



ifa
INTERNATIONAL
FERTILIZER ASSOCIATION



INTEGRATED PLANT NUTRIENT MANAGEMENT: Increasing Yields And Improving Soil Health

The purpose of this policy paper is to address some common misconceptions about organic and mineral fertilizers, examine their similarities and differences and explain why they should always be used together when possible. When used alongside appropriate soil management practices and crop variety selections as a part of integrated soil fertility management (ISFM), integrated plant nutrient management (IPNM) can help to ensure that the world's growing population is fed with nutritious food, land productivity is maximized, nutrient losses are minimized, and our soils are healthy and helping to protect the environment.

Key Messages:

- In addition to light, carbon dioxide and water, plants need essential nutrients to grow, which can come from both organic and mineral fertilizers. As plants can only take up mineral forms, organic sources have to be mineralized by soil microorganisms before their nutrients can be absorbed by plants.
- Mineral fertilizers contain more concentrated, consistent and readily available nutrients than organic fertilizers and enable farmers to grow more on less land. Without them, world agricultural production could fall by as much as half and it would not be possible to feed the global population.
- Local organic fertilizers are important for improving soil health as a source of organic matter, as well as a source of nutrients. Mineral fertilizers should be used to supplement them, when required, to provide additional nutrients to plants to ensure the right combination of essential nutrients for optimal crop health, yield and quality.
- Integrated plant nutrient management, using mineral fertilizer combined with organic fertilizer, has been scientifically proven to be the best method for increasing soil carbon sequestration on farmland, one of the world's most important ways to reduce greenhouse gases in the atmosphere.
- In many places, especially in areas with extremely depleted soils, farmers have limited or no access to nutrient rich organic fertilizers. In Africa, for example, the nitrogen content in manure is often below 2% due to poor quality feed (Harris, 2002). In these cases, mineral fertilizers are required to ensure the right combination of essential nutrients for optimal crop yields and to restore soil health.

- Unlike mineral fertilizers, most organic fertilizers cannot be stored for extended periods of time, are bulky and difficult to transport. As such they cannot meet the entire nutrient needs of farmers who have inadequate local access to them. They may also become an environmental problem where supply significantly exceeds crop requirements.
- To maximize its benefits, integrated plant nutrient management should always be used as a part of integrated soil fertility management, which encompasses additional aspects of nutrient management including the selection of appropriate crop varieties and crop, water and soil management practices adapted to local conditions.
- Whether organic or mineral, nutrients can be lost to the environment if they are not used efficiently. In order to optimize plant nutrient uptake and minimize losses, it is crucial to apply the 4Rs: *using the Right nutrient source, at the Right rate, at the Right time, in the Right place.*

Organic and Mineral Fertilizer: Differences and Similarities

Fertilizers are materials that are applied to soils, or directly to plants, for their ability to supply the essential nutrients needed by crops to grow and improve soil fertility. They are used to increase crop yield and/or quality, as well as to sustain soils' ability to support future crop production.

Mineral fertilizers are produced from materials mined from naturally occurring nutrient deposits, or from the fixation of nitrogen from the atmosphere into plant-available forms. Mineral fertilizers generally contain high concentrations of a single, or two or three, plant nutrients.

Organic fertilizers are derived from plant matter, animal excreta, sewage and food waste, generally in the form of animal manure, green manure and biosolids. Organic fertilizers provide essential nutrients needed by crops, generally containing a wide variety in low concentrations. They also play an important role in improving soil health.



Organo-mineral fertilizers combine dried organic and mineral fertilizers to provide balanced nutrients along with soil health improvements in a long-lasting, easy-to-transport and store form.

Organic and Mineral Fertilizers Are the Same to Plants

Mineral and organic fertilizers contain nutrients in different forms. Ultimately, however, because plants can only take up nutrients in their mineral form, the original fertilizer source makes no difference from a plant nutrition standpoint.

No matter what the source, all nutrients are used in exactly the same way by plants with the same effect.

Mineral Fertilizers: Feeding the World

Today, it would be impossible to feed the planet without mineral fertilizers.

The nitrogen produced by the Haber-Bosch synthesis process for mineral fertilizers is vital for producing large crop yields. Scientific research published in 2008 estimated that the lives of nearly half of the world's population (48%) are only made possible by Haber-Bosch produced nitrogen. (Erisman et al., 2008)

Organic Fertilizers: Feeding the Soil

Organic fertilizers increase soil health, supporting carbon capture and plant growth.

Soil organic matter (SOM) has a strong influence on the overall health of soil and its beneficial functions. By introducing soil organic carbon that helps build up SOM, organic fertilizers stimulate microbial activity, improve soil structure and increase both its water-holding and cation exchange capacity. This can reduce soil erosion and degradation, improve nutrient retention, act as a buffer against soil acidification and limit nutrient losses into waterways. Increased SOM also increases soils' capacity to capture carbon.

Mineral Fertilizers: Providing Precise, Plant Ready Nutrients When Needed

By offering concentrated, consistent, precise, accessible and easily transportable and storable nutrients, mineral fertilizers have a variety of beneficial properties that organic fertilizers alone cannot supply:

Standardized Nutrient Content

Mineral fertilizers are made with standardized and concentrated amounts of specific nutrients, allowing farmers to consistently give optimal nutrient doses to crops. The amount can even be precisely adjusted to meet the varied nutrient needs of small areas within a field, ensuring that an entire crop gets the right nutrient quantities for maximum yields.

Mineral fertilizers can contain up to 820 grams of nitrogen, 620 grams of potassium and 550 grams of phosphorus per kilogram, over 20 times more than organic fertilizers usually contain.

Constant Variation

Organic fertilizers, on the other hand, have variable nutrient content that changes over time. To get an accurate idea of nutrient levels each batch would need to be tested. Relying only on organic fertilizers may not be sufficient to consistently give plants the right amount of nutrients they need at the right time for optimal growth and health. There is also a greater risk of applying excessive amounts of certain nutrients, which can damage plant and soil health and negatively impact the environment.

Table 1. General nutrient content values of crop residues and poultry and livestock manures (Adapted from Barker et al. 2000).

Nutrient	Crop Residues	Poultry Manure	Livestock Manure
	g/kg		
N	10-15	25-30	20-30
P	1-2	20-25	4-10
K	10-15	11-20	15-20
Ca	2-5	40-45	5-20
Mg	1-3	6-8	3-4
S	1-2	5-15	4-50

Readily Available to Plants

The nutrients in mineral fertilizers are formulated to be readily available to plants, absorbed either directly through their roots or leaves. As a result, they can be applied at just the right time they are needed for the most efficient uptake during a plant's growth cycle, for example by micro-dosing during planting, minimizing nutrient losses to the environment while maximizing their efficiency.

Slow, Inconsistent Release

Because the nutrients in organic fertilizers need to be mineralized in the soil before they can be converted to a form that plants can absorb they are released slowly over time. As the conversion rate also changes according to soil moisture and temperature, it is impossible to predict the nutrient release rate or time the application, increasing the chance of losses.

Storage and Transport

Produced in a range of concentrated and stable pellet, powder and liquid forms, mineral fertilizers are compact, easy to transport and can be stored for a long time. They can be kept and used when needed to precisely provide readily available plant nutrients. Mineral fertilizers can also be transported anywhere that farmers need nutrients, turning barren soil productive again.

Limited Lifespans

Due to being quite volatile, organic fertilizers generally need to be used soon after production and are difficult to store for long periods. Manure, for example, produces anaerobic decomposition resulting in methane emissions when stored and should be applied to fields as soon as possible. Organic fertilizers are also bulky and difficult to transport. As such, their supply can be seasonal, limited or entirely unavailable to farmers without local sources.

Slow- and Controlled- Release and Stabilized Fertilizers

Several additives and treatments have been developed to modify the availability of nutrients in mineral (and even some organic) fertilizers. These include 'slow-release fertilizers' that break down gradually to release plant available nutrients (e.g. methylene urea), 'controlled-release fertilizers' that are physically encapsulated in a protective coating (e.g. polymer-coated fertilizers), and 'stabilized fertilizers' that slow N cycling in the soil (e.g. fertilizers treated with urease and/or nitrification inhibitors). All these products aim to extend the release of the nutrients from mineral fertilizers to better match crops' requirements.



Mode of action of a coated/encapsulated controlled-release fertilizer

Mineral and Organic Fertilizers: The Perfect Combination

When it comes to using organic and mineral fertilizers there really need not be any competition. Using a combination of the two has been scientifically proven to be the best solution for maximizing plants yields and sustaining healthy soils with the greatest ability to sequester carbon in agricultural soils.

Within IPNM, both types of fertilizer have a complementary role to play. Mineral fertilizers supplement the nutrients provided by organic fertilizers with concentrated, consistent and plant accessible nutrients. Organic fertilizers provide beneficial SOM that improves soils' health (including fertility, structure, water retention capacity and biological activity), and ability to sequester carbon.

IPNM: Increasing Productivity and Food Security on Existing Land

The expansion of agricultural land to forests, pastures or wetlands releases significant amounts of CO₂ through the burning of cleared bushes and the destruction of carbon sinks. By boosting yields, fertilizers have the potential to prevent further deforestation. Many studies, including the meta-analysis below, have found that using mineral fertilizers in combination with organic fertilizers produces the highest yields possible.

Based upon agricultural research findings across numerous countries and diverse agro-ecological zones of sub-Saharan Africa, for example, a consensus has emerged that the highest and most sustainable gains in crop productivity per unit of nutrient are achieved from mixtures of mineral and organic fertilizers (FAO, 1989; Pieri, 1989; Giller et al., 1998; Vanlauwe et al., 2001, Chivenge et al., 2011).

IPNM Produces the Highest Crop Yields

Maize Yields, sub-Saharan Africa

A meta-analysis of research in sub-Saharan Africa comparing the effects of organic fertilizers, mineral fertilizers and IPNM on maize, found that, on average, **IPNM produced the highest yield responses at 114% over the control.**

a Overall responses vs control

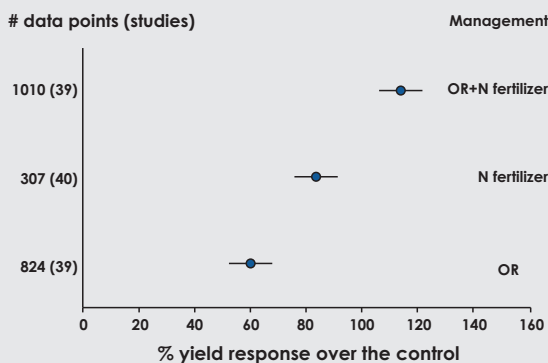


Figure 1. Yield responses to the addition of organic fertilizers (OR), mineral N fertilizers and the combined application of the two (OR + N fertilizer) compared to the control where no input was added (adapted from Chivenge et al., 2011)

IPNM: Improving Soil Health and Carbon Sequestration

- Soils can store up to 50-300 tons of carbon per hectare, which is equivalent to 180-1100 tons of CO₂
- Soils could store up to 1.85 gigatons of carbon each year (7 billion tons of CO₂), around the same amount as the entire world's transport produces (Zomer et al., 2017)
- 90% of agriculture's future mitigation potential is based on soil carbon sequestration (Smith et al., 2007)

Increasing cropland's ability to capture carbon is a potentially very important but currently underutilized tool for mitigating climate change by reducing the amount of CO₂ in the atmosphere.

Within IPNM, both types of fertilizer play their own part in increasing soil organic carbon (SOC). In healthy crops, for every two to three tons of carbon grown above ground, there will generally be one or more tons of carbon below ground in the roots and root exudates.

The residues from mineral fertilizer-fed high crop yields ensure that carbon-containing organic matter (in straw, stems and roots) is added to or

kept in the soil. For their part, organic fertilizers directly add to SOM. Numerous scientific studies have shown that adopting IPNM ensures the highest levels of SOC.

By providing nutrients for plants and improving water availability, high SOM enhances soil fertility and food productivity. By improving soil health, IPNM is also a very effective way to restore degraded soils.

For further information about the current state of global organic carbon please refer to the FAO's Global Soil Organic Carbon Map, produced in partnership with IFA (<http://www.fao.org/3/i8195en/i8195EN.pdf>).

IPNM Produces the Highest Rates of Soil Organic Carbon Accumulation

Newly Cultivated Farmland, China

A 7-year field study comparing 9 different methods of fertilization on newly cultivated farmland in northwest China found that **organic manure combined with mineral fertilizer produced the greatest increase in soil carbon accumulation rates.**

Using IPNM accumulated 2.01 tons of carbon per hectare in a year

(Yang et al., 2016)

Irrigated Wheat-Maize Cropping Systems, Pakistan

A 2-year irrigated wheat-maize field study in north Pakistan investigating the effect of four contrasting organic waste fertilizers - municipal solid waste (MSW), farm yard manure (FYM), sugar industry waste (filter cake) and maize cropping residues - with and without NPK mineral fertilizer found that IPNM produced the biggest improvement on SOC.

The most successful IPNM combination accumulated 7.87 tons of carbon per hectare in a year.

Table 2. Total organic carbon (0-15 cm) as influenced by organic and inorganic sources after wheat harvest.

Treatments	Total organic carbon (t-ha ⁻¹)*		
	Year 1	Year 2	Average
NPK	0.75	2.62	1.68
FYM	2.06	3.37	2.71
Maize residues	2.25	3.53	2.89
MSW	4.87	6.93	5.90
Filter Cake	6.37	6.75	6.56
LSD	0.524	0.524	0.437

*: TOC (organic/incoming fertilizer) - TOC(control)

(Adapted from Shehzadi et al., 2017)

Table 3. Total organic carbon at surface soil (0-15 cm) from different organic sources as affected by addition of NPK after wheat harvest

Treatments	Total organic carbon (t-ha ⁻¹)*		
	Year 1	Year 2	Average
FYM + NPK	3.01	3.56	3.28
Maize residues + NPK	3.75	4.04	3.89
MSW + NPK	6.75	7.12	6.94
Filter Cake + NPK	7.68	7.87	7.78
LSD	0.184	1.791	0.869

*: TOC (organic waste + NPK) - TOC(NPK)

Fertilizer Best Management Practices: Reducing Nutrient Losses for All Fertilizers

When both organic and mineral fertilizers are applied, part of their nutrients remain in the soil, some of which are incorporated into SOM, and some are lost to the environment. Ammonia, nitrous oxide and nitrogen oxides can be lost into the air, while nitrates and phosphorus can enter into water bodies, for example.

If not stored in contained areas, or excessively applied, organic fertilizers in the form of animal manure are particularly susceptible to leaching and runoff, with serious implications for water quality.

Nitrous oxide (N₂O) is a greenhouse gas (GHG) with a global warming potential roughly 300 times greater than that of CO₂. About two-thirds of global N₂O emissions (the equivalent of around 4.5 million tonnes of CO₂) comes from agriculture, including 42% of direct emissions from fertilization and livestock manure and 25% from runoffs and leaching (IPNI, 2015).

The good news is that losses to the environment can be measurably minimized, and fertilizer-related GHG emissions reduced by ensuring a maximum uptake of needed nutrients by plants as efficiently and effectively as possible.

To ensure optimal nutrient use efficiency and effectiveness, the fertilizer industry and its partners have developed the 4R global framework: using the Right nutrient source, at the Right rate, at the Right time, in the Right place. **No matter whether mineral or organic, the 4Rs should always be used by farmers with all types of fertilizers.**

4R Principles of Nutrient Stewardship



RIGHT SOURCE

Matches fertilizer type to crop needs.



RIGHT RATE

Matches amount of fertilizer to crop needs.



RIGHT TIME

Makes nutrients available when crops need them.



RIGHT PLACE

Keeps nutrients where crops can use them.

Policy Recommendations for IPNM

Building Research Capacities

Fund laboratories and staff in research institutions and extensions agencies to increase their capacity to conduct research, interpret data and offer advisory services about soil health, carbon sequestration and IPNM.

Understanding Local IPNM

Support a comprehensive effort at the local level to assess and summarize data on soils, crop nutrient needs, organic and mineral nutrient sources, application methods and nutrient budgets to increase understanding of IPNM.

Ensuring Farmer's Education

Make a specific institution responsible for providing farmers and agribusinesses with comprehensive IPNM information for specific crops, soils and areas.

Increasing Availability of Fertilizers

Support developing transport, financing and supply chain infrastructure to ensure that

appropriate mineral fertilizers are readily available to all farmers worldwide at the right time so that crop yield potentials can be reached with the least cost.

Optimizing Available Organic Sources

Evaluate a range of potential organic fertilizer sources, from planting nitrogen fixing trees to local manure and compost, while taking into account land and labour capacity for producing and using them.

Favouring the Development of IPNM Tools

Develop tools that facilitate farmer implementation of IPNM with access to varied tools and techniques, e.g. nutrient budgeting software, rapid soil test kits and leaf color charts.

Providing Training Capacity to Agribusiness & Retail

Give high quality training to extension services, agribusiness and develop training materials to show the application and benefits of IPNM in specific regional situations.

References

Erisman JW, Sutton MA, Galloway J, Klimont Z, Winiwarter W. 2008. How a century of ammonia synthesis changed the world. *Nature Geoscience* 1(10):636-639.

Barker, AV, Stratton ML, Rechcigl JE (2000). p. 169-213. In Bartels JM (ed.) *Land Application of Agricultural, Industrial, and Municipal By-Products*. Soil Science Society of America. Madison, Wisconsin, USA.

FAO. 1989. *Fertilizers and Food Production. The FAO Fertilizer Programme 1961-1986*. Food and Agriculture Organization (FAO), Rome, Italy.

Pieri C. 1989. *Fertilité des terres de savanes; bilan de trente ans de recherche et de développement agricole au sud du Sahara*. CIRAD-IRAT, France.

Giller KE, Cadisch G, Mugwira LM. 1998. Potential benefits from interactions between mineral and organic nutrient sources. p. 155-158. In Waddington SR, Murwira HK, Kumwenda JDT, Hikwa D, Tagwira F. (Eds.) *Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe*. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe.

Sanginga N, Okogun JA, Vanlauwe B, Diels K, Dashiell K. 2001. Contribution of nitrogen fixation to the maintenance of soil fertility with emphasis on promiscuous soybean maize-based cropping systems in the moist savanna of West Africa. p. 157- 178. In Tian G, Ishida F, Keatinge JDH (eds), *Sustaining Soil Fertility in West Africa*. American Society of Agron., Madison, WI.

Chivenge P, Vanlauwe B, Six J. 2011. Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. *Plant and Soil* 342: 1.

Yang R, Su Y-Z, Wang T, Yang Q. 2016. Effect of chemical and organic fertilization on soil carbon and nitrogen accumulation in a newly cultivated farmland. *Journal of Integrative Agriculture* 15(3): 658-666.

Shehzadi S, Shah Z, Mohammad W. 2017. Impact of organic amendments on soil carbon sequestration, water use efficiency and yield of irrigated wheat. *Biotechnology, Agronomy, Society and Environment*. 21. 36-49.