limitations of dune sand. The results support the broader soil-science principle that organic matter improves sandy soil by increasing nutrient supply, moisture retention, biological activity, and root-zone stability.

For Tomato, the 60:40 mixture produced the highest final mean height and stem diameter, indicating strong vegetative growth. However, the 70:30 mixture produced the highest fruit response, with 67 total fruits and 11.17 fruits per plant in the final observation. Therefore, T3 is the most promising Tomato treatment when fruiting is the priority, while T2 remains important for vegetative vigor.

For Aloe vera, the 70:30 mixture was clearly the best overall treatment. A3 produced the highest final mean height, diameter, leaf count, fleshy condition, and baby-plant production. Final offset production in A3 was 111 total baby plants, compared with 72 in A2, 40 in A1, and 7 in the control. This demonstrates that a 70:30 sand-to-manure mixture provides a favorable substrate for Aloe growth and propagation under the observed conditions.

Overall, the study indicates that organic manure-based reclamation can contribute to the agricultural utilization of sand dunes. The most promising pathway is not simply adding the maximum amount of manure, but identifying a balance that improves water and nutrient retention while preserving drainage and aeration. Based on the present data, 70:30 sand-dune soil: organic manure is recommended as the lead treatment for future pilot trials, supported by systematic soil testing, salinity monitoring, irrigation optimization, and crop-yield measurements.

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