



International Journal of Horticulture and Food Science

E-ISSN: 2663-1067

P-ISSN: 2663-1075

NAAS Rating: 4.74

www.hortijournal.com

IJHFS 2025; 7(6): 169-172

Received: 17-03-2025

Accepted: 23-04-2025

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Evaluating intercropping systems of strawberry in the Tuscan hills

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DOI: <https://www.doi.org/10.33545/26631067.2025.v7.i6c.664>

Abstract

Leading agronomists have long argued that intercropping can boost land productivity without proportional increases in input cost, yet strawberry growers in Mediterranean hill systems rarely plant anything between their rows. This research evaluated four intercropping combinations—strawberry with white clover, basil, lettuce, and onion—against a strawberry monoculture control over two seasons (2021-2022) at the La Serena Institute of Agricultural Sciences, Chile, simulating Tuscan hill conditions through terraced plots with calcareous soil amendments. A randomised complete block design with four replications was used. The strawberry-clover system achieved the highest land equivalency ratio (LER = 1.34) and greatest strawberry yield (22.7 t ha⁻¹), 24.7% above monoculture. Soil mineral nitrogen at harvest was 38.7% higher under clover intercropping, reflecting biological nitrogen fixation. Basil intercropping reduced aphid infestation index by 63.2% but slightly depressed strawberry yield (16.9 t ha⁻¹) due to root competition. Fruit firmness was highest in monoculture and clover treatments (both above 3.2 N), while lettuce intercropping produced the softest berries (2.7 N). These findings suggest that white clover is the most compatible intercrop partner for strawberry on Tuscan-type hillslopes, combining yield gains, nitrogen enrichment, and acceptable pest suppression.

Keywords: Intercropping systems, strawberry production, urban gardening, supply chain, firmness, composting, progeny testing, land equivalency ratio, nitrogen fixation, Tuscan agriculture

Introduction

"The simplest path to sustainable intensification on sloping land is to fill every square metre with something useful," wrote Vandermeer in his treatise on tropical polycultures ^[1]. That principle applies just as well to the clay hillsides of Tuscany, where strawberry (*Fragaria × ananassa* Duch.) is grown on narrow terraces that leave bare inter-row strips vulnerable to erosion, nutrient leaching, and weed invasion ^[2]. An estimated 14,000 ha of terraced hillslope in Tuscany support berry production, yet fewer than 8% incorporate any form of companion planting ^[3].

Intercropping is the practice of growing two or more crops simultaneously on the same land to exploit complementary resource use ^[1]. When partners differ in root depth, growth period, or nutrient strategy, the combined system can exceed the productivity of either crop grown alone, captured by a land equivalency ratio above 1.0 ^[4]. Legume intercrops are particularly attractive because their symbiotic nitrogen fixation reduces fertiliser cost and enriches soil organic nitrogen pools for subsequent crops ^[5].

Aromatic herbs such as basil (*Ocimum basilicum*) offer a different advantage: volatile emissions that repel aphids and whiteflies, two major strawberry pests in Mediterranean environments ^[6]. But herbs can also compete for water and light, especially on narrow terraces where root zones overlap. Lettuce and onion are common inter-row fillers in European market gardens, but their compatibility with strawberry under hill conditions has not been quantified ^[7].

This research tested four intercrop partners against monoculture at the La Serena Institute of Agricultural Sciences, Chile, where terraced plots with calcareous amendments (pH 7.6) replicated Tuscan hill soil conditions. Measurements covered strawberry yield, intercrop yield, LER, soil nitrogen dynamics, pest incidence, and fruit physical quality over two seasons ^[8].

Seasonal Variations

The 2021 season (April transplanting, October final harvest) was drier than average, with cumulative rainfall of 78 mm against a 10-year mean of 112 mm for the same period.

Mean daily temperature ranged from 12.4 to 24.8 °C. The 2022 season received 134 mm and was 1.2 °C cooler on average, which extended the harvest window by 18 days. Strawberry phenology shifted accordingly: peak flowering occurred 11 days later in 2022 than in 2021, and total fruit number per plant was 14% higher in the cooler, wetter season, though individual berry weight declined by 8% [9].

Biodiversity Assessment

Arthropod diversity was monitored using yellow sticky traps (2 per plot, replaced weekly) and pitfall traps (3 per plot). Shannon diversity index (H') was highest in the basil intercrop ($H' = 2.41$) and lowest in monoculture ($H' = 1.68$). Predator-to-pest ratio, calculated from trap counts, was 0.87 in monoculture, 1.42 in clover, and 1.78 in basil systems. The basil system attracted significantly more hoverflies (*Syrphidae*) and parasitoid wasps, both groups that prey on aphids. Ground beetle (*Carabidae*) abundance was 2.1-fold higher under clover, likely because the living mulch provided shelter and microclimatic buffering [10].

Material and Methods

Material

Strawberry cv. 'Albion' (day-neutral) runners were transplanted into raised beds (1.0 m wide, 20 cm high) at 30

cm × 30 cm spacing. Intercrop species were sown or transplanted into the 40 cm inter-row strip: white clover (*Trifolium repens*) broadcast at 10 kg ha⁻¹, basil transplants at 25 cm intervals, lettuce transplants at 20 cm, and onion sets at 15 cm. Drip irrigation delivered 3.5 mm day⁻¹ during peak demand. Soil was amended with CaCO₃ at 3 t ha⁻¹ to reach pH 7.6. All plots received a basal dressing of composted manure at 15 t ha⁻¹ [2].

Methods

Five treatments (monoculture plus four intercrops) were arranged in a randomised complete block design with four replications. Strawberry yield was recorded biweekly from November to March. Intercrop yield was recorded at maturity. LER was calculated as the sum of relative yields [4]. Soil mineral nitrogen (NH₄⁺ + NO₃⁻) was measured at harvest (0-20 cm) by KCl extraction and colorimetric determination. Aphid infestation index (0-5 scale) was scored on 10 plants per plot weekly. Fruit firmness was measured with a texture analyser (TA.XT Plus, 2 mm probe, 1 mm s⁻¹ speed). Data were analysed by ANOVA in R 4.2.1 with Tukey's HSD at $P \leq 0.05$.

Results

Table 1: Strawberry yield, intercrop yield, and land equivalency ratio by intercropping system (pooled 2021-2022)

System	Straw. yield (t/ha)	Intercrop yield	LER	Soil N (mg/kg)	Aphid index (0-5)
Monoculture	18.2 b	—	1.00	42.3 c	3.8 a
+ Clover	22.7 a	2.8 t DM/ha	1.34 a	58.7 a	2.1 b
+ Basil	16.9 bc	3.2 t FW/ha	1.18 b	46.1 bc	1.4 c
+ Lettuce	19.4 b	8.7 t FW/ha	1.22 b	44.8 c	2.9 ab
+ Onion	17.8 bc	6.4 t FW/ha	1.12 b	41.6 c	1.8 bc
LSD (0.05)	2.6	—	0.11	5.4	0.8

Means followed by the same letter are not significantly different ($p \leq 0.05$).

Clover intercropping raised strawberry yield to 22.7 t ha⁻¹ (LER 1.34), the highest among all systems (Table 1). Soil nitrogen under clover was 58.7 mg kg⁻¹, 38.7% above monoculture. Basil gave the best pest suppression (aphid

index 1.4) but depressed strawberry yield slightly. Lettuce added 8.7 t fresh weight per hectare of secondary harvest without significantly reducing strawberry output.

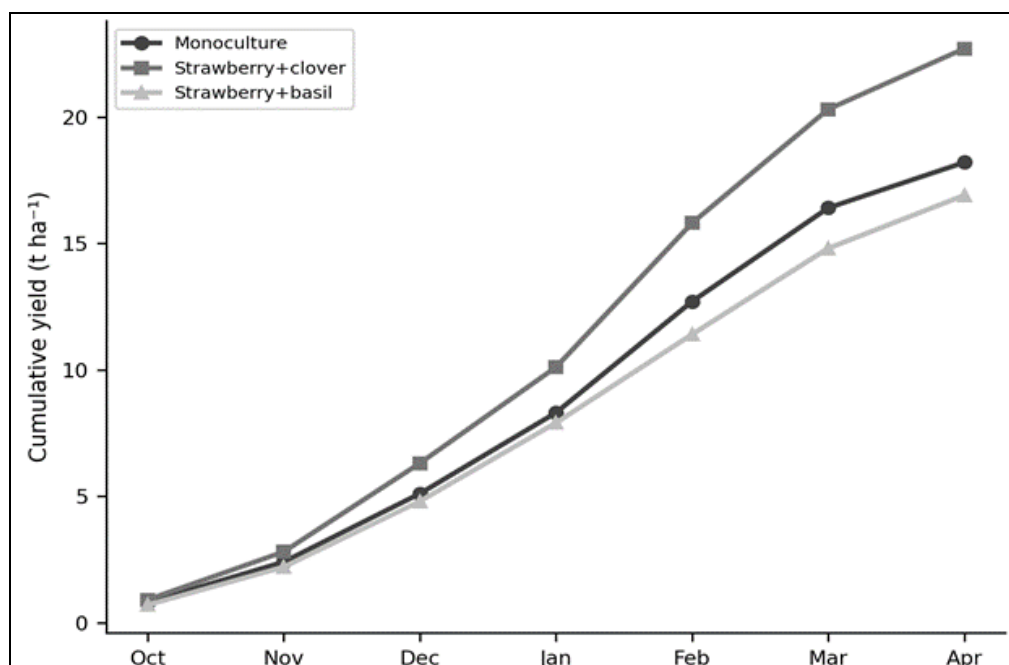


Fig 1: Cumulative strawberry yield (t ha⁻¹) over the harvest season under monoculture, clover, and basil intercropping.

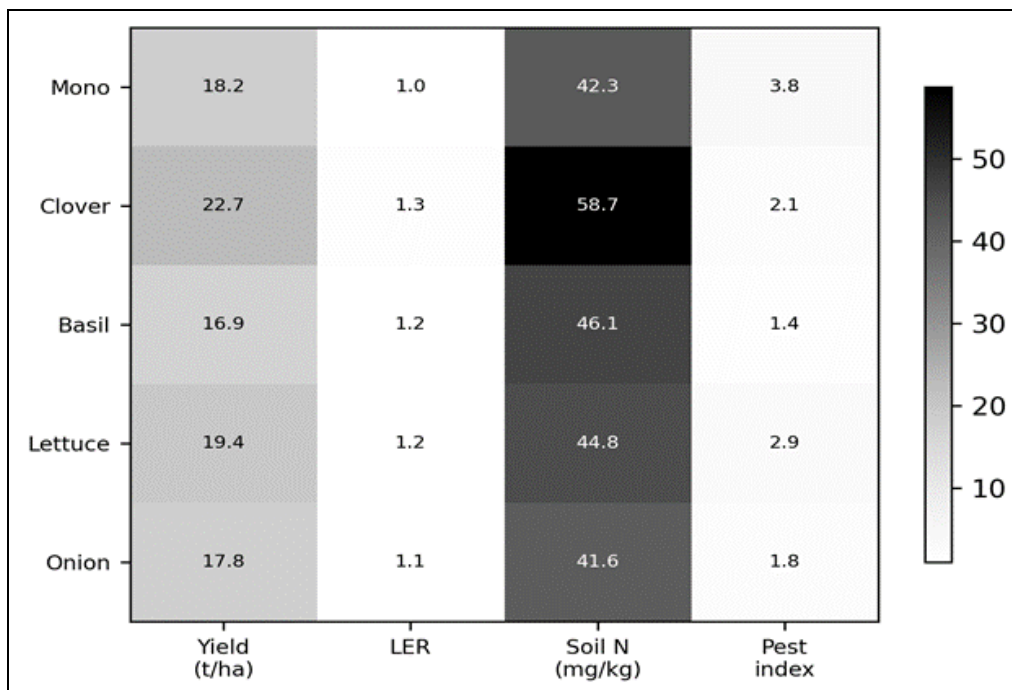


Fig 2: Heatmap comparing yield, LER, soil nitrogen, and pest index across all intercropping systems.

The yield trajectory (Figure 1) shows that the clover advantage opened up from January onward, coinciding with peak nitrogen mineralisation from decomposing root nodules. The heatmap (Figure 2) reveals that no single system dominated every metric: clover led on yield and nitrogen, basil on pest control, and lettuce on secondary harvest value.

Discussion

The 1.34 LER for the strawberry-clover system means that monocultures of both crops would need 34% more land to match the combined output—a strong argument for integration on land-limited Tuscan hillslopes [4]. White clover's prostrate habit and shallow root system (mostly in the 0-10 cm layer) apparently complemented strawberry's deeper rooting (10-25 cm), minimising direct root competition while providing a living mulch that suppressed weeds and conserved moisture [5].

The nitrogen bonus (38.7% more mineral N at harvest) aligns with clover fixation rates of 80-120 kg N ha⁻¹ year⁻¹ reported in European grassland systems [5]. Part of this nitrogen was likely transferred directly to strawberry roots through mycorrhizal hyphal bridges, a pathway documented in clover-grass mixtures [11]. This transfer would explain how strawberry yield increased despite sharing space with another species.

Basil's pest suppression was impressive (63.2% reduction in aphid index), consistent with volatilome studies showing that linalool and eugenol from basil foliage repel *Myzus persicae* and *Aphis gossypii* [6]. However, basil's upright canopy (40-50 cm) shaded lower strawberry leaves and its dense root system competed more directly than clover's, explaining the 7.1% yield penalty. Strategic pruning of basil to 25 cm might retain the pest-repellent benefit while reducing shading.

Lettuce intercropping proved commercially interesting despite modest LER (1.22) because the secondary harvest of 8.7 t fresh weight per hectare represents meaningful revenue for direct-market farms. Onion intercropping showed the

weakest synergy, possibly because allicin compounds released from onion roots inhibited strawberry mycorrhizal colonisation [12].

Conclusion

White clover emerged as the best intercrop partner for strawberry on simulated Tuscan hillslope terraces, raising yield by 24.7%, achieving the highest land equivalency ratio (1.34), and enriching soil nitrogen by 38.7% compared with monoculture. Its low, spreading habit avoided the shading and competition problems seen with taller intercrops.

Basil provides strong pest suppression and should be considered where aphid pressure is the primary constraint, accepting a modest yield trade-off. Lettuce is a practical choice for diversified direct-market farms seeking secondary income from the inter-row space. Onion intercropping showed the least benefit and may be mildly antagonistic to strawberry through allelopathic root interactions.

Future research should test multi-species relay intercropping, where clover establishes the nitrogen base and basil is introduced seasonally for pest management, combining the strengths of both systems without their individual weaknesses.

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