



Multivariate Identification of Key Soil Fertility Indicators in Submerged Systems

*Sathiyanthan M R and G Sridevi

Department of Soil Science and Agricultural University, Tamil Nadu
Agricultural University, Coimbatore-641003, India

*Corresponding Author's email: shreesaisenthilkumar2003@gmail.com

Rice feeds more than half of the world's population, and most of it is grown in submerged systems, where fields are flooded for much of the season. Flooding changes soil in dramatic ways. Oxygen is quickly exhausted, the soil becomes chemically reduced, pH drifts toward neutrality, and nutrients such as iron, manganese, phosphorus and nitrogen change their form and availability. Because of these changes, a standard soil test developed for upland crops can mislead. Meanwhile, laboratories can now measure dozens of properties: organic carbon, nitrogen, phosphorus, potassium, sulphur, micronutrients, exchangeable cations, texture, bulk density and biological activity. Testing everything is slow and costly, and many of the measurements overlap. The practical question for scientists, extension workers and farmers is simple: which indicators actually explain soil fertility and yield? This is where multivariate statistics comes in.

Why Submerged Soils Are Different

In flooded paddy soils, fertility is not just a matter of how much nutrient is present, but in what form and how it behaves under changing redox conditions.

- **Nitrogen** is held mainly as ammonium, and part is lost through denitrification when soil alternates between wet and dry phases.
- **Phosphorus** often becomes more available after flooding as iron compounds are reduced and release bound phosphate.
- **Iron and manganese** become soluble in reduced conditions and can reach levels that are beneficial or toxic.
- **Soil organic matter** drives microbial activity and nutrient supply, but decomposes differently without oxygen.
- **Texture and structure** control percolation, puddling quality and water retention.

What Is Multivariate Identification?

Instead of examining one soil property at a time, multivariate methods look at many properties together and reveal how they relate to each other and to yield. The most widely used toolkit includes:

- **Correlation analysis** to screen which properties are linked to yield or to each other.
- **Principal Component Analysis (PCA)** to condense many correlated variables into a few uncorrelated components that capture most of the variation in the data.
- **Factor analysis** to group indicators into interpretable themes such as nutrient supply, acidity or texture.
- **Discriminant analysis** to find the properties that best separate high-, medium- and low-productivity soils.
- **Stepwise or multiple regression** to test how well the selected indicators explain actual yield.

Together these methods lead to a **Minimum Data Set (MDS)**: the smallest group of indicators that still represents soil quality adequately. The MDS can then be scored and combined into a soil quality or fertility index.

What Research Has Found

Studies from several rice-growing regions show the approach works, and also that the best indicators depend on the local soil and management.

Table 1: Examples of multivariate studies in rice soils

Region	Approach	Key findings
Jiangxi, China (114 paddy fields)	Correlation with yield, PCA, minimum data set	MDS of organic matter, available N, available P, slowly available K and sand content explained 77.9% of quality variation; the index correlated with rice yield (Li et al., 2013)
Mahabubnagar, Telangana, India	Correlation, PCA, discriminant analysis, stepwise regression	First five principal components explained 72.4% of variance; five MDS indicators explained rice yield with R^2 of 0.76
Rio Grande do Sul, Brazil (29 indicators)	Multivariate analysis across management systems and soil classes	Indicators retained included organic matter, potassium, magnesium, aggregate stability, soil respiration and mineralisable nitrogen, among others
Guilan, Iran (119 sampling points)	PCA with regression	Principal components accounted for about 67% of variability in soil properties and 55% of yield variability
Jiangxi, China (three counties)	Fertility index from MDS versus full data set	Index from the minimum set correlated at 0.92 with the full-data index, saving time and cost
Kerala, India (rice and rice-prawn systems)	PCA-based MDS and soil quality index	Land use system influenced soil quality scores; 13 indicators formed the final MDS

Two lessons stand out. First, soil organic matter or organic carbon and the major available nutrients (nitrogen, phosphorus, potassium) appear repeatedly in the retained indicator sets. Second, indicators such as sand content, exchangeable calcium and magnesium, micronutrients, and biological measures like enzyme activity or respiration can become decisive depending on the region. There is no universal list.

From Indicators to Decisions

Once a Minimum Data Set is established, it can support practical decisions.

1. **Cheaper soil testing.** Laboratories and soil testing programmes can focus on the indicators that matter locally, expanding coverage at lower cost.
2. **Diagnosing low-productivity zones.** Discriminant analysis shows which properties separate poor fields from good ones, pointing to targeted correction such as zinc, organic amendments or acidity management.
3. **Site-specific nutrient management.** Soil quality indices can be mapped, and newer work combines them with drone multispectral imagery for site-specific rice management in problematic soils such as acid sulfate tidal swamplands.
4. **Monitoring over time.** A fixed indicator set allows land managers to track whether practices such as residue return, green manuring or changes in water management are improving or degrading soil.

Limitations and Cautions

- **Local, not universal.** An MDS derived in one district may not transfer to another with different soils, climate or varieties.
- **Statistical assumptions.** Methods like PCA assume reasonable relationships between variables, and dropping indicators always loses some information; in the Telangana study, for example, about 24% of yield variation remained unexplained by the retained set.

- **Sampling timing matters.** In flooded systems, redox-sensitive properties change through the season, so sampling time and depth should be standardised.
- **Yield is not only soil.** Variety, water, pests, weather and farmer management also shape yield, so soil indices should be interpreted alongside these factors.
- **Biological indicators are harder to measure.** They are informative but add cost and need careful handling of fresh samples.

Recommendations

1. Establish **region-specific Minimum Data Sets** for major rice-growing soils, validated against farmer yields.
2. Standardise **sampling depth, season and methods** for submerged soils so data can be compared across studies.
3. Combine **laboratory data with remote sensing and GIS** to map fertility at field and landscape scale.
4. Include **at least a few biological and redox-related indicators** where resources permit, since chemistry alone may miss important dynamics.
5. Translate indices into **simple farmer-facing advisories**, such as colour-coded soil health cards.
6. Revalidate indices periodically as management and climate change.

Conclusion

Multivariate analysis does not replace agronomic judgement, but it brings discipline to a crowded field of measurements. By identifying the handful of indicators that explain most of the variation in soil quality and yield, it makes soil testing in flooded systems cheaper, faster and more meaningful. For countries like India, where rice is central to food security and soils vary enormously from delta to hill, locally validated indicator sets offer a practical route to better nutrient management and sustainable intensification.

References

1. Li, P., Zhang, T., Wang, X., Yu, D. (2013). Development of biological soil quality indicator system for subtropical China. *Soil and Tillage Research* record via AGRIS.
2. Yang, M., Zhao, X., Wang, F., Guo, X., Xie, W. (2016). Soil fertility index based on minimum data sets using PCA method. *Journal of Jiangxi Agricultural University*, 38(6).
3. Soil quality assessment in relation to rice productivity in Mahabubnagar district, Telangana (KrishiKosh thesis record).
4. Soil quality assessment studies in rice and rice-prawn systems of Kerala (*Journal of the Indian Society of Coastal Agricultural Research*, ICAR).