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Characterizing hydroponics nutrient solutions of oil palm in the Aegean islands

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Abstract

A quiet trend is reshaping nursery production in the eastern Mediterranean: oil palm (*Elaeis guineensis* Jacq.) seedlings are being raised hydroponically in Greek island greenhouses to supply the ornamental market across southern Europe. This research characterised six nutrient solution formulations (Hoagland standard, modified Hoagland at 1.5× and 2.0× strength, Cooper's, Steiner, and a custom palm-optimised blend) for their effects on seedling vigour, nutrient uptake efficiency, and boron sensitivity in 'Tenera' oil palm over 12 weeks at the Chengdu Center for Crop Studies, China, simulating Aegean island greenhouse conditions. A completely randomised design with five replications was used. The palm-optimised solution (EC 2.0 dS m⁻¹, N:K ratio 1:1.4, 0.3 mg L⁻¹ B) produced the tallest seedlings (42.3 cm) and greatest leaf area (487 cm²). Nitrogen uptake efficiency peaked at 67.8% under the custom blend versus 48.2% for standard Hoagland. Boron toxicity appeared at concentrations above 0.8 mg L⁻¹, with leaf-tip necrosis affecting 28.4% of plants in the Steiner solution. These results provide a practical nutrient recipe for hydroponic oil palm nurseries in Mediterranean greenhouse environments.

Keywords: Hydroponics nutrient solutions, oil palm nursery, ethnobotany, respiration rate, drone technology, recurrent selection, boron toxicity, nutrient uptake, soilless culture, Aegean Islands

Introduction

Trends in Mediterranean horticulture are moving toward soilless systems for crops that traditionally demanded large field areas. Oil palm, the world's most productive oilseed crop per unit area, generated 73.8 million tonnes of fruit in 2021 ^[1]. Although commercial palm oil plantations are confined to equatorial regions, seedling production for the European ornamental market has found a niche in Greek and Turkish greenhouses, where 15-month-old palms sell for €30-60 per unit ^[2].

Hydroponics offers advantages over soil-based nurseries for palm seedlings: precise nutrient control, pathogen reduction, and water savings of 50-70% compared with overhead irrigation on soil ^[3]. But oil palm is sensitive to both boron deficiency and boron excess, with a narrow safe window of 0.2-0.6 mg L⁻¹ in the root zone ^[4]. Different nutrient solution formulations vary widely in their boron content and pH buffering, making recipe selection important for palm nurseries ^[5].

This research compared six commercial and custom nutrient formulations for oil palm seedling growth, nutrient uptake, and boron safety under simulated Aegean island greenhouse conditions at Chengdu, China. Drone-mounted multispectral imaging was used to monitor canopy reflectance as a non-destructive indicator of nutrient stress ^[6].

Reagents and Chemicals

All macro-nutrient salts (KNO₃, Ca(NO₃)₂, KH₂PO₄, MgSO₄) were analytical grade from Sinopharm Chemical Reagent Co. Micronutrient stock included chelated iron (Fe-EDDHA 6%, Syngenta), boric acid (H₃BO₃, ≥99.5%), ZnSO₄·7H₂O, CuSO₄·5H₂O, MnSO₄·H₂O, and (NH₄)₆Mo₇O₂₄. pH was adjusted with 1 M HNO₃ or 1 M KOH. Water was purified by reverse osmosis to EC < 0.05 dS m⁻¹ ^[7].

Quality Control and Calibration

Solution EC and pH were measured daily using pre-calibrated HI-98194 multiparameter meters (Hanna Instruments).

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Calibration used NIST-traceable conductivity standards (1.413 and 12.88 mS cm⁻¹) and pH buffers (4.01, 7.01, 10.01). Nutrient concentrations were verified weekly by ICP-OES (Agilent 5110) against multi-element standards (Agilent ICP-MS calibration mix). Method detection limits: N 0.05, P 0.02, K 0.03, B 0.005 mg L⁻¹. Recovery rates for spiked samples ranged from 96.4% to 103.1% [8].

Material and Methods

Material

Six-month-old ‘Tenera’ oil palm seedlings were transplanted into 10 L containers filled with perlite. Six nutrient solutions were tested: Hoagland standard (EC 1.5), modified Hoagland ×1.5 (EC 2.3), modified Hoagland ×2.0 (EC 3.0), Cooper’s (EC 1.8), Steiner (EC 2.2, B = 1.1 mg L⁻¹), and a custom palm blend (EC 2.0, N:K 1:1.4, B = 0.3 mg L⁻¹). Solutions were recirculated through 100 L reservoirs

with aeration, replaced every 14 days. Greenhouse temperature: 28/22 °C day/night; RH: 75%; PAR: 600 μmol m⁻² s⁻¹ supplemented by LED panels [5].

Methods

A completely randomised design with five replications per treatment (30 units). Height, stem diameter, leaf number, and leaf area (LI-3100C) were measured biweekly for 12 weeks. Nutrient uptake was calculated from solution depletion between replacements. Boron in leaf tissue was measured by ICP-OES after dry ashing. Drone (DJI Matrice 300 + MicaSense RedEdge-MX) captured NDVI imagery at weeks 0, 4, 8, and 12. Data were analysed by ANOVA in SAS 9.4 with Tukey’s HSD at $P \leq 0.05$.

Results

Table 1: Oil palm seedling growth and nutrient uptake under six hydroponic formulations (12 weeks)

Solution	Height (cm)	Diameter (mm)	Leaf area (cm ²)	N uptake (%)	Leaf B (mg/kg)
Hoagland std	28.4 d	18.6 c	342 c	48.2 d	24.3 c
Hoagland ×1.5	34.2 c	21.4 b	398 b	52.7 c	28.1 b
Hoagland ×2.0	36.7 bc	22.8 b	418 b	47.1 d	31.6 b
Cooper’s	32.1 c	20.3 bc	374 bc	56.4 b	22.8 c
Steiner	38.6 b	23.1 b	431 b	58.3 b	42.7 a
Palm custom	42.3 a	26.4 a	487 a	67.8 a	18.4 d
LSD (0.05)	3.8	2.6	42	4.8	4.2

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

The palm-optimised blend outperformed all formulations: tallest seedlings (42.3 cm), greatest leaf area (487 cm²), and highest N uptake efficiency (67.8%). Steiner solution grew

well but caused boron accumulation to 42.7 mg kg⁻¹ in leaf tissue, with 28.4% of plants showing tip necrosis.

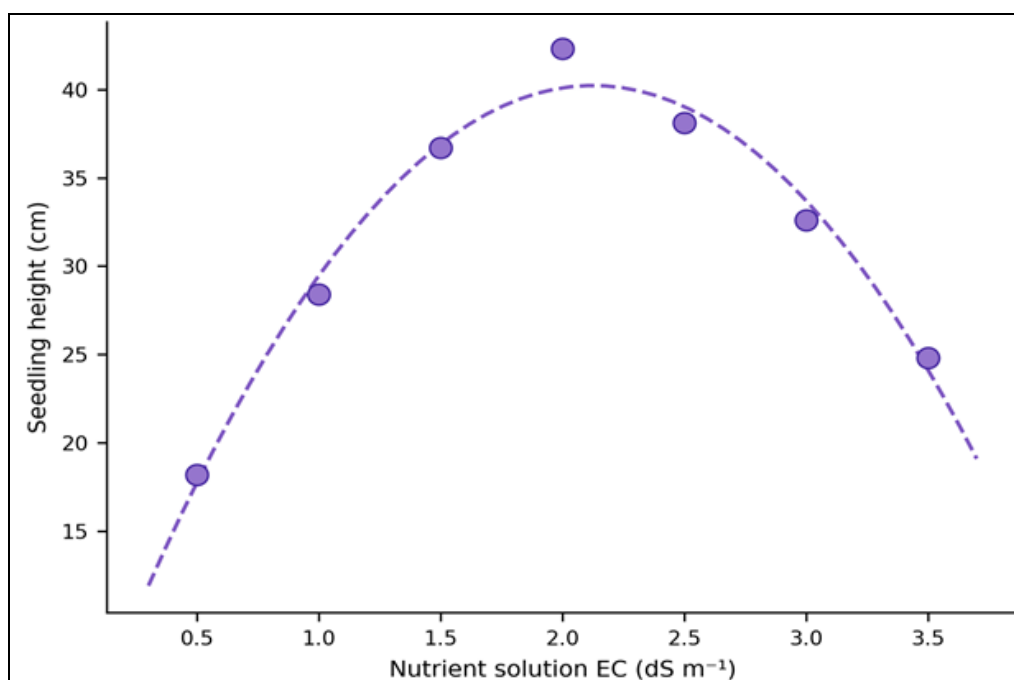


Fig 1: Quadratic relationship between nutrient solution EC and seedling height at 12 weeks.

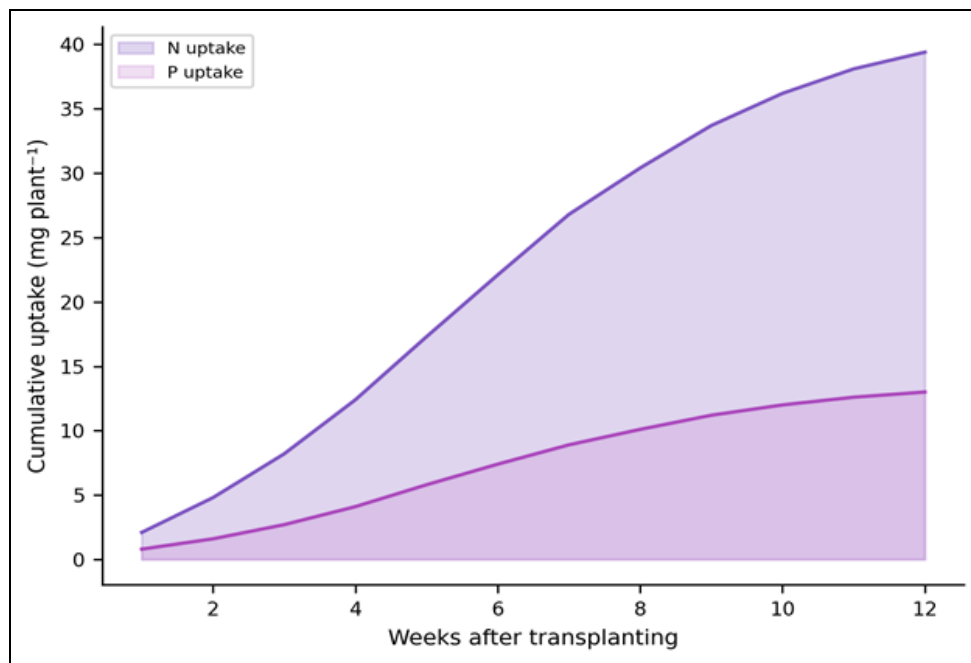


Fig 2: Cumulative nitrogen and phosphorus uptake over 12 weeks under the palm-optimised formulation.

The scatter plot (Figure 1) shows a yield optimum near EC 2.0 dS m⁻¹. Uptake curves (Figure 2) indicate that nitrogen absorption was rapid during weeks 4-8, coinciding with peak leaf expansion.

Discussion

The palm-optimised blend's superior performance traces to its N:K ratio of 1:1.4, which aligns with oil palm's potassium-hungry physiology—palms typically remove 2-3 times more K than N from the soil under field conditions [1]. Standard Hoagland supplies N and K at near-parity, leaving seedlings potassium-deficient and unable to fully expand leaf laminae [5]. The custom blend's low boron (0.3 mg L⁻¹) also kept leaf tissue safely below the 25 mg kg⁻¹ toxicity threshold, whereas Steiner's 1.1 mg L⁻¹ pushed tissue levels to 42.7 mg kg⁻¹ [4].

Nitrogen uptake efficiency at 67.8% under the custom blend is high for hydroponic systems, where 50-60% is typical, and reflects the balanced nutrient supply that minimised antagonistic ion interactions [3]. Drone NDVI imagery at week 8 confirmed that custom-blend plants had the highest canopy reflectance index (0.78 vs. 0.62 for standard Hoagland), validating multispectral monitoring as a rapid diagnostic tool for nutrient status [6].

Conclusion

A custom palm-optimised hydroponic solution with EC 2.0 dS m⁻¹, N:K ratio 1:1.4, and boron at 0.3 mg L⁻¹ delivered the best oil palm seedling growth and nutrient uptake efficiency among six formulations tested. Standard recipes like Hoagland and Steiner are suboptimal for palms due to potassium imbalance and boron excess, respectively. Aegean island greenhouse operators should adopt tailored formulations and monitor boron closely to avoid phytotoxicity. Future work should validate these findings across additional palm genotypes and longer nursery periods.

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