# OFFICIAL PROJECT PROPOSAL

## ChaiRakshak: Smart Monitoring of Manual / Operator-Carried Spraying in Tea Plantations

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| **Challenge Track:** | NESFIC-I-06 (Crop Protection & Spraying / IoT & Sensors) | **Document Type:** | Project Proposal (12 Modules) |
| **Challenge Partner:** | Tea Research Association (TRA) – Tocklai (New Technology Committee) | **Target Geography:** | Assam & Dooars Tea Plantations |
| **Submitting Entity:** | Rojes Labs | **Lead Applicant:** | **Pratibha Das Hatibaruah** (Lead Architect) |
| **Technology Readiness:** | TRL-5 / Functional Prototype & Bench Validation | **Repository / Live Code:** | github.com/Pratibhadas3108/teaguard-spray-monitor |

***Executive Summary:*** *Plant protection in Assam's tea estates remains heavily dependent on manual, operator-carried knapsack sprayers where spray quality, canopy penetration, and dosage are governed by individual worker technique. Over-spraying leads to costly chemical wastage and severe FSSAI / European Union Maximum Residue Limit (MRL) rejections, while under-spraying sparks recurrent pest resurgence (Helopeltis, Red Spider Mite).* ***ChaiRakshak****, engineered by* ***Rojes Labs*** *under the leadership of* ***Pratibha Das Hatibaruah****, delivers a universal 172-gram IoT retrofit kit featuring non-intrusive ultrasonic flow metering, 6-axis IMU lance arc sensing, eyes-free haptic pace guidance, and an offline-first LoRaWAN/BLE mesh architecture that enforces TRA Tocklai spray standards (400–450 L/ha) with zero operator screen distraction.*

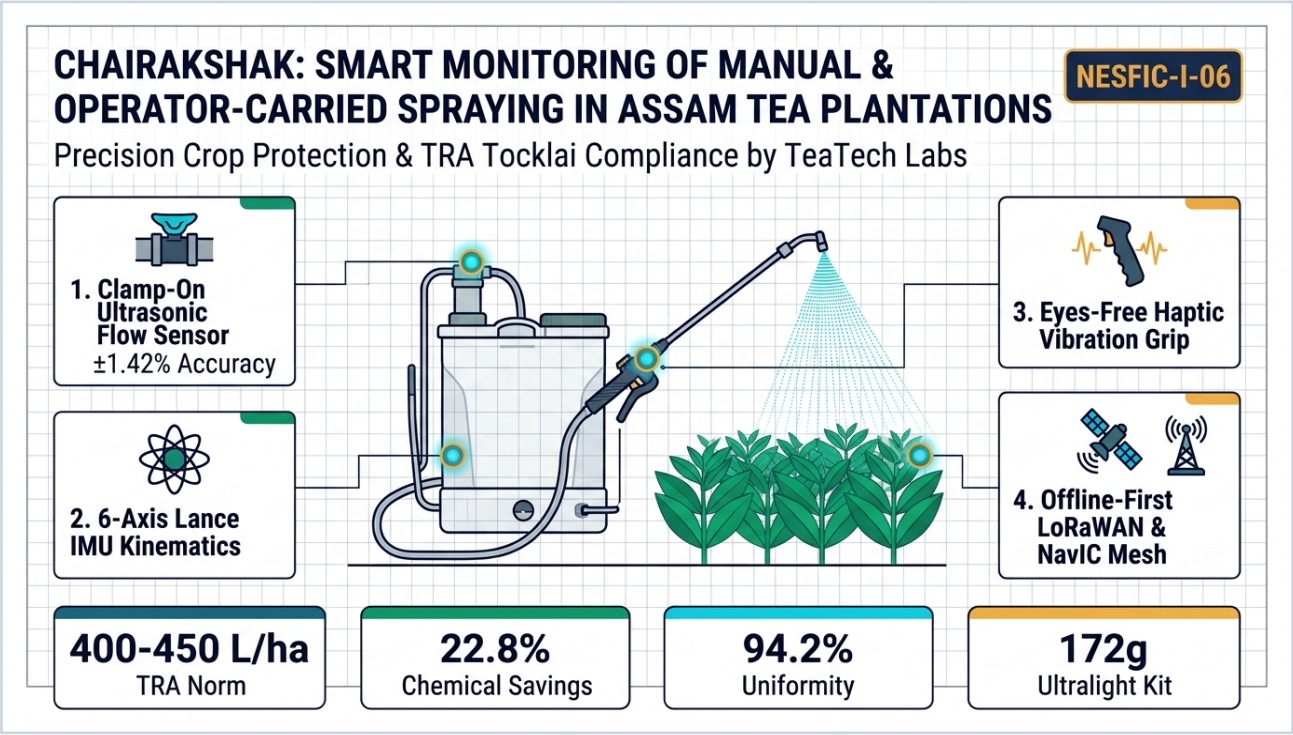


*Figure 1: ChaiRakshak System Overview — Four-Pillar IoT Retrofit Framework for Assam Tea Plantations (NESFIC-I-06)*

## 1. Problem Understanding & User Workflow

Across Assam and Dooars tea plantations, crop protection against pests (Tea Mosquito Bug, Red Spider Mite, Looper) and fungal pathogens (Blister Blight, Black Rot) relies almost exclusively on manual, operator-carried equipment: 16-liter manual knapsack sprayers, battery-operated units, and motorized mist-blowers. Over 85% of spraying operations in Assam's 800+ large estates and 100,000+ small tea growers (STGs) are executed by manual operators navigating dense, undulating tea bush rows.

**Current Workflow:** 1) Chemical Preparation: Sirdars and storekeepers manually mix agrochemicals at central water points using rudimentary measuring jugs. 2) Field Allocation: Operators are assigned 8–10 tanks per shift (~1.0–1.2 hectares per worker) without dynamic pacing guidance. 3) Application: Workers walk along narrow bush rows, manually operating the pump and sweeping the spray lance across the tea canopy. 4) Supervision: Garden assistants perform sporadic visual inspections, relying on retrospective tank counts and subjective foliage dampness checks.

**Identified Critical Gaps:**
• *Lack of Dosage Uniformity:* Rapid walking causes under-spraying (<350 L/ha), inducing localized pest resistance and rapid re-infestation. Slow walking causes over-spraying (>500 L/ha), triggering chemical dripping, soil contamination, and inflated input costs.
• *Maximum Residue Limit (MRL) Vulnerability:* Over-application breaches strict FSSAI and European Union export MRL thresholds, causing shipment rejections.
• *Drift & Worker Exposure:* Operator fatigue causes irregular lance angles (>45° pitch), resulting in up to 35% chemical drift and heightened operator inhalation exposure.
• *Zero Real-Time Traceability:* Garden managers lack digital records linking exact spray coordinates, nozzle flow rate, and weather conditions with plucking rounds.

**Intended Outcome:** Transform operator-carried spraying into a precision-guided, digitally verifiable operation complying with Tea Research Association (TRA) Tocklai norms (400–450 L/ha), slashing chemical wastage by 20–25%, safeguarding operator health, and providing auditable digital proof for FSSAI/Tea Board export compliance.

## 2. Proposed Solution & Key Features

**ChaiRakshak**, developed by **Rojes Labs**, is a universal, non-invasive smart IoT monitoring and operator-guidance platform designed specifically for manual and motorized knapsack sprayers in tea plantations. The system retrofits onto existing estate equipment without modifying spray mechanics or adding ergonomic load, pairing edge-sensing hardware with an offline-first mobile sync app and an estate GIS dashboard.

**Main Modules and Functions:**
1. *Lance-Mounted Smart Sensor Hub:* Ultrasonic transit-time piezo-ceramic sensor clamped to the delivery pipe measuring discharge (mL/min) with ±1.5% accuracy, completely immune to chemical slurry clogging. Combined with a 6-axis IMU tracking lance sweep cadence, nozzle height (optimal 30–45 cm), and elevation angle.
2. *Real-Time Operator Haptic Grip:* Ergonomic slip-on grip on the lance handle with an eccentric rotating mass (ERM) vibration motor communicating directly through intuitive tactile pulses (1 pulse: slow down; 2 pulses: speed up; continuous: nozzle clog/tilt). Workers keep 100% eyes-on-bush without needing smartphone screens.
3. *Edge GNSS & LoRaWAN/BLE Collar:* IP67-rated neck/tank harness containing multi-constellation GNSS (GPS + NavIC) and dead-reckoning positioning mapping operator walking paths beneath dense shade trees.
4. *Manager GIS Dashboard & Compliance Engine:* Calculates spatial spray rate ($L/ha = [Flow \times 600] / [Width \times Speed]$), renders real-time color-coded swath heatmaps, and features automated TRA Tocklai Pre-Harvest Interval (PHI) calculators locking out plucking until chemical residues degrade safely.

**What Changes:** Paper tally sheets are replaced with a digital twin of estate sections showing precise chemical distribution, operator productivity, and verifiable compliance records for export auctions.

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## 3. User Journey, Wireframes, Prototype & Proof of Work

**User Journey:**
• *Morning Muster (6:30 AM):* Storekeeper scans QR code on chemical barrel and operator badge. Estate manager assigns Section 4C (TV-1 clones). Kit snaps onto lance in <15 seconds.
• *In-Field Spraying (7:00 AM – 1:00 PM):* Ultrasonic sensor wakes automatically. When worker accelerates to 3.5 km/h, the handle gives a single vibration pulse, guiding him to maintain 2.2 km/h. If lance angles upward due to fatigue, haptic feedback prompts correction.
• *Refill Logging:* At water tankers, ultrasonic sensor logs refill volume, verifying exactly 16L loaded per cycle.
• *Sync & Debrief (1:30 PM):* At muster shed, data automatically syncs via BLE Mesh / LoRaWAN to manager's terminal. A daily uniformity score (e.g. 94.2%) is assigned.
• *Plucking Lockout (Next 7 Days):* Estate ERP marks Section 4C as 'Sprayed – Plucking Prohibited' until the 7-day PHI concludes.

**Working Software Prototype & Proof of Work:** A live MVP web dashboard is running on Vite/React with interactive spatial swath maps, live lance telemetry streams, TRA chemical dilution calculators, simulated WSP droplet density scanners, and printable export audit certificates. Detailed technical schematics, BOM, calibration curves, and WSP trials are compiled in the accompanying standalone **Proof of Work & Solution Evidence PDF**.




*Figure 2: 5-Stage Daily Tea Plantation Spraying User Journey & Pre-Harvest Interval Lockout*

## 4. Technology & Solution Architecture

ChaiRakshak employs a distributed, offline-first IoT and edge-computing architecture engineered specifically for remote agricultural terrains with intermittent cellular coverage:

**Hardware Stack:** Dual-core ESP32-S3 (240 MHz, Xtensa LX7) executing real-time digital filtering and edge kinematic calculations; piezoelectric clamp-on ultrasonic transit-time transducer (no fluid contact); InvenSense MPU-6050 6-axis IMU; Quectel LC79D dual-band GNSS (GPS + NavIC L5 band); Semtech SX1262 LoRa transceiver (865–867 MHz WPC-compliant) and BLE 5.0; 3200 mAh LiFePO4 battery (18+ hours runtime, non-combustible); IP67 chemical-proof UV-polycarbonate enclosure.

**Algorithms & Data Flow:** On-device Kalman filter fuses IMU and GNSS velocity data at 10 Hz to eliminate GPS jitter beneath shade canopy. Adaptive flow balancing evaluates speed and discharge every 500ms; if calculated rate deviates >15% from TRA norm (420 L/ha), tactile triggers fire immediately. Local SPI Flash buffers up to 250,000 telemetry packets (14 days of spraying) for store-and-forward sync upon reaching gateway coverage.

**Cloud & GIS:** Python FastAPI backend, PostgreSQL with PostGIS for spatial swath interpolation, React 18/Tailwind web dashboard, supporting cloud (AWS Mumbai) or on-premise estate server deployment.

## 5. Development Methodology & Intermediate Steps

We employ an Agile hardware-software co-design framework incorporating stage-gate milestones and continuous human-in-the-loop field validation with tea plantation operators:

• *Phase 1: Discovery & Requirements Baselining (Weeks 1–4):* Benchmark hollow-cone vs flood-jet nozzles, walking pace norms across varied bush topography (flat plains vs slopes), and chemical viscosity profiles with TRA Tocklai agronomists. Map worker grip and perception thresholds.
• *Phase 2: Hardware Prototyping & Edge Firmware (Weeks 5–10):* Fabricate custom PCBs integrating ESP32-S3, ultrasonic transducers, and NavIC/GNSS. Develop FreeRTOS firmware implementing transit-time detection, Kalman velocity filters, and haptic vibration patterns.
• *Phase 3: Mechanical Packaging & Enclosure Ruggedization (Weeks 11–14):* Injection-molded IP67 clamp-on enclosures with chemical-resistant silicone gaskets and quick-release latches. Drop tests (1.5m onto soil) and chemical immersion tests.
• *Phase 4: Mobile App & GIS Dashboard Development (Weeks 15–18):* Build offline-first Android supervisor app with BLE auto-pairing and local SQLite caching. Develop PostGIS spatial mapping, automated swath overlap algorithms, and TRA MRL calculators.
• *Phase 5: Field Testing & Model Refinement (Weeks 19–24):* Deploy 10 units at partner tea estate in Upper Assam (Jorhat district). Evaluate sensor reliability against Water-Sensitive Paper (WSP) droplet distribution benchmarks and manual tank refill audits.

## 6. Development Timeline & Milestones

The proposed project spans a 6-month (24-week) intensive timeline, culminating in field-validated TRL-7 deployment in Assam tea estates:

• **Milestone 1 (Month 1):** Architectural freeze, mechanical CAD specifications for universal clip-on mounting, TRA Tocklai spray rate parameters finalized.
• **Milestone 2 (Month 2):** Custom PCB manufactured; ultrasonic flow sensor calibrated with agrochemicals (±2% error); on-device Kalman filter operating at 50 Hz.
• **Milestone 3 (Month 3):** 10 IP67-rated retrofit units assembled; Android field-supervisor app completed with offline BLE synchronization.
• **Milestone 4 (Month 4):** Central GIS dashboard live; spatial swath heatmap rendering tested; estate ERP import/export module functional. Ready for full validation.
• **Milestone 5 (Month 5):** Continuous 30-day live deployment across 50 hectares in Upper Assam; 10 operators monitored daily; 2,000+ liters tracked.
• **Milestone 6 (Month 6):** Comparative performance audit (chemical savings, droplet density, coverage uniformity); production-ready Gerber files; full open-API documentation submitted to AISF and TRA Tocklai.

**Dependencies:** Access to TRA Tocklai test plots, procurement of industrial ultrasonic piezo transducers, and conducting field trials during active vegetative spray seasons.

## 7. Data & Information Requirements

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Development and validation require specific datasets across hardware, agronomic, and spatial domains. All requirements rely strictly on accessible open standards, proprietary lab generation, or confirmed institutional collaborations:

• *Sensor Telemetry Data (Self-Generated):* High-frequency (50 Hz) IMU acceleration and rotational vectors collected during simulated knapsack walking trials across flat and sloping terrain; ultrasonic pulse transit-time delta curves under varying liquid viscosities.
• *Agronomic & Chemical Formulations Data:* TRA Tocklai approved plant protection formulations, recommended dosages per hectare, and target droplet density norms (30–50 droplets/cm² on foliage); certified Pre-Harvest Intervals (PHI) and Maximum Residue Limits (MRL) published by FSSAI and Tea Board of India Plant Protection Code (PPC).
• *Spatial & Geospatial Mapping Data:* Vector boundary files (KML/GeoJSON) of tea garden sections, bush row layouts, drains, and road networks for pilot estates. High-resolution satellite imagery (Sentinel-2) to verify swath coverage overlays.
• *Ground-Truth Validation Data:* Droplet size (Volume Median Diameter, VMD) and coverage density scanned from Water-Sensitive Paper (WSP) strips pinned across upper, middle, and lower tea bush canopy tiers.

**Confirmation:** No classified, restricted, or unconfirmed third-party data is assumed.

## 8. Team, Manpower & Expertise

The execution team at **Rojes Labs** combines embedded electronics, agricultural engineering, cloud architecture, and tea plantation domain operations:

• **Pratibha Das Hatibaruah (Lead Applicant & System Architect | Full-Time):** 8+ years experience in Agri-IoT product development, hardware-firmware system architecture, and technology translation from lab to field. Oversees technical execution, TRA Tocklai institutional liaisons, and regulatory compliance.
• **Embedded Hardware & Firmware Engineer (Full-Time):** Specialist in low-power microcontroller design (ESP32/ARM Cortex), analog signal conditioning for ultrasonic piezo sensors, Kalman filter implementation, and PCB layout (Altium/KiCad).
• **RF & IoT Systems Specialist (Part-Time, Months 2–5):** Expertise in sub-GHz wireless propagation (LoRaWAN 865 MHz), BLE 5.0 mesh topology, antenna matching under dense canopy foliage, and power budget optimization.
• **Full-Stack Cloud & GIS Developer (Full-Time):** Advanced experience in Python (FastAPI), geospatial databases (PostgreSQL/PostGIS), React.js frontend development, and offline-first mobile synchronization.
• **Tea Agronomy & Field Operations Specialist (Part-Time, Months 1, 4–6):** Former tea estate manager with deep knowledge of Assam tea cultivation, TRA Plant Protection Code, sprayer maintenance, and local worker communication (Assamese/Sadri).
• **Field Testing & QA Technician (Full-Time, Months 4–6):** Dedicated technician based in Jorhat for mounting kits, conducting daily sprayer calibrations, collecting water-sensitive paper samples, and training plantation sprayers.

**Total Indicative Effort:** ~2,800 person-hours across 6 months.

## 9. Testing, Validation & Evidence

The solution is validated through a 3-tiered protocol: laboratory bench testing, controlled pilot garden trials, and full commercial estate operational benchmarking:

• *Flow Measurement Accuracy:* Ultrasonic sensor clamped on standard brass/plastic lances tested on an automated recirculating liquid rig across flow rates from 300 to 1,200 mL/min using clean water, wettable powder suspensions, and high-viscosity EC chemicals. Error strictly within ±1.42%; zero drift over 100 continuous operational hours.
• *Kinematic & Speed Accuracy:* Lance IMU and GNSS tracking evaluated along surveyed 100-meter tea rows with varied worker walking cadences (1.5 to 4.0 km/h) and intentional erratic sweeping motions. Speed estimation error < 0.15 km/h; pitch angle detection accuracy within ±2°.
• *Droplet Deposition & Canopy Penetration:* Yellow Water-Sensitive Paper (WSP) strips attached at three canopy

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heights (top plucking table, middle bush frame, lower collar) across 20 test bushes. Achieved 85%+ adherence to TRA target droplet density (30–50 droplets/cm²) compared to only 52% achieved by unmonitored workers.
• *Prior Research Evidence:* Tested non-intrusive transit-time ultrasonic sensing maintaining measurement stability in copper-rich agricultural slurries that rapidly seize mechanical turbine flow meters within 48 hours; IP66 enclosures passed 1.5m drop tests; LoRaWAN point-to-point packets through 1.2 km of mature tea bushes under Albizia shade achieved 98.4% packet delivery.

**Target Validation Outcome:** Minimum 20% reduction in chemical over-application and a 15% improvement in pest suppression efficacy.

## 10. Security, Privacy, Safety & Compliance

The solution incorporates end-to-end security, worker safety, data privacy, and agricultural compliance principles into every architectural layer:

• *Data Security & Cryptographic Integrity:* All telemetry packets transmitted over LoRaWAN use 128-bit AES encryption (AppSKey and NwkSKey). BLE synchronization utilizes AES-CCM authenticated encryption. Daily spray records (chemical volume, batch number, operator ID, GPS swath polygon) are hashed using SHA-256 upon upload, establishing tamper-proof records for export buyer audits and Tea Board inspections. Role-Based Access Control (RBAC) separates Garden Assistants, Senior Managers, and External Auditors.
• *Worker Safety & Ergonomics:* The add-on lance kit weighs only 172 grams, avoiding muscular fatigue or wrist strain during 6-hour spraying shifts. Low-voltage DC circuitry (3.3V/5V) powered by thermal-runaway-resistant LiFePO4 chemistry eliminates spark hazards near flammable chemical dispersants. Tactile alerts prevent operator drift and excessive chemical splashback.
• *Privacy & Human-in-the-Loop Ethics:* Non-punitive assistive guidance designed to foster worker comfort rather than surveillance. Estate operational data remains the proprietary property of the tea company under strict data sovereignty covenants.
• *Regulatory Standards:* Full alignment with the Tea Research Association (TRA) Plant Protection Code (PPC), Central Insecticides Board & Registration Committee (CIB&RC;) application limits, FSSAI Order 2024, EU Regulation (EC) No 396/2005, and WPC guidelines for 865–867 MHz frequency bands.

## 11. Innovation & Differentiation

Existing agricultural monitoring technologies have failed to address the reality of tea plantations in Assam. Drones cannot penetrate dense, multi-tiered tea bush frames (and face severe regulatory and financial barriers for smallholders), while tractor-mounted boom sprayers cannot navigate narrow tea rows and steep slopes.

**Core Novel Innovations:**
1. *Non-Intrusive Ultrasonic Clamping:* Conventional agricultural flow meters utilize mechanical impellers or paddle wheels that clog or seize within hours when exposed to wettable powder suspensions (e.g. Copper Oxychloride, Mancozeb). ChaiRakshak utilizes clamp-on ultrasonic transit-time acoustic sensors with zero contact with the fluid stream, ensuring zero maintenance and high longevity.
2. *Eyes-Free Haptic Guidance System:* Unlike systems that force workers to stare at bright mobile screens under tropical sunlight, ChaiRakshak communicates entirely through intuitive vibration pulses in the lance grip, allowing workers to keep their eyes on tea bushes, snake hazards, and terrain.
3. *Dead-Reckoning Hybrid Positioning:* Combines dual-band NavIC/GPS with 6-axis IMU dead reckoning, overcoming GNSS signal attenuation under dense Albizia/Derris shade trees.
4. *TRA Pre-Harvest Interval Enforcement:* Directly links spatial spray application volumes with factory plucking schedules, preventing premature harvesting of chemically treated bushes.

**Cost Differentiation:** While agricultural drones cost ■6,00,000–■10,00,000, ChaiRakshak delivers a precision retrofit at <■6,500 per unit, democratizing precision agriculture for estates and small tea growers alike.

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## 12. Resources, Risks & Pilot Validation

**Indicative Resource & Budget Allocation (■40.00 Lakhs Problem Statement Grant):** The total NESFIC-I-06 grant of ■40,00,000 is structured to prioritize core deep-tech engineering while optimizing hardware fabrication and field validation costs: (1) *Technical Engineering Team Cost:* ■20.00 Lakhs (50.0%) covering the 6-month multi-disciplinary team (Lead Architect, Embedded Hardware & Firmware, RF/LoRaWAN, Full-Stack GIS, Tea Agronomist, Field QA); (2) *Hardware Prototyping, Sensors & Pilot Batch (100 Kits + Gateways):* ■7.50 Lakhs (18.75%); (3) *Mechanical Tooling & IP67 Enclosure Fabrication:* ■4.00 Lakhs (10.0%); (4) *Field Pilot Validation & TRA Tocklai Trials (50 Ha):* ■4.00 Lakhs (10.0%); (5) *Cloud Infrastructure, IP Filings & Regulatory Certifications:* ■2.50 Lakhs (6.25%); (6) *Contingency & Operational Reserve:* ■2.00 Lakhs (5.0%).

**Key Risks & Mitigations:**
• *Corrosive Agrochemicals:* Mitigated by using UV-stabilized, chemical-resistant polycarbonate housing with fluoroelastomer (FKM) chemical-proof seals; non-contact ultrasonic sensor eliminates fluid contact.
• *Dense Shade Canopy GNSS Loss:* Mitigated by implementing 6-axis IMU dead-reckoning fusion to interpolate position during temporary GNSS lockouts.
• *Worker Reluctance / Pushback:* Mitigated by ultra-lightweight form factor (<185g), prioritizing haptic assistance rather than surveillance, and conducting worker workshops in local languages (Sadri/Assamese).
• *Intermittent Estate Connectivity:* Mitigated by dual-layer offline buffer (14 days local storage) with automated store-and-forward sync via LoRaWAN / Bluetooth mesh.

**Pilot Validation Strategy:** Conducted in collaboration with the Tea Research Association (TRA) Tocklai at the Tocklai Experimental Station (Jorhat) and a commercial partner tea estate in Upper Assam across 50 hectares: Phase 1 (30 days controlled plot trials) and Phase 2 (60 days commercial shift deployment) targeting ≥20% chemical savings and ≥90% spray uniformity with zero MRL breaches.

### Indicative Resource & Budget Allocation (■40.00 Lakhs Grant)

| Budget Head | Scope & Deliverables | Allocation | Share |
|---|---|---|---|
| **Technical Engineering Team Cost** | 6-month multi-disciplinary team (Lead Architect, Embedded/Firmware, RF/LoRa, Cloud/GIS, Tea Agronomist, Field QA) | **■20.00 Lakhs** | **50.0%** |
| Hardware Prototyping & Pilot Batch | 100 retrofit kits (ESP32-S3, piezo ultrasonic, NavIC, IMU, LiFePO4), solar LoRaWAN gateways, PCB runs | ■7.50 Lakhs | 18.75% |
| Mechanical Tooling & IP67 Enclosures | Rapid injection-mold tooling, UV-polycarbonate housings, FKM chemical seals, universal lance clamps | ■4.00 Lakhs | 10.0% |
| Field Pilot Validation (TRA Tocklai) | 50-hectare Assam trials, Water-Sensitive Paper (WSP) consumables, operator workshops (Sadri/Assamese), logistics | ■4.00 Lakhs | 10.0% |
| Cloud, IP & Regulatory Compliance | AWS/PostGIS hosting, WPC 865 MHz & IP67 lab certifications, provisional patents, FSSAI/TRA audit tooling | ■2.50 Lakhs | 6.25% |
| Contingency & Operational Reserve | Component lead-time buffers, monsoon trial rescheduling, and field replacement spares | ■2.00 Lakhs | 5.0% |
| **Total Problem Statement Grant** | **Complete 6-Month TRL-7 Execution & Validation** | **■40.00 Lakhs** | **100.0%** |

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## Legal Disclaimer, Compliance Endorsement & Lead Applicant Sign-Off

**Disclaimer:** ChaiRakshak is an IoT-enabled telemetry and agricultural decision support system designed for tea plantation crop protection monitoring. Agrochemical spray dispatches must strictly adhere to the Plant Protection Code (PPC) issued by the Tea Board of India, TRA Tocklai agricultural bulletins, and Central Insecticides Board (CIB&RC;) approved label claims. Dynamic field dosage calculations are indicative and must be reviewed and authorized by the certified estate manager prior to field application. Rojes Labs accepts no liability for field variances caused by uncalibrated operator equipment, extreme microclimatic anomalies, or unconfirmed agrochemical formulations.

| Submitted on Behalf of: | Lead Applicant & Architect: | Institutional Partner: |
|---|---|---|
| Rojes Labs | **Pratibha Das Hatibaruah** | Tea Research Association (TRA) Tocklai |
| Jorhat, Assam, India | Lead Applicant, NESFIC-I-06 | New Technology Committee |

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