quality, indicating that a staged potassium supply strategy during early reproductive growth and fruit development can provide positive effects (Al-Sabbagh and El-Gioushy, 2024).

Soil potassium application remains the primary potassium management strategy in orchards because it can continuously support root uptake throughout the growing season. However, citrus studies have shown that foliar potassium application plays an important complementary role when soil conditions limit nutrient availability. Ahmad et al. (2022) reported that in alkaline or calcareous citrus soils, soil fertilization alone often fails to achieve optimal leaf nutrient levels, making foliar fertilization an effective rapid correction method. Field comparisons in citrus have demonstrated that both basal soil potassium application and foliar potassium spraying promote plant growth and improve fruit quality. However, foliar application generally produces faster or more pronounced quality responses, whereas soil potassium application is more effective for increasing fruit weight and maintaining long-term tree nutrient supply (Tahir et al., 2023).

Fertigation provides a more precise approach for potassium management by matching potassium supply with seasonal nutrient requirements and root-zone environmental conditions. Based on lysimeter experiments in citrus, Zayani et al. (2024) found that nutrient concentrations in soil solutions varied substantially with irrigation amount, fertilizer input, and soil conditions, indicating that data-driven fertigation management based on real-time monitoring has advantages over fixed fertilization schedules.

6.2 Optimization of potassium application rates and nutrient balance

When potassium deficiency occurs in citrus orchards, increasing potassium supply generally improves plant performance. However, this response is not always linear, and excessive potassium application may reduce fertilizer use efficiency or cause nutrient imbalances. A meta-analysis of 92 citrus fertilization studies conducted by Xu et al. (2024) showed that optimized fertilization strategies increased K_2O application by an average of 6.6% compared with conventional fertilization practices, while simultaneously improving fertilizer productivity, yield, individual fruit weight, total soluble solids content, sugar content, and the sugar–acid ratio. The greatest production benefits were mainly achieved through integrated nutrient management, particularly strategies involving optimized N-P-K ratios combined with the application of secondary and micronutrients.

Experiments with different potassium application rates have also supported this pattern. In ‘Salustiana’ orange, low, medium, and high annual potassium application rates altered potassium concentrations in leaves and flavedo tissues, but high potassium supply did not further improve the measured fruit quality parameters (Manzi et al., 2026). In Newhall navel orange, moderate application of organic fertilizer combined with potassium sulfate produced the best fruit quality performance, with a recommended K_2SO_4 application rate of 1.15-1.20 kg per tree under the tested soil conditions (Wen et al., 2021).

For a long time, citrus nutrient management recommendations have suggested that potassium supply should be maintained at a level close to nitrogen supply to achieve high yield and superior fruit quality (Khan and Nabi, 2023). However, excessive potassium availability may inhibit calcium and magnesium uptake. In hydroponically grown lemon, high potassium concentrations reduced the overall uptake of phosphorus, calcium, magnesium, boron, manganese, and zinc, with these effects being particularly evident at 6 mM potassium concentration (Papadakis et al., 2023). Brital et al. (2024) further found in Valencia orange orchards in Morocco that potassium-magnesium antagonism could still occur in leaves even when soil potassium availability was sufficient, indicating that soil potassium content alone cannot accurately reflect the nutritional balance status of citrus trees.

6.3 Precision potassium management

In recent years, commercial orchard data analysis has provided more quantitative evidence for potassium management. For example, Lima Neto et al. (2025) used boundary line analysis to estimate the optimal soil potassium concentration range for citrus orchards as 161.4-326.0 mg/dm^3 and the suitable leaf potassium concentration range as 7.8-11.3 g/kg. The study also established optimal ranges for other nutrients, including nitrogen, calcium, and magnesium. Monitoring studies in Clementine mandarin orchards in Morocco similarly