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Land resource inventory-based fertilizer recommendation systems in fruit crops

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Abstract
Fruit crops are long-duration, high-value perennials whose nutrient requirement varies sharply across orchard blocks, tree age, canopy volume, and rootstock–scion combinations, making blanket, district-level recommended dose of fertilizer (RDF) prescriptions poorly suited to their management. Land Resource Inventory (LRI) the systematic characterization of soil, terrain, drainage, climate, and land-use attributes at a defined spatial resolution provides the foundational database on which scientifically defensible, site-specific fertilizer recommendation systems can be built. This review synthesizes the conceptual basis of LRI, the evolution of fertilizer recommendation approaches from blanket RDF to Soil Test Crop Response (STCR) targeted-yield equations, and their convergence with Geographic Information System (GIS), remote sensing, and land capability/suitability classification frameworks. It examines Site-Specific Nutrient Management (SSNM) and computer-based decision-support tools such as Nutrient Expert, reviews Indian and global case studies of GIS-based nutrient mapping in field and orchard situations, and discusses variable-rate and precision fertilization technologies emerging for fruit crops. Constraints including the paucity of orchard-specific soil-test calibration data, spatial variability within single management zones, and the cost of dense grid sampling are identified, along with future directions such as integration of hyperspectral/proximal sensing, machine-learning-based prescription models, and mobile-based farmer advisories. Adoption of LRI-based fertilizer recommendation systems can substantially improve nutrient use efficiency, orchard productivity, fruit quality, and environmental sustainability in comparison with conventional blanket dose approaches.

Keywords: Land resource inventory, GIS, land capability classification, soil test crop response, site-specific nutrient management, fruit crops, precision nutrition

Introduction
Fruit crop production in India and other tropical/subtropical regions is expanding rapidly under horticultural diversification programmes, yet productivity per unit area continues to lag behind potential yields largely because of imbalanced and non-site-specific fertilizer use. Unlike annual field crops, fruit trees occupy the same piece of land for several decades, during which soil properties evolve under the combined influence of parent material, orchard floor management, irrigation water quality, and repeated fertilization; consequently the nutrient status of an orchard block can differ markedly even within a few hundred metres.

Historically, fertilizer recommendations for fruit crops have been generalized at the state or agro-climatic zone level as a single recommended dose of fertilizer (RDF) per tree per year, largely disregarding soil type, tree age, canopy spread, and yield potential. Such blanket recommendations frequently result in under-fertilization of high-potential orchards and over-fertilization of low-fertility or already nutrient-sufficient blocks, lowering nutrient use efficiency (NUE), inflating input costs, and increasing the risk of groundwater nitrate pollution and secondary soil-fertility imbalances.

Land Resource Inventory (LRI) offers a scientific alternative. An LRI is a systematically compiled, spatially referenced database of soil morphological, physical, chemical, and fertility properties together with terrain, drainage, land use, and climatic attributes, generated through conventional soil survey integrated with remote sensing and GIS. When linked with crop-response models such as the Soil Test Crop Response (STCR) targeted-yield approach or computerized decision-support tools such as Nutrient Expert, an LRI becomes the backbone of a fertilizer recommendation system capable of prescribing orchard- or even tree-block-specific nutrient doses. This review consolidates the concepts, methods, technological components, case evidence, and constraints of LRI-based fertilizer recommendation systems as applied to fruit crops, and outlines future research priorities.

Land Resource Inventory: Concept and Components
Soil resource inventory provides awareness of the potentialities and limitations of soil for effective utilization, offering sufficient information on soil characteristics, landform, terrain, and vegetation that can subsequently be employed for land resource management and development planning.

An LRI for fruit crop nutrient management is generated in three broad stages. First, base data are compiled from toposheets, high-resolution satellite imagery, digital elevation models (DEM), and cadastral/orchard-block boundary maps. Second, systematic ground-truthing through physiographic-soil correlation and grid- or orchard-block-based soil sampling generates soil morphological, physical, and chemical data, including horizon-wise depth, texture, drainage class, slope, erosion status, pH, electrical conductivity, organic carbon, and available macro- and micronutrient status. Third, these point observations are spatially interpolated and integrated in a GIS environment to generate continuous thematic layers covering the entire inventory area (Figure 1).

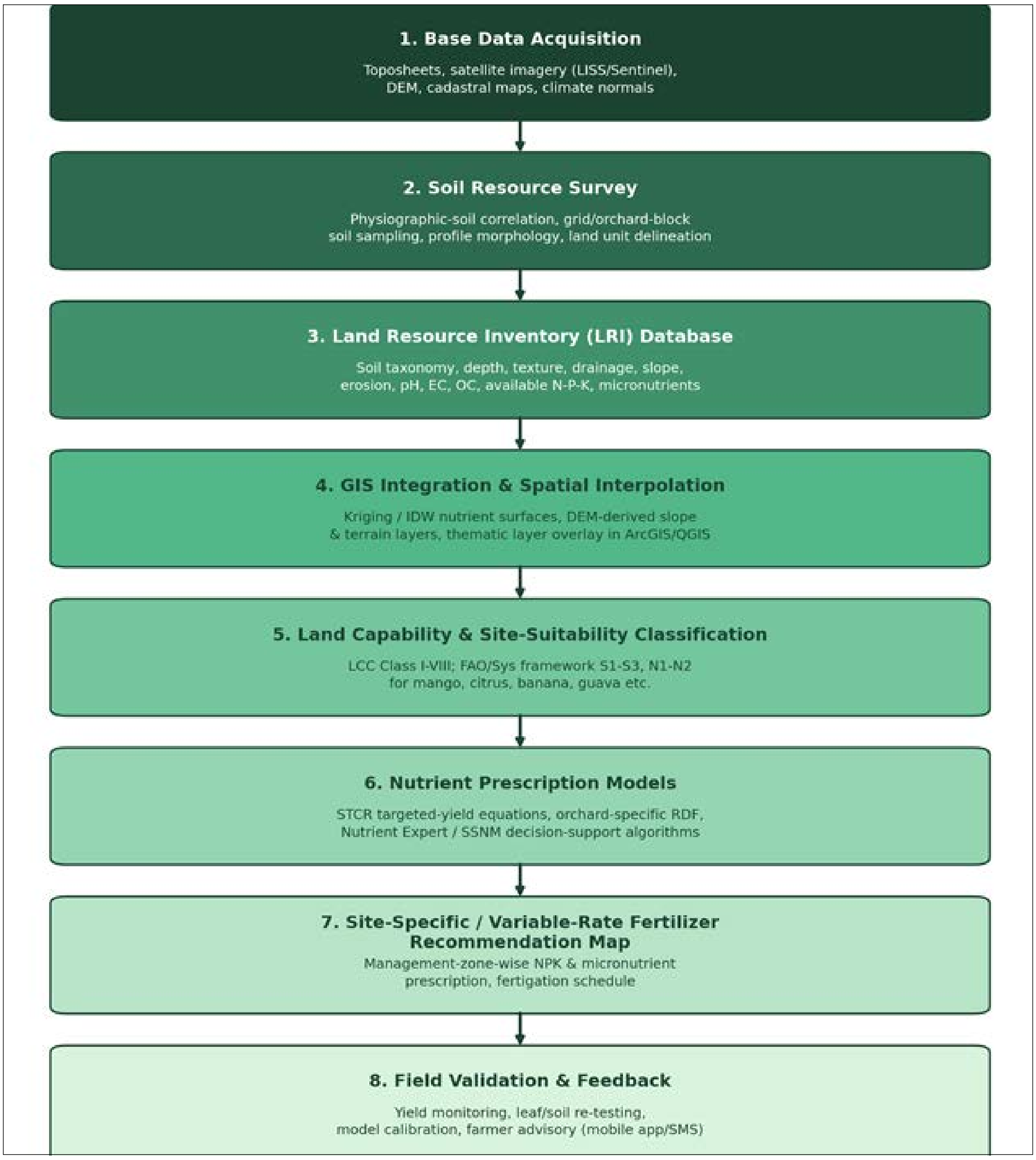

Fig 1: Generalized pipeline of a Land Resource Inventory (LRI)-based fertilizer recommendation system for fruit crops.

1. Data Layers Used in Land Resource Inventory

A comprehensive LRI database for orchard nutrient planning typically comprises the layers summarized in Table 1.

Table 1: Principal Data Layers Compiled in a Land Resource Inventory for Fruit Crop Nutrient Management

Category	Parameters/Attributes	Typical Source
Soil morphology & physical properties	Depth, texture, structure, drainage class, coarse fragments	Soil survey, profile study
Soil chemical/fertility properties	pH, EC, organic carbon, available N, P, K, S, Ca, Mg, DTPA-extractable Zn, Fe, Cu, Mn, B	Grid/orchard-block soil sampling & laboratory analysis
Terrain attributes	Slope, elevation, aspect, landform, erosion class	DEM, toposheet, field survey
Hydrology	Depth to water table, irrigation water quality, drainage	Well inventory, water analysis
Climate	Rainfall, temperature, evapotranspiration, frost incidence	IMD climate normals
Land use / land cover	Orchard age, planting density, cropping pattern, canopy cover	Satellite imagery, ground survey

2. Land Capability and Site-Suitability Classification

Land capability classification (LCC) groups land into classes I–VIII on the basis of the degree and kind of permanent limitation (slope, erosion, depth, drainage, soil-related hazards) affecting its use, ranging from land with no significant limitation (Class I) to land unsuited to any commercial production (Class VIII). Land suitability evaluation, following the FAO framework and the parametric system, further rates land units for a specific crop into suitability orders and classes (e.g., S1-highly suitable to N2-permanently not suitable) based on how well land qualities match the crop's specific requirements. For fruit crops such as mango, citrus, banana, guava, apple, and drumstick, suitability evaluation additionally weighs rootstock compatibility, chilling requirement, drainage sensitivity, and salinity tolerance.

Representative distribution of land capability classes recorded across LRI-based watershed studies in fruit-growing tracts is illustrated in Figure 2; such distributions guide planners in earmarking blocks for intensive orchard establishment (Classes I–III) versus those requiring conservation-oriented, low-input management (Classes VI–VIII).

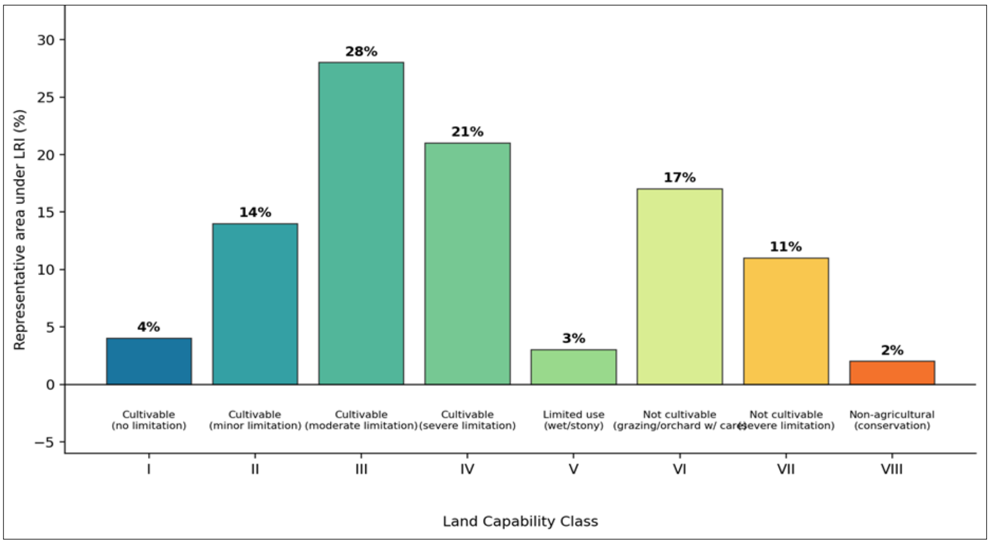

Fig 2: Illustrative land capability classification (LCC I–VIII) distribution in a fruit-growing watershed under land resource inventory.

Evolution of Fertilizer Recommendation Approaches

Fertilizer recommendation methodology for fruit crops has evolved through several stages of increasing site-specificity, summarized comparatively in Table 2.

1. Blanket Recommended Dose of Fertilizer (RDF)

The oldest and still most widely practiced approach prescribes a single, generalized per-tree or per-hectare dose of N, P, and K for a crop across an entire agro-climatic zone or state, derived from average response trials. While simple to communicate, blanket RDF ignores inherent soil fertility gradients, tree age, and yield potential, and is now recognized as the principal cause of low nutrient use efficiency in Indian orchards.

2. Soil Test Crop Response (STCR) — Targeted Yield Approach

The STCR approach is considered the most scientific fertilizer-recommendation strategy currently advocated, relating soil test values and targeted yield through empirically derived prescription equations that account for the contribution of nutrients from soil, farmyard manure, and fertilizer, developed through multi-location field calibration trials. Grounded in Liebig's law of the minimum, STCR ensures balanced rather than merely proportionate N-P-K application and allows a grower to select an economically appropriate yield target based on available resources and soil fertility status. Long-term STCR-based nutrient prescription trials under Alfisols of southern India have demonstrated improved yield, nutrient uptake, utilization efficiency, and soil-quality index outcomes relative to general RDF and soil-fertility-rating approaches.

3. GIS-Based Spatial Fertilizer Recommendation Mapping

Coupling STCR prescription equations with GIS-interpolated soil-test surfaces converts point-based recommendations into continuous fertilizer-recommendation maps. In a study on the Hanjihalli micro-watershed of Hassan district, Karnataka, geo-referenced surface soil samples collected on a systematic grid were analyzed for available N, P, and K, and STCR equations were embedded in an ArcGIS platform to generate ready-reckoner nutrient tables and site-specific fertilizer-recommendation maps for major field crops, validated on farmers' fields with more than 90 percent achievement of targeted yield. Comparable GIS/GPS-based nutrient mapping combined with kriging and inverse-distance-weighting interpolation has been used to assess soil fertility and generate balanced fertilizer-recommendation maps for micro-watersheds, underscoring the transferability of the approach from field crops to orchard systems.

4. Site-Specific Nutrient Management (SSNM) and Decision-Support Tools

Site-Specific Nutrient Management emphasizes balanced, crop-need-based nutrient application tailored to field- or zone-level variability rather than a fixed regional dose. Computer-based decision-support software such as Nutrient Expert operationalizes SSNM by generating field- or area-specific fertilizer recommendations from yield-response and nutrient-use-efficiency algorithms, and has been standardized and validated for cropping systems in South Asia, improving system productivity and agronomic efficiency relative to farmer fertilizer practice. Extension of comparable decision-support logic to fruit crops — combining soil-test ratings, canopy volume, and orchard-specific yield targets — is an active area of applied research.

Table 2: Comparative Features of Fertilizer Recommendation Approaches Used in Fruit Crops

Approach	Basis of Recommendation	Spatial Resolution	Key Limitation
Blanket RDF	Average response trial for the crop/zone	State/agro-climatic zone	Ignores soil and orchard-level variability
Soil Fertility Rating	Low/medium/high soil-test class adjustment factor	Field/orchard block	Coarse fertility classes; no yield target
STCR (targeted yield)	Prescription equations from soil test + yield target	Field/orchard block	Needs location-specific calibration trials
GIS-based STCR mapping	STCR equations embedded on interpolated soil-test surfaces	Grid cell / management zone	Dense sampling cost; interpolation error
SSNM / Nutrient Expert	Decision-support algorithm using yield gap & NUE	Field/zone	Requires robust local calibration database
Variable-rate/precision (VRT)	Sensor- or map-based prescription applied in real time	Sub-plot/tree-zone	High equipment cost; limited orchard-specific algorithms

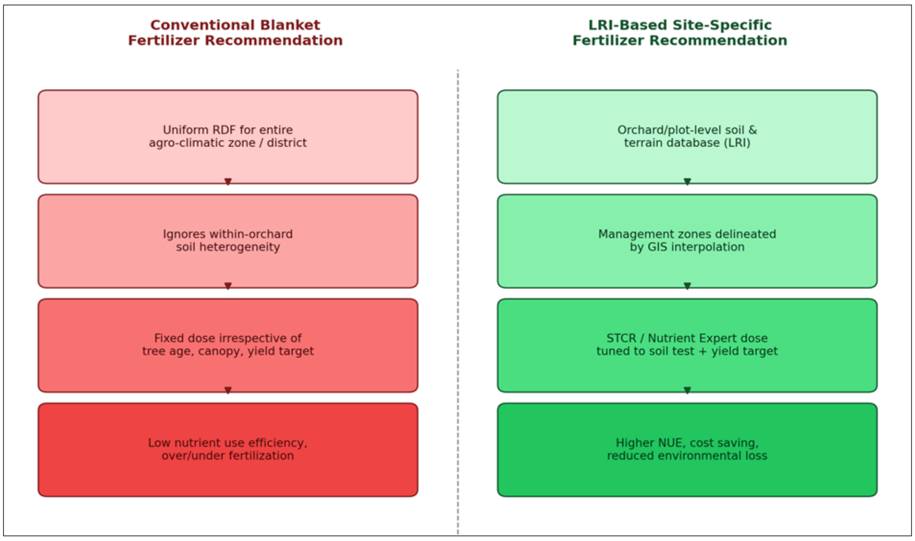

Fig 3: Conceptual comparison of conventional blanket fertilizer recommendation and land resource inventory-based site-specific fertilizer recommendation in fruit crops.

Role of Gis and Remote Sensing in Land Resource Inventory

Geostatistics, remote sensing, and GIS are the principal tools used to understand and represent the spatial variability of soil properties, which change with time and space owing to soil-formation processes, land-use patterns, and repeated fertilization. Digital maps generated on GIS platforms such as ArcGIS or QGIS provide a precise, powerful means of relating soil and terrain attributes to a specific geographic location with strong visual and analytical impact for decision-makers.

Point-based soil-test observations are typically converted into continuous nutrient-status surfaces using geostatistical interpolation techniques such as kriging or inverse distance weighting (IDW), after which the interpolated layers are overlaid with terrain, climate, and land-use layers to delineate nutrient-management zones (Figure 4). Multi-criteria decision analysis, frequently implemented through the Analytic Hierarchy Process (AHP), is used to assign relative weights to soil, terrain, and climatic parameters when generating composite land-suitability maps for a target crop.

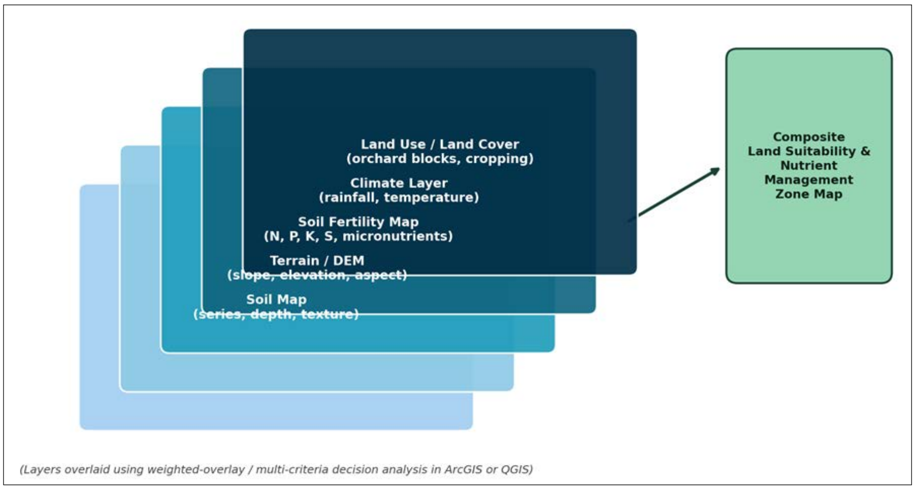

Fig 4: GIS-based overlay of thematic data layers used in land resource inventory for fertilizer recommendation.

The concept of grid-based fertilizer application through such recommendation maps helps supply nutrients according to actual crop demand and improves crop growth and yield; when a field or orchard is divided into smaller management zones, site-specific fertilizer management becomes feasible at a resolution unattainable with blanket recommendations. Institutionally, the ICAR-National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) has generated land/soil resource databases for southern Indian states and has specifically undertaken assessment of land resources for horticultural crops under national horticulture mission projects, illustrating the institutional pathway through which LRI outputs feed into orchard-siting and nutrient-planning decisions.

Case Studies and Applications

Table 3 summarizes representative case studies illustrating the application of land resource inventory, GIS, and STCR/SSNM approaches to fertilizer and land-use recommendation, spanning both field-crop micro-watersheds (which have generated the underlying methodology) and fruit/plantation-crop-specific applications.

Table 3: Representative Case Studies of Land Resource Inventory / GIS-Based Nutrient and Land Suitability Assessment

Study Area / Crop	Approach	Key Outcome	Source
Hanjihalli micro-watershed, Hassan, Karnataka (paddy, maize)	GIS + STCR targeted-yield mapping using ArcGIS with grid soil sampling	Site-specific N-P-K recommendation maps; validated recommendations achieved >90% of targeted yield on farmers' fields	Raddy et al. (2021)[16]
Hanjihalli micro-watershed (balanced fertilizer recommendation)	Kriging/IDW-interpolated soil fertility mapping using 100 composite samples on a 100 m grid	Balanced fertilizer-recommendation maps for improved crop productivity	Soil fertility assessment study, Hanjihalli watershed
Cacao plantations, Côte d'Ivoire	GIS-linked soil diagnosis software converting a single blanket fertilizer into 130 land-unit-specific recommendations	Locally adapted cacao fertilizer prescriptions replacing a single national formula	Land-unit-based cacao fertilizer study
Apple orchards, Kashmir valley	Scenario-based land suitability modelling integrating remote sensing, DEM, and NBSS&LUP soil data	Delineation of highly suitable to marginally suitable zones for apple cultivation under climate scenarios	Kashmir apple land suitability study
Chamarajanagar district, Karnataka	GIS-based integration of soil texture, depth, erosion, slope, flooding for multi-crop suitability/capability mapping	Land suitability and capability maps identifying constraints for agricultural planning	Chamarajanagar land suitability/capability study
Coastal region of India (rice, coconut)	AHP-integrated GIS/remote sensing multi-criteria suitability analysis using nine soil-terrain-climate parameters	First region-wide integrated AHP-GIS-RS suitability map for coastal cropping	Coastal India crop suitability study
Citrus orchards (precision trials)	Variable-rate fertilizer application guided by soil-sensor prescription maps	Reduced total fertilizer use and cost while increasing fruit counts compared with uniform-rate application	Citrus VRT trial synthesis
Mango orchards (soil vs. foliar micronutrients)	STCR-based RDF combined with soil and foliar Zn, Fe, Cu, Mg, B application	Highest individual fruit weight and yield per tree under combined STCR + micronutrient soil/foliar schedule	Mango micronutrient trial

Collectively, these studies demonstrate that the LRI-GIS-STCR/SSNM pipeline is technically transferable across field crops, plantation crops, and fruit orchards, with fruit-crop-specific applications increasingly incorporating canopy volume, tree age, and rootstock as additional covariates beyond the soil-test values used for annual crops.

Toward Precision Nutrient Management in Fruit Crops

Precision nutrient management is an emerging strategy for optimizing nutrient supply in fruit crops so that plants receive the required amount of essential elements at the right time and place, addressing the deficiencies, over-fertilization, and uneven distribution associated with traditional methods through real-time data on soil condition, plant health, and nutrient status. The strategy draws on remote sensing, variable-rate technology, fertigation, slow/controlled-release fertilizers, and organic amendments to tailor nutrient application to the specific needs of each orchard block and, ultimately, individual trees.

Development of production-linked nutrient norms based on crop-specific index plant parts requires re-examination at the orchard level, comparing conventional basin irrigation with fertigation systems, while hyperspectral analysis as a form of proximal sensing is beginning to impart precision to nutrient-stress diagnosis. A persistent constraint is that soil-test ratings remain insufficiently purposeful for orchard use because spatial variation in soil fertility within a single orchard is rarely resolved into distinct soil-fertility analogues for fruit crops; conjoint use of geoinformatics with nutrient-expert decision-support tools, canopy-volume-linked nutrient algorithms, and nutrient-microbe synergies has been identified as a route to overcoming this gap.

At the equipment level, variable-rate technology (VRT) applies fertilizer according to GPS-referenced prescription maps derived from soil tests and yield history, allowing nutrient-rich zones to receive little or no additional fertilizer while low-fertility zones receive more; in citrus orchard trials, VRT decreased total fertilizer use and cost while increasing fruit counts relative to uniform-rate application, illustrating the direct productivity and efficiency gains achievable when LRI-derived spatial data are translated into machine-executable prescriptions.

Constraints and Research Gaps

1. Orchard-specific STCR calibration equations are lacking for most fruit crops and agro-climatic regions; existing equations are largely derived for annual field crops and adapted with limited validation to perennials.
2. Dense grid soil sampling required for reliable spatial interpolation is cost- and labour-intensive, restricting

LRI generation to pilot watersheds rather than routine district-wide coverage.

3. Within-orchard spatial variability in soil fertility is frequently finer than the resolution of available soil-fertility analogues, limiting the precision of derived management zones.
4. Canopy volume, rootstock-scion interaction, and tree-age-linked nutrient demand are inconsistently incorporated into GIS-based recommendation algorithms designed originally for annual crops.
5. Interpolation techniques such as kriging and IDW carry inherent estimation error, particularly in areas of sparse sampling or complex terrain typical of hill and plateau fruit-growing tracts.
6. Integration of LRI outputs into farmer-usable advisories (mobile apps, SMS-based recommendations) remains limited in scale, constraining field-level adoption despite technical feasibility.

Future Prospects

Future strengthening of LRI-based fertilizer recommendation systems for fruit crops is likely to proceed along several converging lines: (i) generation of crop- and rootstock-specific STCR/SSNM calibration databases through coordinated multi-location orchard trials; (ii) wider use of hyperspectral and proximal canopy sensing to diagnose nutrient stress non-destructively and update prescription maps within a season; (iii) coupling of digital soil mapping with machine-learning prediction models to reduce interpolation error and sampling cost while improving spatial resolution; (iv) expansion of variable-rate and fertigation-linked precision nutrition equipment adapted to orchard row geometry; and (v) delivery of LRI-derived, tree-block-specific fertilizer advisories through mobile applications to bring precision nutrient management within reach of small and marginal fruit growers, who constitute the majority of orchard holdings in India.

Conclusion

Land Resource Inventory provides the spatially explicit soil, terrain, and climate database without which fertilizer recommendation for fruit crops remains generalized and inefficient. Integration of LRI with GIS-based interpolation, land capability/suitability classification, STCR targeted-yield equations, and emerging decision-support and precision-nutrition technologies allows fertilizer prescriptions to move from a single blanket dose toward orchard- and zone-specific recommendations. Evidence from field-crop micro-watersheds and initial fruit-crop applications indicates that this shift can substantially improve nutrient use efficiency, yield, and fruit quality while reducing input cost and environmental risk. Realizing this potential at scale in fruit crops will require dedicated orchard-level calibration trials, cost-effective spatial data acquisition, and farmer-accessible advisory delivery mechanisms.

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