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Precision Horticulture in Fruit Production: Tools and Techniques

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Abstract

Fruit orchards are complex, living systems where variability is the norm between trees, within blocks and across seasons. Precision horticulture turns that variability into an advantage by pairing high-resolution sensing (drones, proximal and in-canopy sensors, machine vision) with decision tools (models, maps and simple alerts) and variable-rate actions (precision irrigation, fertigation and intelligent spraying). This article translates the buzzwords into orchard-floor practice: what each tool really measures, where it fits in a season and how to build a sensible stack whether you manage two acres of guava or two hundred of apples. You'll see how spectral and thermal data reveal stress before it's visible, why a few well-placed soil and microclimate nodes can halve guesswork and how modern sprayers and controllers turn maps into action.

Keywords: Precision horticulture; fruit orchards; drones; LiDAR; multispectral imaging; thermal imaging; soil moisture sensors

The big idea why precision matters more in orchards

Row crops reset every season; orchards carry yesterday's decisions into tomorrow's harvest. Tree age, canopy architecture, rootstock, slope, soil pockets, irrigation hydraulics and wind exposure all create micro-zones that behave differently. Treating everything the same water, same nutrients, same spray guarantees waste in some places and shortages in others. Precision horticulture doesn't demand you become a data scientist. It asks you to blend your fieldcraft with better "eyes and ears," then act where it counts: a dripline section that runs hot, a canopy zone that lags, a disease window that opens at 2 a.m. on a muggy night.

The sensing layermaking the invisible visible

Above the canopy (UAVs and satellites).

- **RGB cameras** spot emergence gaps in young plantings, pruning misses, storm damage, windbreak failures and weed breaks on the orchard floor.
- **Multispectral & hyperspectral** cameras derive vigour indices (NDVI, NDRE and red-edge metrics) that pick-up chlorophyll and canopy density changes earlier than the eye can.
- **Thermal cameras** reveal water stress and clogged emitters as “hot” stripes or patches and help assess irrigation uniformity during heat events.
- **LiDAR** builds 3D canopy models useful for estimating leaf area, optimizing spray rates and planning pruning or training.

In the canopy (proximal and on-tree).

- **Leaf wetness, temperature and RH sensors** track the disease triangle hour by hour.
- **Dendrometers and fruit growth sensors** monitor micro-changes in trunk or fruit diameter to warn of stress before wilting is visible.
- **Sap-flow, PAR and UV sensors** add context for heat load, transpiration and photosynthetic activity.
- **Camera traps and machine-vision nodes** watch for pests, flowering intensity, fruit set and colour change.

In the soil (below and between rows).

- **Soil moisture (tension or volumetric) and EC sensors** make irrigation and fertigation scheduling evidence-based, spot salt accumulation and confirm distribution after a set.
- **Tensiometers and capacitance probes at two depths** (e.g., 20–30 cm and 50–60 cm) show whether water is staying in the rootzone or leaching past it.
- **Pressure sensors** along mainlines and laterals identify hydraulic drops that create uneven sets.

Placement tips that save headaches.

- Pair one “benchmark” node you never move with a second “roving” node to explore variability.
- Avoid unrepresentative spots (wheel tracks, shaded depressions, rodent tunnels).
- In sloping blocks, instrument both shoulder and swale; in micro-sprinklers, place sensors midway between emitters; in drip, place near a representative emitter in wetting pattern.

Turning signals into decisions maps, models and simple alerts

Sensing without synthesis just yields pretty pictures. A modern decision-support platform ingests sensor streams, drone layers, terrain and soil data and short-term forecasts. It then does three practical things:

1. **Prioritize:** surfaces the “few things that matter this week” for example, a block with rising leaf wetness hours and night-time temperatures in the disease risk band.
2. **Localize:** shows *where* to act north edge, rows 12–20, trees 5–15.
3. **Prescribe:** generates a variable-rate map or at least a checklist open valve B for 25 min; increase sprayer fan RPM only in dense canopy zones; top-dress N at 30 kg/ha in light-coloured polygons.

Good tools also explain *why* a tiny sentence next to an alert (“NDRE down 12% vs. last week, sandy seem likely N-limited”) builds trust and teaches your team as the season unfolds.

Acting with precision irrigation, fertigation and intelligent spraying

Variable-rate irrigation (VRI) in micro-irrigated orchards.

Even without expensive new hardware, you can approximate VRI by zoning sets based on soil and canopy variability and using sensor-driven triggers. Where budgets allow, automated valves and prescriptions let you shorten or lengthen sets by zone. Thermal flights during heat waves confirm whether adjustments are cooling the canopy uniformly.

Precision fertigation.

Feed the plant, not the calendar. Start with tissue tests to set seasonal targets, then let weekly canopy vigour, soil moisture/EC and fruit growth trends nudge small course corrections. A modest reduction in total N with better timing often improves colour and storability while protecting groundwater.

Intelligent spraying.

Modern sprayers measure canopy density (via LiDAR or vision), modulate airflow and nozzles and maintain deposition while cutting drift and active ingredient use. In practice, that means less fog in sparse rows after pruning, more penetration in dense rows approaching closure and smarter speeds on turns and slopes.

Other variable-rate actions.

Site-specific thinning, bloom or fruitlet treatments, targeted reflectance mulches for colour, anti-hail netting deployment driven by risk and spot herbicide passes based on orchard-floor object detection all fit naturally once maps and zones exist.

A season in miniature three fruit examples

Apple (temperate).

- *Early season:* RGB + NDVI flights post-budbreak flag uneven green-up; microclimate nodes show long dew hours fungicide timed before a forecasted warm front prevents a primary infection event.

- *Mid-season:* LiDAR-derived canopy volume guides sprayer airflow; NDRE dip on a sand seam triggers a small VRA N correction; thermal mapping spots a hot lateral two clogged emitters are fixed the same day.
- *Pre-harvest:* Vision-based sampling estimates size distribution and blush; night-time thermal images verify irrigation cuts didn't overshoot; picking starts in the most uniform rows to reduce pack-out sorting pain.

Grapes (viticulture).

- *Canopy growth:* NDRE + canopy height maps identify over-vigorous pockets; leaf removal is targeted rather than blanket, reducing sunburn risk.
- *Water stress:* Tensiometers at two depths plus thermal flights guide deficit irrigation; berry growth curves stay smooth; tannin goals are met without shrivel.
- *Disease windows:* Leaf wetness and wind patterns refine spray intervals so you skip one pass in a dry spell money saved, residue reduced.

Mango or banana (tropics/subtropics).

- *Heat and humidity management:* Microclimate nodes drive disease risk alerts; spot-sprays replace calendar passes.
- *Irrigation:* Soil EC warns of salt build-up after a hot week; schedule changes prevent tip burn.
- *Quality:* Camera-based sampling monitors size progression; staggered harvest windows are planned block-by-block to match market slots.

People, process and data the unglamorous bits that make it work

- **Start with questions, not gadgets.** “Where am I over- or under-watering?” “Which rows always ripen unevenly?”
- **Routines beat heroics.** A 20-minute weekly review with last week's maps and alerts keeps the signal-to-noise high.
- **Ground-truth everything unusual.** Every red patch gets a short walk, photo and note; if the sensor is right, you'll trust it more next time.
- **Calibrate on a schedule.** Probes drift. Cameras lie when the sun is low. A quarterly ritual keeps faith in the numbers.
- **Keep data portable.** Pick platforms that export standard formats and write down who owns what and for how long.
- **Train a backup operator.** The tools should work even when the “tech person” is on leave.

Emerging trends to watch (and which ones to pilot first)

- **Computer vision for fruit counting and sizing.** On-tree yield estimates unlock per-row and per-zone harvest planning and trial clarity. Pilot on one block; compare estimates with pack-out.
- **Digital twins of canopy structure.** Combining LiDAR with colour and thermal layers makes spray and pruning models far more accurate.
- **Edge AI and low-power networks.** Smarter, battery-sipping nodes mean more sensing points without a wiring project.
- **Quality sensing before harvest.** Handheld or on-platform NIR for dry matter or Brix to schedule picking; reflectance mulches and films chosen by data, not habit.
- **Autonomous ground platforms.** UGVs that mow, spray, or haul bins, guided by orchard maps.
- **Climate resilience in practice.** Frost fans triggered by on-site inversions, netting decisions driven by hail probability and heat-wave irrigation that balances fruit growth with disorder risks.

Twenty orchard decisions and the digital signals that sharpen them

Management question	Signal(s) / data you need	Tool or technique	Typical action
Is canopy fill even after budbreak/flush?	RGB orthomosaic; NDVI trend	UAV RGB + multispectral	Replant/retie only where needed
Where is water stress starting?	Thermal hotspots; soil moisture at 30/60 cm	UAV thermal; tensiometers	Advance set in hot zones; shorten elsewhere
Are some laterals under-delivering?	Pressure drops; uneven soil moisture	Inline pressure sensors; soil probes	Flush line; fix clogged emitters
Do I need that fungicide pass now?	Leaf wetness hours; night temp/humidity	Canopy microclimate nodes; risk model	Spray now/hold 48 h/just scout
Which rows get variable N or K?	NDRE stability; tissue test follow-up	Multispectral mapping; lab tests	Small VRA top-dress/fertigation tweak
Is drift under control in sparse canopies?	LiDAR canopy volume; weather at boom height	Intelligent sprayer; met node	Reduce fan speed/nozzles in sparse rows
Where to thin or regulate growth?	NDRE high zones; shoot length	Multispectral + field checks	Target growth regulator or mechanical thinning
Is floor management slipping?	RGB weeds/bare soil index	UAV RGB + object detection	Spot herbicide or mow only where needed
Are fruit sizing evenly by block?	Camera samples; fruit growth curves	Vision app; dendrometers	Split harvest plan; adjust irrigation
Is salinity building up?	Soil EC trend after fertigation	EC probes	Leach in affected zones; adjust recipe

Are trees over- or under-vigorous?	3D canopy volume; NDRE	LiDAR + multispectral	Prune selectively; adjust N strategy
Where to place pheromone traps?	Historical hot spots; canopy gaps	Heat maps from past captures + RGB	Cluster traps where risk is highest
Are hail or wind damages actionable?	Post-storm RGB; lodging map	Rapid UAV re-flight	Prioritize propping, insurance proofs
Is irrigation uniform during heat wave?	Thermal at midday; sap-flow (optional)	UAV thermal; sap sensors	Balance sets; cool down hotspots
Where to sample soil/tissue?	Persistent low-vigour polygons	Vigour maps across season	Sample targeted polygons only
Is harvest maturity aligned with markets?	Colour change; Brix/dry matter spot checks	Vision sampling; handheld NIR	Stagger picks; schedule labour/logistics
What's the ROI of a practice?	Yield per row vs. input history	Yield estimates; pack-out; platform analytics	Keep/modify/drop practice next season
Is frost risk true tonight?	Inversion profile; wet-bulb temps	Multi-height temp sensors; forecast	Start fans/overhead; pre-position crews
Are bins and routes efficient?	Heat map of pick rates; row times	GPS logs; simple UGV/tractor telemetry	Re-route crews; place bins smarter
Is my plan improving year over year?	KPI dashboard (water, AI, residues, pack-out)	Season rollups; consistent zones	Scale what worked; retire what didn't

Cost-smart pathways for small and mid-size growers

- **Share the high-ticket items.** A cooperative UAV pilot or sprayer with canopy sensors can serve several farms on a schedule.
- **Lease before buying.** Many vendors offer season-long trials. Insist on keeping your data and exporting it in standard formats.
- **Start with software + a few sensors.** A strong microclimate node and two soil probes deliver immediate, cash-visible wins; imagery can be purchased as a service.
- **Use your phone as a sensor.** Vision apps for flower counting, fruit sizing and color progression are surprisingly good when paired with a consistent sampling routine.
- **Pick vendors who support your crops.** Apples are not mangoes; grapes are not bananas. Templates and models tuned to your fruit save months.

Common pitfalls (and easy fixes)

- **Pretty maps, no decisions.** Every data layer should end in a yes/no or a number (minutes, liters, kg/ha). If not, fly or measure less often until each pass is actionable.
- **Shadows and midday biases.** Fly close to solar noon; avoid partly cloudy “flicker” days for multispectral.

- **Over-zoning too early.** Keep zones simple in year one. Add complexity only when you've proven a clear benefit.
- **Ignoring hydraulics.** A perfect NDVI map won't fix a pressure drop. Walk the lines, read the gauges.
- **Skipping calibration.** A cheap standard solution (EC, pH) and one field-checked spot weekly keep sensors honest.
- **Under-communicating with crews.** A 30-second briefing "Rows 10–22, 25-minute set tonight" turns digital insight into real-world action.

Conclusion

Precision horticulture pays back because it respects the orchard's patchwork reality. Drones and spectral layers help you *see* earlier. Soil, canopy and microclimate sensors help you *feel* the orchard's physiology in numbers. Intelligent sprayers, variable-rate irrigation and well-timed fertigation help you *act* precisely where it matters. Wrap it all in simple routines and candid season-end reviews and you'll watch fruit size, colour and pack-out consistency improve while inputs and frustrations drop. The future here isn't sci-fi it's the everyday habit of noticing sooner and responding smarter.

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