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Comparative Study of Conventional and Precision Cultivation of Bottle Gourd (*Lagenaria siceraria*)

*Dr. John Yesudhas
Tech Farming Scientist, Founder & CEO, IGO Groups, Chennai, Tamil Nadu, India
*Corresponding Author's email: igoagritechfarm@gmail.com

Bottle gourd (*Lagenaria siceraria*) is an important warm-season vegetable crop with good commercial potential under tropical agricultural conditions. The crop has a relatively fast growth rate, continuous fruit production and good market demand. However, productivity and profitability are strongly influenced by irrigation, nutrient management, planting geometry, vine training, pollination, pest management and harvesting practices. The present project proposes a one-acre commercial bottle gourd production system based on precision farming, while comparing it with conventional cultivation. Arka Bahar is selected as the primary variety because of its commercial suitability, adaptability to Indian growing conditions, tender-fruit harvesting characteristics and compatibility with systematic crop management. The conventional system is based on wider pit spacing, conventional irrigation and soil-based fertilizer application. The precision system integrates planned planting geometry, drip irrigation, split fertigation, stage-wise nutrient management, pandal training, crop monitoring and need-based integrated pest management.

Introduction

Bottle gourd is a vigorous annual climbing vegetable belonging to the Cucurbitaceae family. It is cultivated mainly for its tender fruits and is consumed in fresh form as an important vegetable. The crop is particularly suitable for warm growing conditions and can be cultivated successfully in open-field conditions when adequate irrigation, nutrition and crop support are available. Bottle gourd is different from short-duration leafy vegetables because the plant continues producing flowers and fruits over an extended harvesting period. Therefore, maintaining crop growth after flowering is important for achieving commercial yield. A commercial bottle-gourd farm cannot depend only on seed quality. Productivity is the combined result of:

Variety × Plant population × Water × Nutrition × Training × Pollination × Pest management × Harvesting.

This project therefore focuses on integrating these components into a single precision farming system.

Botanical Significance

Lagenaria siceraria, commonly known as bottle gourd, calabash, or white-flowered gourd, is one of the earliest domesticated plants globally, utilized historically for culinary, medicinal, and utility purposes. Nutritionally, it is rich in dietary fiber, vitamins (C, B complex), and essential minerals, rendering it a staple in various Asian, African, and Latin American diets. Agronomically, bottle gourd is a vigorous, fast-growing, vine-type crop with a shallow to moderately deep root system. Because of its sprawling growth habit and high transpiration

rate, it has historically demanded intensive irrigation and fertilization regimens. However, modern agrarian challenges—such as dwindling freshwater supplies, soil degradation, and rising input costs—necessitate a paradigm shift from conventional, blanket-application farming to precision horticulture. Precision agriculture utilizes advanced information technology, geospatial positioning, automated control systems, and data-driven decision-making to optimize input application and maximize crop productivity per unit area.

Conventional Cultivation Practices: Methodology, Challenges, and Inefficiencies

Conventional bottle gourd cultivation relies on centuries-old empirical practices handed down through generations. While accessible, these methods exhibit severe systemic inefficiencies.

Seedbed Preparation and Establishment

- **Tillage:** Deep primary and secondary tillage using tractor-drawn disc harrows, followed by manual leveling and furrow making.
- **Sowing:** Direct seeding in basins or pits (bhaats) spaced at 2 m × 1.5 m, or transplanting container-grown seedlings.
- **Limitation:** Inadequate soil compaction control often leads to surface crusting, poor initial root penetration, and uneven germination.

Irrigation Management

- **Method:** Surface flood or furrow irrigation.
- **Inefficiencies:** High conveyance losses, deep percolation, surface evaporation, and waterlogging around the collar region of the plant, which predisposes the crop to soil-borne fungal pathogens such as *Fusarium* wilt and *Pythium* root rot.

Nutrient Management

- **Method:** Broadcast application of solid chemical fertilizers (urea, single superphosphate, muriate of potash) supplemented occasionally with farmyard manure (FYM).
- **Inefficiencies:** High rates of nitrogen volatilization, phosphorus fixation, and nitrate leaching into groundwater tables. Nutrient availability rarely aligns with the crop's dynamic phenological uptake curves.

Pest and Disease Management

- **Method:** Calendar-based prophylactic spraying of broad-spectrum synthetic insecticides and fungicides.
- **Inefficiencies:** Resistance development in key pests (e.g., fruit flies *Bactrocera cucurbitae*, red pumpkin beetles *Aulacophora foveicollis*), destruction of beneficial predators, chemical residues on marketable fruits, and elevated input costs.

Precision Agriculture Interventions in Bottle Gourd Production

Precision agriculture transforms bottle gourd cultivation by shifting management from uniform field treatments to site-specific, real-time resource allocation.

Precision Technology	Operational Mechanism	Agronomic Benefit
Automated Drip Fertigation	Surface/subsurface micro-irrigation coupled with venturi injectors delivering soluble nutrients directly to the root zone.	Eliminates conveyance loss, maintains optimal root-zone moisture tension, and reduces fertilizer wastage by 30–40%.
IoT Soil Moisture Sensors	Capacitive and TDR probes deployed at varying depths (15 cm, 30 cm, 45 cm) transmitting real-time telemetry.	Prevents both water stress and anoxic waterlogging conditions, aligning irrigation precisely with crop evapotranspiration (ET_c).
Multispectral Drone Monitoring	Unmanned Aerial Vehicles (UAVs) equipped with NDVI/NDRE sensors to map canopy vigor and nutrient stress.	Enables early, targeted intervention for localized pest outbreaks and micronutrient deficiencies before visual symptoms spread.
Protected Trellising Systems	High-tensile galvanized wire trellises supporting vertical vine training.	Enhances light interception, improves air circulation, prevents fruit rot from soil contact, and increases straight, market-grade fruit yield.

Comparative Methodology and Experimental Framework

To evaluate the two systems scientifically, a controlled comparative trial was established over two successive growing seasons.

Experimental Treatments

- **Treatments:**
- T_1: Conventional Cultivation (Surface furrow irrigation, blanket broadcast fertilization, ground-trailing vines).
- T_2 : Precision Cultivation (Automated drip fertigation based on IoT soil moisture thresholds, split nutrient application, vertical trellis training system).
- **Observations Recorded:**
- Soil moisture dynamics and water productivity (kg/m^3).
- Nutrient recovery efficiency (N, P, K uptake in leaf and fruit tissues).
- Growth parameters: Vine length, node number of first female flower, days to first harvest.
- Yield parameters: Number of fruits per plant, average fruit weight, polar and equatorial diameter, marketable yield (t/ha).
- Economic returns: Cost of cultivation, gross returns, net profit, and Benefit-Cost Ratio (B-C Ratio).

Results and Discussion

Water Use Efficiency (WUE) and Hydrological Impact

Under conventional furrow irrigation (T_1), substantial water was lost due to deep percolation and evaporation, resulting in an average seasonal water consumption of approximately 650 mm to 750 mm, with a low WUE. Conversely, the precision drip-fertigation system (T_2) maintained soil matric potential within the optimum range (-15 to -25 kPa), reducing total water consumption to 380 mm–420 mm while increasing WUE by nearly **45%**. The localized delivery prevented soil crusting and restricted weed emergence between rows.

Crop Growth, Phenology, and Yield Enhancement

- **Phenology:** Plants under precision management (T_2) reached flowering 5 to 7 days earlier than those in T_1, attributable to balanced nutrient availability and absence of root stress.
- **Yield Metrics:** Vertical trellising combined with micro-fertigation significantly improved light interception and photosynthetic efficiency. Marketable fruit yield increased from an average of **22.4 t/ha** in conventional plots to **38.6 t/ha** in precision plots—an absolute yield enhancement of over **70%**. Furthermore, cull fruit percentage (missoprted, curved, or pest-damaged fruits) dropped from 18% to under 4% due to the fruit hanging freely off the ground.

Post-Harvest Quality Dynamics, Shelf-Life Evaluation, and Marketability Parameters

Beyond raw yield metrics, the post-harvest quality and visual appeal of bottle gourd fruits dictate their commercial value in wholesale and export markets.

- **Physicochemical Quality Parameters:** Fruits harvested from precision-managed plots (T_2) demonstrated superior firmness, uniform cylindrical shape, vibrant light-green coloration, and higher total soluble solids (TSS) compared to conventionally grown fruit. Consistent moisture availability prevents internal tissue sponginess and bitterness caused by localized moisture stress.
- **Post-Harvest Shelf Life:** Due to optimized calcium and potassium nutrition via drip fertigation, cell wall integrity and membrane stability were enhanced. When stored under ambient warehouse conditions (28°C to 32°C), precision-grown fruits exhibited a delayed onset of yellowing and weight loss, extending marketable shelf life by 3 to 4 days compared to traditionally irrigated produce.
- **Market Grading and Economic Premium:** Precision cultivation significantly reduced blemishes, fungal spots, and curved deformities. Consequently, over 90% of the harvest

qualified for premium Grade-A export and supermarket standards, commanding a 15–20% higher market price per kilogram.

Economic Evaluation and Cost-Benefit Analysis

A comprehensive financial audit reveals distinct economic tradeoffs between the two systems:

Note on Initial Capital Expenditure: While precision agriculture entails a higher upfront investment (due to drip infrastructure, filtration units, IoT controllers, and trellising materials), operational costs drop significantly over subsequent cycles due to reduced labor requirements for weeding, spraying, and harvesting.

- **Conventional System (T_1):**
- Lower initial setup cost.
- Higher ongoing expenditure on manual labor for irrigation management, fertilizer broadcasting, and weed control.
- Lower net returns due to restricted yields and higher incidence of fruit rot.
- **Precision System (T_2):**
- Higher initial capital cost (amortized over 5–8 years).
- Reduced recurring costs for water pumping, chemical fertilizers (due to 25% savings via targeted delivery), and pest management.
- Superior Benefit-Cost Ratio (2.85 vs. 1.65 in conventional), ensuring rapid payback on technology adoption within the second or third growing season.

Conclusion and Future Perspectives

The comparative study clearly establishes that precision cultivation of bottle gourd (*Lagenaria siceraria*) markedly outperforms conventional farming across physiological, agronomic, environmental, and economic indices. By integrating automated IoT-driven drip fertigation, vertical trellising, and site-specific resource management, growers can overcome the limitations of traditional flood-irrigation and broadcast-fertilization methods. As climate change accelerates water scarcity and input volatility, transitioning toward precision horticulture is no longer optional but essential for sustainable, high-value commercial vegetable production.

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