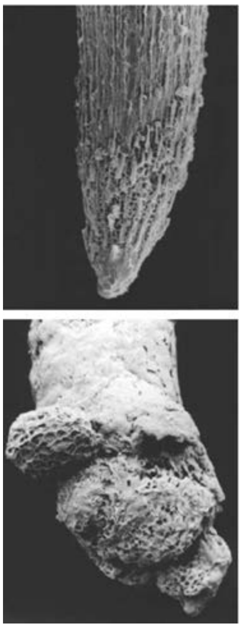
SOIL ACIDIFICATION

Jean-Pierre Pellissier and Pieter Swanepoel discuss its implications for agricultural systems

Soil, the matrix beneath our feet and a natural resource essential for life on Earth, is facing human-induced repercussions. Roughly 37% of all land area is classified as agricultural land intended to feed the global population, currently totalling some 7.8 billion people and increasing all the time. But with long-term intensive agriculture comes various consequences for soil health, one of these being soil acidification.



CSIRO

Microscopy reveals the difference between a normal root (top) and one affected by aluminium toxicity due to severe soil acidity.

Soil pH is considered a master variable affecting numerous chemical and biological processes within the soil. For example, the ability of plant roots to flourish and penetrate deep soil layers is greatly affected by soil pH, so it is essential for the sustainability of crop-production systems that optimal soil pH is maintained.

Causes of acidification

Two balances govern soil pH, namely the balance of acid ions and base cations on the surfaces of soil particles, and the balance of acid (H^+) and alkaline (OH^-) ions in soil-water solution surrounding soil particles. Acid soils can be ascribed to an imbalance, where H^+ ions exceed OH^- ions, resulting in low soil pH. During these conditions, base cations on soil particle surfaces are often displaced by H^+ ions, which leads to further soil acidification.

Soils acidify naturally through processes of soil formation. Weathering of soil minerals yields H^+ ions, causing a decreasing pH over time. Furthermore, even unpolluted rain has a naturally acid pH of roughly 5.6, and therefore contributes to the process of soil acidification. When mineral-rich soil is exposed to excessive rainfall, the base cations calcium, magnesium, potassium and sodium are often leached from the soil profile, resulting in an acid-base imbalance. The same applies if farmers overirrigate their crops, so this is one mechanism of human-induced soil acidification.

The main human-induced mechanism, though, is through the use of ammonium-based fertilisers, commonly used in commercial agriculture to add nitrogen to the soil. After ammonium fertiliser is applied, ammonium molecules (NH_4^+) undergo biological oxidation to nitrates (NO_3^-). During this process, the transformation of a single ammonium molecule to a nitrate molecule yields two acid (H^+) ions, contributing to acidification of the soil.

Even without fertilisers, intensive agriculture disrupts natural nutrient cycles. Particularly where a single crop type is produced season after season, soil tends to get depleted of specific essential plant nutrients. When harvesting a crop, nutrients absorbed via plant roots and incorporated into seed or fruit are removed, resulting in loss of soil calcium, magnesium and potassium in the long term. Depletion of these base cations leads to soil acidification over time.

Jean-Pierre Pellissier establishes treatment blocks with different forms and sources of lime to create a randomised block design field trial, like the one for wheat shown in the aerial photo taken with a drone.

Impacts on agriculture

Soil acidity has immense implications for agricultural sustainability as most crops grow optimally in the pH range 5.8–6.5. Soil pH below 5.5 tends to decrease a soil's crop-production potential.

Soil pH ultimately controls nutrient availability to plant roots. Although a soil's nutrient content might be sufficient for a specific crop, soil pH regulates whether nutrients are accessible to crop roots. Therefore, soil pH truly regulates crop nutrition. Farmers often inadvertently overfertilise their crops, causing nutrient pollution of nearby watercourses, because their crop plants are showing signs of nutrient deficiencies, not realising that the problem is soil pH rather than insufficient soil nutrients.

Soil biology is also adversely affected by acidification. Under acidic conditions, fungal communities tend to dominate whilst bacterial communities diminish. Soil bacteria play an essential role in nutrient recycling of soil organic material, so conversion of organically bound nutrients to plant-available nutrients is retarded in very acidic soil. In addition, soil bacteria are vital for biological nitrogen fixation, a process whereby nitrogen is sequestered from the atmosphere and converted to plant-available forms of nitrogen within the soil. For these reasons, soil acidity requires increased dependency on synthetic fertilisers for nutrients.

What's more, at low soil pH the elements aluminium, manganese, zinc and iron become soluble. High levels of these soluble elements can be toxic to plant roots, which further decreases a soil's crop-production potential. Aluminium toxicity, in particular, is commonly observed in acid soil. It causes shallow, poorly developed root systems, which reduce yield by restricting access to water and nutrients.

Mitigation measures

Mitigation of soil acidification is achieved by addition of agricultural lime, a natural product derived from limestone. Agricultural lime neutralises excess H^+ ions in the soil via a chemical reaction with carbonate molecules to form water and carbon dioxide.

Regular soil sampling and analyses, every one to three years, is essential to estimate an accurate amount of lime required to alleviate soil acidity. Since lime is fairly immobile within the soil and does not solubilise readily, it needs to be applied at appropriate intervals to be effective.

Nowadays, conservation agriculture is being adopted in an effort to rehabilitate soil health and ensure the sustainability of our farming systems. The conservation agriculture concept relies on three fundamental principles – minimum mechanical soil disturbance (i.e. no-tillage/ploughing), permanent organic soil cover, and diversification of crop species. In the long term, however, no-tillage leads to acidic pH stratification, meaning an increase in acidity in subsoil layers because liming has only neutralised the topsoil. As a result, plant roots are often limited to the topsoil layers with little to no subsoil penetration, a phenomenon known as J-rooting.

Ensuring the sustainability of crop-production systems to feed our ever-growing population requires a greater focus on soil health. While conservation agriculture aims to address the degradation of our soils, the approach has potential limitations. More research is therefore needed on ways of slowing down soil acidification, and mitigating its adverse effects.

Pieter Swanepoel

An example of J-rooting of a canola plant due to subsoil acidity in a long-term no-tillage system.

Jean-Pierre Pellissier is conducting his MSc project at Stellenbosch University on alleviation of acidic pH stratification in no-tillage conservation agriculture systems.
Dr Pieter Swanepoel is one of his supervisors and is head of the Stellenbosch University Agronomy Department.

2021

Quest Volume 17 Number 2 2021

Academy of Science of South Africa (ASSAf)

Academy of Science of South Africa (ASSAf)

Cite: Academy of Science of South Africa (ASSAf), (2021). Quest: Science for South Africa, 17(2). [Online] Available at: http://hdl.handle.net/20.500.11911/191

http://hdl.handle.net/20.500.11911/191