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SWISS CHARD (*Beta vulgaris* var. *cicla*) GROWTH AND YIELD RESPONSE TO SOLID WINERY WASTE COMPOST AND NPK FERTILISER APPLICATION IN SANDY SOIL

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ABSTRACT. Vegetable producers struggle with soil fertility challenges and ever-increasing inorganic fertiliser prices. Solid winery waste compost provides a promising solution to these problems and mitigates the environmental consequences of discarded winery waste. The use of organic soil amendments improves crop growth and yield; however, there is limited information on the responses of Swiss chard (*Beta vulgaris* var. *cicla*) to solid winery waste compost. This study assessed the effect of NPK fertiliser and two rates of solid winery waste compost on Swiss chard growth and yield. The experiment was conducted at the Agricultural Research Council, Bien Donné Farm, Paarl, South Africa, from April to June and was laid out in a randomised complete block design with four treatments: control, NPK fertiliser, and two solid winery waste compost rates. All plant growth parameters, the number of leaves, leaf length, and leaf width improved significantly with the solid winery waste compost treatments compared to the control. This was linked to the compost's ability to act as a sponge, retaining water and slowly releasing nutrients throughout the growth cycle. The fresh yield of Swiss chard did not show a statistically significant difference (p>0.05) among the amended treatments. The lower compost rate resulted in a slightly larger, but not significantly different, yield (12.95 t/ha) compared to the high compost rate (11.78 t/ha) and NPK treatment (11.39

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t/ha). This was attributed to a potential optimal application rate at the lower compost rate, in which conditions were optimal for nutrient absorption and soil pH. The high compost rate may have resulted in an antagonistic relationship with nutrients due to its higher pH and sodium content, leading to osmotic stress. These findings suggest that although solid winery waste compost is an effective soil amendment for improving Swiss chard growth, further research is needed to determine the optimal application rate necessary for significant yield improvement.

Keywords: inorganic fertiliser; leafy vegetables; plant growth; plant nutrition; soil fertility; yield.

INTRODUCTION

Vegetable production and consumption have potential roles to play in improving household food security amidst global population growth (Sithole *et al.*, 2023). Vegetables are rich in minerals and vitamins essential for human health (Sindesi *et al.*, 2023). However, vegetable production faces challenges, including the ever-increasing input costs (fertiliser costs) and soil fertility decline due to continuous cropping (Dhillon and Moncur, 2023). In South Africa, vegetable production is practised in sandy soils (Ferreira and Nell, 2022). Sandy soil has poor water retention, a low nutrient-holding capacity, and rapid nutrient leaching (Abdulrahman *et al.*, 2023). Many producers meet their vegetable nutrient requirements through inorganic fertiliser application, particularly that of nitrogen (N)-based fertilisers. This overreliance on inorganic fertiliser is detrimental to the soil and the environment (Kopittke *et al.*, 2019). N fertilisers lead to soil acidification and reduced soil organic matter decomposition, reducing soil fertility, crop growth, and yield (Pandian *et al.*, 2024).

Organic soil amendments, such as waste products, including solid winery waste compost, increase the soil organic matter content and microbial diversity while providing slow nutrient release (Pinto *et al.*, 2023). These soil benefits improve crop growth and yield. However, many distillers discard solid winery waste in fields or burn it, causing environmental problems through pollution (Genisheva *et al.*, 2023). Composting solid winery waste for crop cultivation is an alternative to using a landfill or incineration for waste disposal (Bertran *et al.*, 2004). Dumian *et al.* (2024) also found that vegetable waste could be sustainably managed by being composted and used as planting media, promoting soil health and agricultural productivity. Thus, solid winery waste composting represents a sustainable waste management strategy and a potential soil fertility amendment for improving vegetable production in sandy soils. Although there have been numerous studies on the use of organic compost for crop productivity (Bertran *et al.*, 2004; Ho *et al.*, 2022; Oueld Lhaj *et al.*, 2025). Although solid winery waste compost has been studied, little is known about its specific effects on the performance of Swiss chard (*Beta vulgaris* var. *cicla*) in sandy soils. This study assessed the effects of nitrogen, phosphorus, potassium (NPK) fertiliser and two rates of solid winery waste compost on Swiss chard growth and yield. Swiss chard is a widely consumed leafy vegetable in South Africa. Consumers favour it for its nutritional content, and growers prefer it due to its

ease of cultivation (Sindesi *et al.*, 2022). Swiss chard is a nutrient-heavy feeder that is sensitive to soil fertility changes (Smith *et al.*, 2001). Due to this and its economic importance in South Africa, it was selected as the test crop.

MATERIALS AND METHODS

Experimental site and research design

A field experiment was conducted at the Agricultural Research Council (ARC) Bien Donné Farm, Paarl, Western Cape, South Africa (33.84274°S, 18.98425°E) to evaluate the effects of solid winery waste compost and NPK fertiliser on the growth and yield of Swiss chard (*Beta vulgaris* var. *cicla*). Swiss chard was planted in autumn and harvested in early winter (April to June). The Paarl region is characterised by a Mediterranean climate with cool, wet winters and warm, dry summers. The average annual rainfall ranges from 450 to 500 mm, with most precipitation falling in the winter. Paarl soils have a large diversity, which includes Hutton and Clovelly clay loam soils derived from Cape granite and red shale soils with a higher clay content (Jonker, 2021). However, the soil used for this experiment was sandy soil with 61% sand, 14% silt, and 25% clay with a density of 1.63 g/cm³. The experiment was arranged in a randomised complete block design with four treatments: i) control, with no fertiliser or compost application; ii) T1, with inorganic NPK 2:3:4 (30) and 5 g Zn% (500 kg/ha) fertilisers before transplanting and 175 kg/ha lime ammonium nitrate LAN (28) at 4 and 8 weeks after transplanting; iii) T2, with 2.18 t/ha of composted solid winery waste; and iv) T3, with 8.72 t/ha of composted solid winery waste. The inorganic fertiliser treatment was used, as it is the fertiliser application level recommended by FERTASA (2016). Additionally, the two compost levels were selected based on standards for compost application on vegetable fields in the range of 5–15 t/ha. The lower application rates were selected because many local farmers are resource-poor and struggle with the transportation of large quantities of organic composts. All treatments were replicated 4 times in sub-plots with dimensions of 4 m × 4 m (16 m^2) and were applied 1 week before transplanting Swiss chard.

Agronomic practices used

Before applying treatments, the field was tilled using a disc plough, after which a disc harrow was used to create a fine transplanting bed. The nutrient status of the sandy soil and the solid winery waste compost was analysed before treatment application (*Table 1* and *Table 2*). Six-week-old healthy Swiss chard seedlings at the 5–7 leaf stage were transplanted at a spacing of 50 cm between plants and 70 cm between rows (an equivalent of 28,571 plants/ha). Tensiometers Irrometer Model SR (Irroafrica (Pty) Ltd, Somerset West, Cape Town, South Africa) were installed at soil depths of 0–30 cm and used to guide the irrigation schedule. Irrigation was applied through microjets (1.5 L/hr) three times per week; irrigation was maintained at a constant rate for all treatments. Weeds were manually removed from the plots, and insect pests were controlled using 100 g/L alpha-cypermethrin (pyrethroid; ALPHA-THRIN 100 SC©) (Villa Crop Protection (Pty) Ltd, Aston Manor, Gauteng, South Africa).

Table 1 – Initial winery waste compost nutrient characteristics

Parameter	Unit	Value	Comparison against agronomic threshold
pH (KCL)	-	10.3	Highly alkaline (above optimal range for most crops, 6.0–7.5)
Sodium (Na)	mg/kg	10,525.5	Extremely high
Potassium (K)	mg/kg	66500	High
Phosphorus (P)	mg/kg	4800	Moderate to high
Calcium (Ca)	mg/kg	7500	Moderate
Magnesium (Mg)	mg/kg	1500	Low to moderate

Table 2 – Initial soil characteristics (0–30 cm)

Parameter	Value	Agronomic Interpretation for Swiss Chard
pH (KCL)	6.00	Slightly acidic and falls within the optimum range of 6.0–7.5
P (Bray II)	25.3	Generally adequate for vegetable production
Soil Exchangeable Cations (cmol (+)/kg)		
K	54.00	Typically considered adequate
Ca	3.92	Moderate
Mg	0.88	Moderate
Na	0.06	Very low and ideal

Data collection

Measurements of plant growth parameters

For plant growth parameters, three Swiss chard plants were tagged and assessed in each sub-plot. The three Swiss chard plants were selected in the middle of each sub-plot for data collection, and plants in the outer rows were excluded. The number of leaves on each plant, leaf length, leaf width, and chlorophyll content index (CCI) were recorded.

These parameters were observed and measured at 2, 4, 6, and 8 weeks after seedling transplant. The leaf length was measured from the first vein of the leaf to the tip of the leaf with a ruler. The leaf width was measured using a ruler at the broadest section of the leaf. The number of leaves was also counted. CCI was measured from the top edge of the largest leaves using a CCM-200 plus chlorophyll content meter (Opti-Sciences, Hudson, New Hampshire, USA).

Fresh yield of Swiss chard

Swiss chard leaves were harvested once, at 10 weeks after transplanting, and all large-sized (greater than 15 cm length) leaves were harvested; no border plants were selected. Leaves greater than 15 cm in length were harvested, as 15 cm Swiss chard leaves are the recommended size to initiate harvest in South Africa.

Data analysis

Data were subjected to an analysis of variance (ANOVA) using SAS (version 9.4, SAS Institute Inc., Cary, NC, USA, 2000). Treatment means were separated using Fisher's least significant difference (post-hoc test), and the difference was calculated at the 5% level. A probability level of 5% was considered significant for all tests.

RESULTS AND DISCUSSION

Effects of treatment on Swiss chard growth parameters

The growth, yield, and quality of green leafy vegetables are highly affected

by light and N nutrient availability, especially due to their tendency to accumulate nitrate (NO_3) in leaves (Mola *et al.*, 2021). N plays a crucial role in regulating meristematic cell activity, which is essential for plant growth and development. It is also a fundamental component of proteins and nucleic acids, which directly influence cell division, promoting increased division rates in meristems and enhancing overall plant growth (Sindesi *et al.*, 2025a). NPK fertilisers have been used to improve the growth and yield of leafy vegetables (Oloyede, 2012). The main growth parameters studied in leafy vegetables include plant height, leaf count, leaf area, leaf width, fresh and dry weight, and chlorophyll content. These parameters are used to assess plant health and yield potential. Correlation analysis of plant growth and yield parameters conducted by Sindesi *et al.* (2025b) showed that plant height and leaf area were the best indicators of yield potential in Swiss chard. In this study, CCI, the number of leaves per plant, leaf length, and leaf width were studied (*Figure 1*).

As expected, all growth parameters increased over time. Overall, the growth parameter results from this study agree with those obtained by Libutti and Rivelli (2021) and Kebede *et al.* (2023), who also found that the use of organic compost improved Swiss chard growth. Leaf CCI did not show any significant differences ($p>0.05$) among treatments in the first 4 weeks. After 6 weeks, the highest rate of solid winery waste compost (T3) showed higher ($p<0.05$) CCI values compared to the control. In the first 6 weeks, leaf CCI values tended to be larger ($p>0.05$) under T3. However, in week 8, NPK fertiliser treatment obtained the largest ($p<0.05$) CCI values, followed by T3. Leaf chlorophyll is affected by many factors, with N availability, moisture availability, light, and temperature being the most important (Li *et al.*, 2018).

In this study, the tendency of T3 to have better CCI values than the other treatments may be attributed to better soil water retention and better nutrient uptake by the plant. Compost application increases soil water retention and provides a slow release of plant nutrients, which can be used by the plant throughout the growth cycle (Ho *et al.*, 2022; Khater, 2015). In the soil, compost responds like a sponge, binding water with its organic matter, and improves soil aggregation (Sharma *et al.*, 2021). Additionally, as soil microorganisms interact with compost, it decomposes in the soil, slowly releasing essential nutrients, such as N, P, and K (Jacoby *et al.*, 2017).

However, the large CCI value observed in week 8 under NPK treatment can be attributed to LAN application, which was performed at 4 and 8 weeks after transplant. At 4 weeks after transplant, the plant root system was not yet fully developed or elongated within the soil. N, particularly NO_3-N, is highly mobile and can leach below the root zone if the root has not properly developed before the plant can absorb it (Kant and Rothstein, 2011).

All other Swiss chard growth parameters (number of leaves, leaf length, and leaf width) showed a significant improvement in the solid winery waste compost treatments, except for the number of leaves in week 2, when the NPK treatment had the highest value.

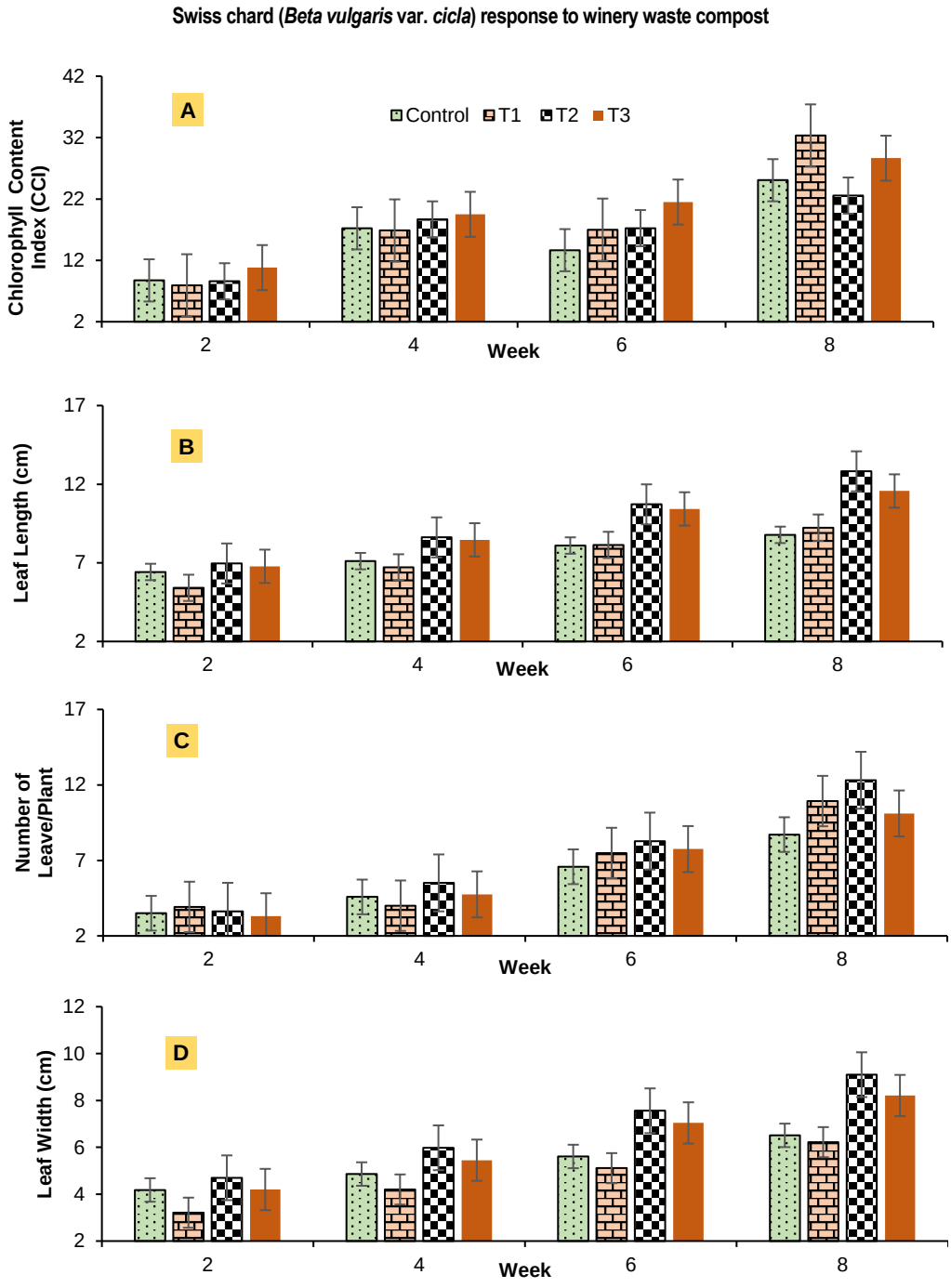

Figure 1 – Swiss chard growth response to solid winery waste compost and NPK fertilisation

A - Chlorophyll content index, B - leaf length, C - number of leaves, D - leaf width.
Overlapping error bars (standard error) show no significant difference at $p<0.05$
Control = No fertiliser or compost treatment, T2 = Inorganic NPK treatment,
T2 = 2.18 t/ha solid winery waste compost treatment, T3 = 8.72 t/ha of solid winery waste compost treatment

This may be attributed to the water and nutrient retention potential of the composted soil, where plants received sufficient nutrients throughout their growth (Jacoby *et al.*, 2017). Whereas the NPK and LAN treatments contained available N in the form of NH_4 and NO_3. NH_4 is converted to NO_3 in the soil, which is easily leached from the soil by rain and irrigation water, leading to losses and less utilisation in crop growth (Meng *et al.*, 2014). The higher number of leaves, leaf length, and leaf width under the lower rate of composted solid winery waste, rather than the higher rate, suggest that the lower dose is the optimal application rate. An optimal application rate enables nutrients to be sufficiently absorbed, and nutrient toxicity and deficiencies are not a problem (Botha, 2025). This optimal application rate may be influenced by differences in soil pH, carbon-to-N ratio, nutrient imbalances (toxicity and deficiency), and over-compaction (caused by excess water retention) due to too much compost (Ahmad *et al.*, 2022). Soils amended with the higher rate of solid winery waste compost (T3) had high N, P, K, and Na contents compared to T2 (unpublished data). The high Na content may have increased the soil electric conductivity, resulting in osmotic stress and making it difficult for plant roots to absorb water and nutrients (Zhou *et al.*, 2024). In extreme cases, a high Na content may lead to stunted plant growth, wilting, and plant death.

Response of fresh Swiss chard yield to the application of solid winery waste compost and NPK fertiliser

The fresh yields of green leafy vegetables are highly dependent on soil moisture and N availability (Abiya *et al.*, 2022). In plants, moisture and N have a complex and synergistic relationship, with the availability of one often impacting the plants' ability to utilise the other. Moisture supports a plant's ability to uptake nutrients from the soil; it further assists with nutrient transport from the roots to the leaves and moves photosynthates from the canopy to other parts of the plant (Holz *et al.*, 2024). Additionally, the leaf size and overall plant mass are primarily driven by cell turgor, which is the water pressure within plant cells (Van Der Zanden, 2008). This pressure provides structural support for leaves and enables cell expansion. As Swiss chard is a leafy vegetable, the increased water retention properties of compost favour its cultivation. N is the main component of amino acids, which are the building blocks of all proteins (Sindesi *et al.*, 2025a). Proteins regulate, control, and execute cell division and elongation, leading to leaf expansion and a vigorous canopy (Mironov *et al.*, 1999). In this study, the fresh yield of Swiss chard did not show a significant difference ($p>0.05$) among the treatments (*Figure 2*). This trend contradicts the findings of Kebede *et al.* (2023), who found that increasing rates of food waste compost significantly increased the fresh yield of Swiss chard. Additionally, the low rate of composted solid winery waste resulted in a slightly ($p>0.05$) higher fresh yield than the NPK treatment and the high rate of solid winery waste compost. The slight difference observed between the solid winery waste compost amended treatments (T2, 12.95 t/ha; T3, 11.78 t/ha) may be attributed to the optimal application rate, as the soil pH

and available moisture caused by compost water retention and the slow release of nutrients were optimal for Swiss chard growth and yield. Compost water retention is due to organic matter, which influences soil physical and hydraulic characteristics, and the slow release of nutrients can be attributed to soil microorganisms interacting with the compost. Additionally, extremely thick compost layers may lead to a dense, waterlogged environment, which restricts oxygen flow to the roots, hindering root respiration and overall plant growth and yield. This may have been possible for extended periods after irrigation or rainfall on T3 with high amounts of solid winery waste compost. Additionally, pH and N availability cannot be linked to this slight increase, as Swiss chard is sensitive to alkaline stress (Liu *et al.*, 2013), not to slightly acidic soils. Moreover, N is mostly available to plants in slightly acidic to neutral soils, within a pH range of 6.0–7.5. Unpublished data from this study confirm that the soil pH of T3 was highest (6.43) at 6 weeks after transplanting and lowest (5.9) at 2 weeks after transplanting. That of T2 was highest at 6.03 and lowest at 5.92 during the same periods. These ranges are within the optimum N bioavailability range. However, the pH difference may have resulted in an antagonistic relationship with one or more soil nutrients, leading to slightly reduced Swiss chard yields (Potash Development Association, 2005). Furthermore, the slightly (p>0.05) lower fresh yield under NPK treatment may have also been affected by N availability, as the highest soil pH during the bi-weekly observation (2–8 weeks after transplanting) was 5.65, a pH outside of the range for optimum N bioavailability. Additionally, this treatment did not contain any organic matter, which could support soil moisture retention; as such, it may have had high-water losses, leading to slight (p>0.05) yield reductions.

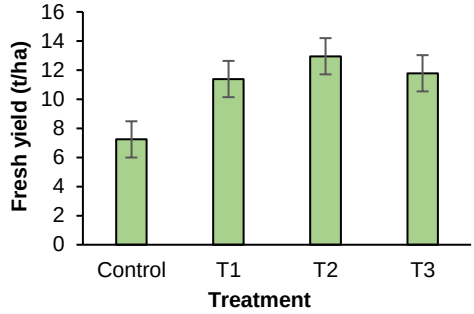

Figure 2 – Effect of winery waste compost and NPK fertiliser on Swiss chard yield

Overlapping error bars (standard error) show no significant difference at p<0.05. t/ha = tonne per hectare. Control = No fertiliser or compost treatment, T2 = Inorganic NPK treatment, T2 = 2.18 t/ha composted solid winery waste treatment, T3 = 8.72 t/ha of composted solid winery waste treatment

CONCLUSIONS

This study assessed the effect of NPK fertiliser application and two rates of solid winery waste compost on Swiss chard growth and yield. Swiss chard growth and yield were improved by solid winery waste compost. All growth parameters, the number of leaves, leaf length, and leaf width improved significantly with solid winery waste compost compared to the control. This suggests that compost, which acts like a sponge to retain water and provides a slow release of nutrients, effectively supports plant growth during the growth cycle. However, despite these positive effects on plant growth, the fresh yield of Swiss chard did not show a statistically significant difference among the

amended treatments (NPK and both compost rates). The obtained yields were 11.39, 12.95, and 11.78 t/ha for T1, T2 and T3, respectively. Slight, non-significant yield differences were observed, with the lower rate of solid winery waste compost (T2) resulting in a larger yield than the higher rate (T3) and the NPK treatment. This was attributed to the potential optimal application rate of the lower compost rate, in which optimal conditions for nutrient absorption, moisture, and soil pH existed. In contrast, the high compost rate (T3) may have increased the soil pH and Na content, causing an antagonistic relationship with one or more soil nutrients and osmotic stress. The NPK treatment may have also suffered from water losses due to a lack of organic matter for moisture retention, leading to a slightly reduced yield. Nevertheless, this study demonstrated that solid winery waste compost is an effective soil amendment for improving Swiss chard growth. Additionally, 2.18 t/ha performed slightly better than both the high rate and the inorganic fertiliser and appears to be more beneficial than higher rates under sandy soil conditions. Based on the results of this study, the recommended optimal application rate is 2.18 t/ha (T2) of solid winery waste compost. This rate achieved growth parameters and fresh yield that were statistically comparable to the inorganic fertiliser standard; it effectively met the requirements for commercial production without the risks associated with inorganic fertiliser use or organic fertiliser overuse.

Future studies should determine the exact optimal rate of solid winery waste compost suitable for crop productivity. This could involve a more detailed experimental design with smaller, incremental increases in compost rates to identify the optimal application rate, in which plant growth and yield are maximised without causing issues, such as nutrient imbalances or toxicity. Additionally, future research should assess the long-term effects of solid winery waste compost versus NPK fertiliser. As compost improves soil organic matter and microbial diversity over time, a multi-year study would better demonstrate its cumulative benefits on soil fertility and its potential to reduce the reliance on inorganic fertilisers.

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