AGRIVITA
Journal of Agricultural Science
www.agrivita.ub.ac.id

Utilization of Yeasts in Promoting Plant Growth in Acidic Soil – A Review

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ARTICLE INFO

Keywords:
Crop production
Growth promoter
Problematic soil
Sustainability
Yeasts

Article History:
Received: July 11, 2023
Accepted: January 24, 2024

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ABSTRACT

The ecosystem's biodiversity and soil microorganisms are impacted by the increasing use of synthetic fertilizers and pesticides, which causes soil acidity and limits the sustainability of agricultural output. The majority of microbial functions in acidic soil are inhibited because of decreasing nutrient cycling and organic matter decomposition as well as diminishing bacterial and fungal growth and reproduction. In light of these growing concerns, the use of microorganisms as bio fertilizers is a recommended as alternative agricultural practice. Recent times have brought about a change in the paucity of study on yeasts and their ability to safely boost plant growth. Numerous works on bacteria have been made available. The primary objective of the study is to highlight the widespread application of yeasts in sustainable agricultural practices to promote plant growth in acidic soils. All of the advantages that yeasts provide may contribute to the growth of plants. Therefore, a thorough investigation into yeasts may be fruitful and offer a sustainable means of boosting agricultural yields that are necessary in acidic soil.

INTRODUCTION

Promoting high-yield crop production is depended on the use of fertilizers, as crops typically require significant amounts of essential nutrients for optimal growth. These nutrients include nitrogen (absorbed as NH_4^+ or NO_3^-), phosphorus (absorbed as H_2PO_4), calcium (absorbed as Ca^{2+}), sulphur (absorbed as SO_4^{2}), magnesium (absorbed as Mg^{2+}), potassium (absorbed as K^+), iron (absorbed as Fe^{2+} or Fe^{3+}), and zinc (absorbed as Zn^{2+} or $Zn(OH)_2$) (White & Brown, 2010). Mineral fertilizers are commonly used to deliver these macro nutrients in modern agricultural systems, often in the form of processed natural minerals or artificial compounds. However, unsustainable fertilizer practices are causing detrimental effects on Earth's biogeochemical cycles, contributing to issues such as soil erosion, waterway eutrophication, and greenhouse gas emissions (Syed et al., 2021). Additionally, there is a concern that known reserves of phosphate rock, a key component of fertilizers, may be depleted within a few decades. The energy-intensive Haber-Bosch method, which produces fertilizer mostly from fossil fuels, aggravates environmental effects such as resource depletion and global warming.

Exploring substituted techniques to maintain plant nutrition in acidic soil while lowering reliance on mineral fertilizers is a crucial topic of concentration for agricultural science research (Dawson & Hilton, 2011; Jwaideh et al., 2022). Using microorganisms that can depolymerize and mineralize organic nutrients connected to plant material is one method of substituting organic inputs for mineral fertilizers. This tactic takes use of the large amount of nutrient-rich "waste" that may be composted and utilized as organic fertilizers, coming from a variety of operations, including agricultural, municipal, and industrial ones (Jacoby et al., 2017). Since organic inputs are more stable in the soil and less prone

ISSN: 0126-0537

Cite this as: Rawichandran, D., Kasim, S., Kee Zuan, A. T., Effendi, M. I., & Raguraj, S. (2024). Utilization of yeasts in promoting plant growth in acidic soil – a review. *AGRIVITA Journal of Agricultural Science, 46*(1), 196-210. http://doi.org/10.17503/agrivita.v46i1.4241

to leaching and volatilization than mineral fertilizers, especially those related to biological processes, they may provide more environmentally friendly options.

Although farming systems currently use bio-fertilizers, such as microorganisms, the interaction between plant cultivars and microbial inoculations is not well understood mechanistically. This lack of accuracy is caused by two main insights gaps: the question of whether plants can use helpful microbes to their fullest potential and the lack of genetic variety needed to produce desirable features. Significantly, there is still a dearth of study on some microorganisms, including yeasts, which are the subject of many patents for improving plant nutrition from organic sources of phosphorus, sulphur, and nitrogen (Alkharabsheh et al., 2021; Ndoung et al., 2021).

A key player in this situation is yeast, a kind of fungal cell that has the capacity to absorb large quantities of nitrogen and carbon. Some yeasts are facultatively anaerobic and can ferment carbohydrates. They thrive in conditions are favored by perennial plants, low-disturbance soils, stable organic residues with high carbon-to-nitrogen (C:N) ratios, slower recycling rates, and slightly acidic pH. Yeasts reproduce mainly through asexual cell fission and budding, adapting to various environments, including liquid suspension, biofilms, and soil, including sand grains. Extensive research on yeast development has revealed its potential to support plant growth in acidic soil and its high proliferation capacity in endophytic environments, making it a valuable candidate for applications like soil bioremediation (Lynd et al., 2002; Schlegel & Jannasch, 2006).

MATERIALS AND METHODS

The study addressed the use of yeasts to enhance plant development in acidic soil by reviewing over around 85 published scientific publications (2001–2022) from a variety of backgrounds and archives. The papers that highlighted the role of yeasts in soil acidity, the interaction between plants and soil, and the Green Revolution in improving soil quality were incorporated.

RESULTS AND DISCUSSION

Yeast and Ecology

Yeasts, classed as unicellular fungus, create spores externally during their reproductive phases, mostly by budding, occasionally utilizing fission. Yeast identification and taxonomy are accomplished through a variety of molecular biology techniques, such as amplified fragment length polymorphism of D1/D2 domain, DNA reassociation, hybridization, karyotyping, random amplified polymorphic DNA (RAPD), ribosomal DNA phylogeny, and physiological testing (Zhang et al., 2020). While other yeast genera, including Candida and Brettanomyces (Deuteromycete) and Cryptococcus and Rhodotorula (Basidiomycota), are categorized differently, the well-known “baker’s yeast” is classified within the Ascomycota subclass (Botha, 2011).

Yeasts are found in a variety of habitats, including soil, water, plants, animals, and insects, although being less common than bacteria. Certain yeasts may live in the tissues of plants and form commensal or parasitic partnerships with mammals. Notably, opportunistic human infections are caused by *Candida albicans.* Certain conditions with low oxygen, temperature, or water potential are conducive to yeast adaptation. They support insects like *Drosophila spp*. and have an impact on Drosophila physiology and reproduction, therefore adding to the food chain (Fenner et al., 2022; Ljunggren et al., 2019; Naranjo-Ortiz & Gabaldón, 2019). Marine filter feeders also eat yeast.

In the biogeochemical cycle, filamentous fungus and bacteria are more important in microbial ecology than yeasts (Table 1). But yeasts, which use a variety of carbon sources to transform plant waste into carbon dioxide, are essential saprophytes in the carbon cycle (Frey-Klett et al., 2011; Gupta et al., 2017). While most yeasts absorb ammonium ions or amino acids as organic nitrogen, others contribute to the nitrogen cycle by decreasing nitrate or ammonia nitrite. Furthermore, certain yeasts are sulfur auxotrophs, meaning they may decrease sulfate (Frey-Klett et al., 2011; Gupta et al., 2017; Naranjo-Ortiz & Gabaldón, 2019).

Importance of Yeast

For thousands of years, yeast has been used traditionally to manufacture bread, wine, and beer. The products of modern yeast biotechnologies have an influence on many economically significant industries, including as food and beverages, chemicals, industrial enzymes, medications, agriculture, and the environment (Table 2) (Sicard & Legras, 2011). The most widely used bacterium, *Saccharomyces cerevisiae*, is the primary yeast cell factory in biotechnology and produces the world’s most valuable biotechnological product, industrial and drinking ethanol (Parapouli et al., 2020). However, the production of industrial goods is employing an increasing number of non-Saccharomyces species (Faria-Oliveira et al., 2015; Maicas, 2020).

For example, certain industrial yeasts are harmed by spoilage yeasts used in the production of food and drink. Food spoilage yeasts have a detrimental effect on food's nutritional value and are thus economically significant for food producers, even though they do not infect or intoxicate humans (Fleet, 2011). Apart from their conventional uses in the food and fermentation industries, yeasts have an increasing number of vital roles in the environment and the biotechnology industry of healthcare. Furthermore, fundamental biology and medical studies greatly benefit from the use of yeast as a model eukaryotic cell (Faria-Oliveira et al., 2015; Maicas, 2020).

Environmental and Agriculture

Several yeast species are known to pose threats to plants, such as *Ophiostoma novo-ulmi* causing Dutch Elm disease and certain *Eremothecium* species causing issues like cotton ball ailments (McLeod et al., 2005). Conversely, some yeasts play a beneficial role in plant health by preventing fungal diseases. Yeasts like *Cryptococcus laurentii*, *Metschnikowia pulcherrima*, *Pichia anomala*, and *Pichia guilliermondii* have demonstrated potential in biocontrolling fungal fruit and grain spoilage, particularly in mitigating post-harvest fungal deterioration (Ferraz et al., 2019; Muccilli & Restuccia, 2015). For example, *S. cerevisiae* shows promise as a phytoalexin elicitor, stimulating the defence mechanisms of cereal plants against fungal pathogens (Ahuja et al., 2012; Kaur et al., 2022; Raasch-Fernandes et al., 2019).

Table 1. Natural yeasts' habitat

Habitat	Explanation	Examples yeasts	References
Soil	Many yeasts may not be able to thrive in soil; rather, they may just serve as a reservoir for their long-term survival. Nevertheless, yeasts are only present in the top, aerobic soil layers (10–15 cm) and are common in farmed soils (approximately 10,000 yeast cells per gram of soil). Some genera are separated only from soil.	• *Lipomyces* • *Schwanniomyces*	(Johnson, 2013)
Water	Yeasts predominate in surface layers of fresh and salt waters but are not present in great numbers (about 1000 cells per litre). Many aquatic yeast isolates belong to red-pigmented genera. Halotolerant yeast that can grow in nearly saturated brine solutions	• *Rhodotorula* • *Debaryomyces hansenii*	(Butinar et al., 2005; Gadanho et al., 2003)
Atmosphere	Per cubic metre of air, a few viable yeast cells may be anticipated. Air currents spread yeast from layers above soil surfaces.	• *Cryptococcus,* • *Rhodotorula,* • *Sporobolomyces,* • *Debaryomyces*	(Faniyi et al., 2019)
Plants	Insects contribute in the spread of yeasts on the phyllosphere, and certain yeasts cause plant diseases. The border between soluble plant nutrients (sugars) and the septic environment is a frequent habitat for yeasts (the surface of grapes). Conditions are favourable for the growth of many yeasts due to the abundance of organic substances in decaying areas and on the surface (exudates, flowers, fruits, phyllosphere, rhizosphere, and necrotic zones).	• *Drosophila* spp.	(Hernández-Fernández et al., 2021).
Animals	Warm-blooded animals' skin and digestive tracts are home to a variety of non-pathogenic yeasts, some of which are opportunistically harmful to humans and other animals. Insects, which play a key role as vectors in the natural dispersion of yeasts, are commensally linked with a variety of yeasts.	• *Candida albicans*	(Malassigné et al., 2021; Suh et al., 2008)

Additionally, yeasts contribute to environmental benefits by reducing pollutants. Certain yeasts, including *Candida utilis*, efficiently detoxify chemical contaminants from industrial effluents and act as bio-sorbents for heavy metals. Yeasts like *Candida utilis* can also effectively remove nitrogen and carbon from organic wastes (Ferraz et al., 2019). In agriculture, living cultures of *S. cerevisiae* have been shown to enhance nutrient availability and regulate the rumen environment in domestic livestock, such as cattle, promoting animal growth or milk production (Elghandour et al., 2020). Yeasts may scavenge oxygen to protect rumen bacteria from oxidative stress or provide dicarboxylic acids to stimulate rumen bacterial growth (Elghandour et al., 2020; Wang et al., 2022).

Table 2. The importance of yeast on industrial, agriculture and medical sectors

Uses	Yeast	References
1. Many uses in foods, chemicals, pharmaceuticals, and xylose fermentation. 2. Some species are used in the production of microbial biomass protein, vitamins, and citric acid. 3. Some species are food spoilers in frozen poultry.	• *Candida shehatae* • *Candida utilis, Candida guilliermondii* • *Candida zeylanoides*	(Voidarou et al., 2020)
1. Lactose, inulin-fermented, and high in enzyme sources (lactase, lipase, pectinase, and recombinant chymosin). 2. Cheese whey is fermented with lactose-fermenting yeasts to create alcoholic beverages. 3. The fermentation of cocoa is a source of the dietary enzyme's pectinase, microbial rennet, and lipase. 4. Dairy products that include mouldy yeast (fermented milk and yoghurt).	• *Kluyveromyces* spp.	(Aitzhanova et al., 2021; Erten et al.,2014)
1. Methylotrophic yeasts used in cloning technology. 2. Production of microbial biomass protein, riboflavin. 3. An important surface film spoiler of wine and beer.	• *Hansenula* and *Pichia (H. polymorpha* and *P. pastoris)* • *P. pastoris* • *P. membranefaciens*	(Mack et al., 2009; Rozanov et al., 2020)
1. Amylolytic yeasts (starch-degrading). 2. Traditional food and beverage fermentations (baking, brewing, winemaking, source of savoury food extracts, and food enzymes. 3. Used as fodder yeast (livestock growth factor). 4. Sparkling wine fermentations. 5. Wild yeast spoiler of beer. 6. Used as a probiotic yeast.	• *Saccharomycopsis* and *Schwanniomyces* • *S. cerevisiae* • *S. diastaticus* • *S. boulardii*	(Bruner & Fox, 2020; Elghandour et al., 2020; Johnson, 2013)
1. Some strains are used as biocontrol agents to combat the fungal spoilage of post-harvest fruits. 2. Food spoilage yeast (poultry).	• *Cryptococcus* spp. • *C. laurentii*	(Carmona-Hernandez et al., 2019; Freimoser et al., 2019)
1. Source of food enzymes such as lipases. 2. Some species are food spoilers of dairy products.	• *Rhodotorula* spp.	(Geronikou et al., 2022)
1. Biocontrol of fungal fruit diseases (post-harvest). 2. Osmotolerant yeasts.	• *Metschnikowia* spp.	(Di Canito et al., 2021; Freimoser et al., 2019; Steglińska et al., 2022)

While most yeasts contribute positively to human existence, some can be opportunistically harmful. *Candida albicans*, causing candidiasis, is a common opportunistic yeast infection, particularly affecting immunocompromised individuals (Pappas et al., 2018). In certain cases, *C. albicans* infections in AIDS patients can be fatal. Yeast recombinant DNA technology has enabled the production of novel human medicinal molecules, showcasing the beneficial medical properties of yeasts (Mayer et al., 2013). Yeasts also play a crucial role as experimental models in biomedical research, particularly in cancer, pharmacology, toxicology, virology, and human genetics.

Extent And World Distribution Of Acid Soil

About 3.95 billion hectares of the world's free Iceland are covered in acid soil. Ultisols make up 9.3% of the world's land area, or about 12,347 million acres. According to Von Uexküll & Mutert (1995), Oxisols and Ultisols make up the majority of tropical acid soil worldwide, making up around 21.87% and 18.4% of all tropical soil, respectively (Fig. 1).

Acidic soils are characterized by elevated levels of toxic elements such as aluminum (Al), manganese (Mn), and iron (Fe), along with deficiencies in calcium (Ca), magnesium (Mg), potassium (K), and nitrogen (N). A significant portion of global acid soils exhibits chemical imbalances, insufficient cation retention capacity, nutrient losses, and suboptimal crop performance. Soil pH serves as an indicator of acidity, providing insights into nutrient availability, the presence of free lime (calcium carbonate), and the abundance of specific ions like sodium, hydrogen, aluminum, and manganese (Fageria et al., 2008).

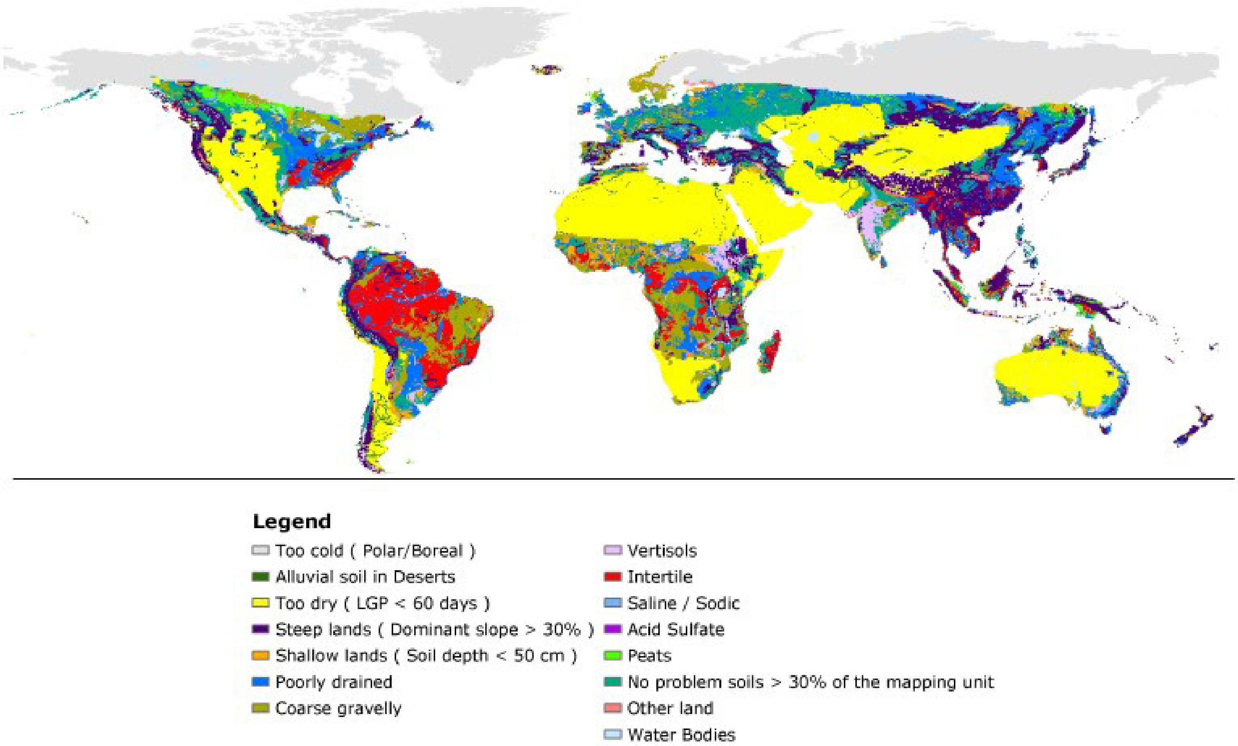

Fig. 1. Dominant type of soils (Source: Sumner & Noble, 2003)

Soil acidity formation serves as an indicator of weathering and leaching within the soil (Fageria et al., 2008). Widespread soil acidity poses challenges to agricultural productivity globally. The soil's acidic nature results from substantial percolation, leading to leaching and the generation of biological acids. Plant roots and the dissolution of CO_2 in water release H^+ ions, contributing to soil acidification (Danh et al., 2009). Acidification occurs when leaching causes soil solution acidity, replacing negatively charged acidic cations with H^+ ions and $Al(OH)_3$. Reduced yields and nutrient utilization were followed as a result of the displaced cations being leached deeper into the soil profile and causing soil acidity dominance in the exchange complex (Chintala et al., 2012).

Higher Al^{3+} concentrations are seen in lower pH soil solutions and cation exchange sites. Both natural and man-made processes, such as land clearance and contemporary agricultural methods that include overuse of chemical fertilizers like urea and ammonium nitrate, or cation loss from crop harvesting, can cause soil acidification. In some tropical soils, pollution and acid rain increase the acidity of the soil by introducing H^+ ions and making the acidity worse (Chintala et al., 2012; Danh et al., 2009; Mijangos et al., 2010; Zubrzycki et al., 2014).

The main causes of acidity in soil are a mix of human and natural activities. High-yielding crop cultivation, acidic parent material, organic matter decomposition, ammonium nitrification, and a lack of buffer capacity from insufficient clay and organic matter are some of the factors that cause acidification (Bünemann et al., 2018; Cai et al., 2015; Yan et al., 2020; Zhang et al., 2019). When there are more acidic cations, such as hydrogen (H^+) and aluminum (Al^{3+}), than alkaline cations, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+), the soil is considered acidic (Bedigian, 2005).

A number characteristics of the soil may be used to determine its acidity, and Ultisols and Oxisols can be categorized using soil taxonomy. An argillic horizon in the subsoil and subsurface clay accumulation in the B horizon as a result of leaching in a tropical, humid climate are characteristics of Ultisols. To be classified as high-weather soil, a mineralogical study must demonstrate that kaolanoitite and sesquioxides are dominant. Tropical soils are rich in kaolinite, a non-expansive 1:1 phyllosilicate with a low surface area and cation exchange capacity (Shamshuddin & Anda, 2008). In comparison to Ultisols, Oxisols have undergone greater weathering and have an oxic horizon in the subsurface. They also include a clay component that is mostly composed of kaolinite and sesquioxides, which leads to a very low CEC and leaching losses of nutrients (Castellini et al., 2021; Murphy, 2014).

Types of Soil Acidity

The active acidity in the soil solution is quantified based on the concentration of H^+ ions, influenced by carbonic acid (H_2CO_3), water-soluble organic acids, and chemically acidic salts. The immediate impact of active acidity on plant development and soil microbes is determined by the presence of H^+ and Al^{3+} ions, which precipitate on soil surfaces, indicating exchange acidity. Adsorbed and dissolved organic ions maintain a dynamic equilibrium, allowing a swift transition between forms. The exchangeable H^+ and Al^{3+} ions contribute to soil acidity, readily exchangeable in a basic saline solution like KCl (Agegnehu et al., 2021).

Buffer pH, measured as the proportion of H^+ ions associated with clay and organic matter in a buffer solution, reflects the soil's buffer potential. Adsorbed H^+ and Al^{3+} ions migrate into the soil solution, representing potential, accumulated, or reserve acidity. The bulk of H^+ ions in acidic soil is absorbed by the soil (reserve acidity) (Thomas, 2018; Elita et al., 2022). The relationship between active and reserve acidity is influenced by soil properties, including clay type and quantity, organic matter content, and free lime in the soil. The reserve-to-active acidity ratio indicates the soil's buffer potential, with sandy soil having lower buffer capacity compared to clay-rich soil like silt loam. The calculation of pH buffer helps determine the lime required to neutralize a significant portion of the reserve acidity when the soil pH is 6.3 or below (Zibilske, 1998).

Acidity in the soil adversely affects plant growth and productivity, leading to increased weed growth, reduced soil cover, and the potential for soil erosion (Barth et al., 2018). Aluminum toxicity in the subsurface soil is a major concern associated with soil acidity (Laekemariam et al., 2016). Low pH in topsoil affects nutrient availability, hinders nodulation of legumes, and reduces nitrogen fixation in pastures. The impact of aluminum and manganese toxicity on root development and soil biota is significant. Elevated levels of Al and Mn released into the soil solution contribute to reduced soil cover, increased runoff, water contamination, and deposition in streams (Barth et al., 2018).

Soluble aluminum concentrations exceeding 2 mg/kg or exchangeable aluminum levels exceeding 5% can be toxic to plant roots. Topsoil with sufficient organic matter typically prevents Al toxicity to plant roots, even though laboratory studies may remove it. Excessive Al in the soil solution disrupts root cell division and elongation, resulting in poor crop and pasture development, reduced yields, and smaller grain sizes. The negative effects of Al poisoning are particularly evident during dry-finish seasons, where roots struggle to penetrate acidic subsurface soil, limiting access to stored subsurface water (Gazey & Andrew, 2009).

The nutrient loss in acidic soils, including potassium (K), calcium (Ca), and magnesium (Mg), through leaching or removal in harvested products like hay and grain, results in soil impoverishment. Insufficient calcium can also contribute to structural issues in the soil. As soil acidity increases, nutrient tie-up occurs, rendering nutrients such as phosphorus (P) and manganese (Mn) unavailable (Stuart Chapin III et al., 2009). Soil pH significantly influences nutrient availability to plants, with acidic soils reducing the availability of major nutrients and trace elements, including nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), manganese (Mn), and molybdenum (Mo) (Fig. 2). Liming to raise the pH of acidic soil enhances the availability of these nutrients. Conversely, acidic soils exhibit increased concentrations of iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and aluminum (Al). Leaching in acidic soils contributes to groundwater and surface water pollution through the release of nitrate, other nutrients, and heavy metals from the soil profile (Ngoune Tandzi et al., 2018).

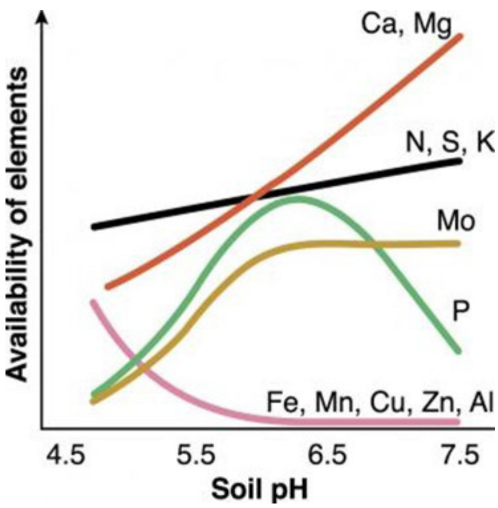

Fig. 2. Relationship between soil pH and nutrient availability, in acidic soils (Source: Ngoune Tandzi et al., 2018)

Soil Microbial Acidity

In soils with moderate to strong acidity, microbial activity, particularly among microbes involved in nitrogen fixation or organic matter decomposition, is diminished. The growth and reproduction of soil microbes, primarily bacteria and fungi, are hampered in acidic conditions, leading to a reduction in the breakdown of organic matter and nutrient cycling. The microbial processes responsible for mineralizing nutrients into forms accessible to plants occur at a slower rate, potentially limiting plant nutrient uptake. Under favorable conditions, nitrogen-fixing rhizobia bacteria form a symbiotic relationship with legumes in root nodules, yet their populations are significantly reduced in acidic soils, impacting the successful establishment of this symbiosis (Laekemariam et al., 2016).

Different species of rhizobia bacteria vary in their resistance to soil acidity, with some, like medicinal rhizobia, being highly susceptible and unable to persist (Howieson & Ewing, 1986). The inability of pasture legumes to thrive in acidic soil can lead to grass-dominated pastures. Low pH levels in top soils can negatively affect microbial activity, notably decreasing legume nodulation. Signs of resulting nitrogen deficiency in plants, such as reddening of stems and petioles in pasture legumes or yellowing and death of the oldest leaves in grain legumes, may occur. Reduced rhizobia populations in acidic soils can impede successful nodulation and the establishment of a functional symbiosis, causing certain pasture legumes to struggle or fail to survive (Yazie et al., 2021; Ngoune Tandzi et al., 2018).

Soil ecosystems host a diverse range of microflora and microfauna, including protozoa, nematodes, earthworms, moles, and ants. The density of living organisms in soil is exceptionally high, with billions of creatures per gram of soil. Cultivated soil typically has a lower organism density than uncultivated land, and population density tends to decrease with increasing soil acidity. Soil ecosystems comprise both autotrophic and heterotrophic species, with heterotrophs utilizing organic carbon for decomposition or consumption and autotrophs serving as primary producers using organic carbon derived from carbon dioxide (Christel et al., 2021).

In their natural environment, plants exist within a diverse ecosystem alongside numerous microorganisms. While the influence of certain microorganisms, like nitrogen-fixing symbiotic bacteria or mycorrhizal fungi, on plant nutrition has long been recognized, recent research has unveiled the broader spectrum of plant-associated microorganisms and their potential to replace artificial agricultural inputs. Advances in understanding the composition and dynamics of rhizosphere microbiomes reveal that plants exert an influence on the microbiome, likely through root exudates, and bacteria have adapted to thrive in the rhizosphere niche. However, the mechanisms underlying these interactions and the activities driving changes in the microbiome remain largely unknown (Kuzyakov & Xu, 2013; Liu et al., 2022).

Interconnection of Plants with Soil Microbes

While soil is often viewed solely as a source of nutrients for plants, it functions as a dynamic ecosystem that houses a diverse community of bacteria, fungi, protists, and animals. The interactions between plants and soil-dwelling organisms span a wide range of ecological possibilities, including competitive, exploitative, neutral, commensal, and mutualistic relationships. In contemporary plant science, the majority of research has focused on mitigating pathogenic impacts, such as herbivore and infection, or alleviating abiotic stress conditions (Liu et al., 2022; Lynd et al., 2002). However, there has also been a longstanding interest in understanding the beneficial ecological interactions that support plant development. For instance, in the latter half of the 19^{th} century, mycorrhizal fungi and bacteria in nodulated legumes were recognized as root symbionts. In the 1950s, crop seeds were coated with bacterial cultures (*Azotobacter chroococcum* or *Bacillus megaterium*) to enhance yield and growth. Since the 2000s, research focus has shifted from identifying specific bacterial strains to utilizing metagenomics to map the diversity and abundance of the root microbiome (Larimer et al., 2014; Meng et al., 2015).

According to sequencing studies, a wide variety of microbial species are present in the roots of plants, making the rhizosphere niche a hotspot for biological diversity. In an attempt to replicate beneficial microbial activities in controlled experimental settings, recent studies have focused on building synthetic communities (SynComs) from strains of common rhizosphere species (Jacoby et al., 2017; Singh et al., 2022; Yamamoto et al., 2018). Gaining a mechanistic knowledge of how soil bacteria improve plant development and defense is one of the main goals of this field of study. This information may then be used to create microbial communities that are ideal for carrying out particular tasks.

Microbial Traits and Bioavailability of Nutrients for Plants

As Jacoby et al. (2017) discuss, three main mechanisms are frequently proposed to explain how microbial activity contributes to plant growth: controlling plant hormone signaling, warding off or outcompeting pathogenic microbial strains, and boosting the bioavailability of nutrients borne from the soil. Much of the nutrients in natural ecosystems—such as N, P, and S—are bound in organic molecules and thus only partially available to plants. In order for plants to get organic forms of N, P, and S, soil microorganisms like bacteria and fungus must be able to metabolically break down and mineralize these forms. Essential nutrients including ammonium, nitrate, phosphate, and sulfate are released into the soil as inorganic forms as a result of microbial cell turnover, cell lysis, or protozoic predation (Adomako et al., 2022; Grzyb et al., 2021; Jacoby et al., 2017).

Microorganisms are essential for controlling the nitrogen recycling and carbon cycle, among other soil activities. Plants' capacity to absorb vital nutrients like N, P, and micronutrients is determined by the variety and total number of microbial species present in the soil. Plant variety and abundance have the power to affect the whole soil ecology by generating exudates from their roots that may either promote or inhibit the growth of particular microbial species. Less than 10% to 20% of a plant's total carbon output is released into the soil by plants, which also enriches the soil by providing microorganisms with food and energy (Hattori et al., 2019; Verbruggen et al., 2017). As a reciprocal relationship, bacteria feed plant roots nutrients and encourage the growth of particular microbial species, mainly yeast, to protect plants from dangerous diseases (Hayat et al., 2010; Jacoby et al., 2017; Xiang et al., 2022).

A variety of plants depend on the fungus-to-bacterium ratio (F:B), with different ratios being desired for different crops. Plant preferences are influenced by the F:B ratio; for some vegetables (carrots, lettuce, broccoli, cole crops), values between 0.3 and 0.8 are excellent; for other vegetables (wheat, maize, and tomatoes), values between 0.8 and 1.1 are preferred. In wooded soils, trees grow best at a F:B ratio of 10:1, whereas lawns do best at a ratio of 0.5 to 1.1 (Gondal et al., 2021; Hayat et al., 2010).

Yeast is beneficial to most plants because it helps to prevent infections, improve plant health, and stimulate growth by producing enzymes. Beneficial yeast inhibits the growth of infections and illnesses by competing with harmful bacteria. According to studies, pathogenic fungi that cause plant mortality or substantial crop output impacts include Pythium, Rhizoctonia, and Verticillium. Competition for nutrients and accessible space is thought to be the main cause of yeast response in acidic soils, and yeasts with a variety of antagonistic traits have a better chance of avoiding disease (Ferraz et al., 2019; Hernández-Fernández et al., 2021; Kowalska et al., 2022).

Furthermore, in exchange for the plant's carbon, mycorrhizal fungi develop symbiotic partnerships with plant roots, helping to solubilize phosphorus and transfer soil nutrients to the plant. Endomycorrhizal fungi, which are typically found with grasses, row crops, vegetables, and shrubs, grow inside root cells, whereas ectomycorrhizal fungi, which are connected to trees, develop on the surface layers of roots. It has been demonstrated that the presence of baker's yeast benefits arbuscular mycorrhizal (AM) fungi, a kind of endomycorrhizal fungi and their hyphal development enables colonizing cucumber roots (Freimoser et al., 2019; Zhang et al., 2020).

Agricultural Context: A "Fresh" Green Revolution in the Face of Soil Quality

Through the development of improved crop plants through targeted breeding and sophisticated genetic manipulations, as well as advances in chemical inputs such as pesticides, insecticides, and chemical fertilizers, the Green Revolution—a pivotal movement in the 20th century—markedly increased global food production. To meet the needs of a growing global population for food, fuel, and fiber while addressing changing soil quality over the course of the century would require a new agricultural revolution due to the significant environmental costs involved with fertilizer inputs (John & Babu, 2021).

A new agricultural revolution—often called a "bio-revolution"—that stresses biological inputs like improved crops and the microbiome holds the key to a potential solution. Microbial inoculants, historically applied in agriculture, have proven effectiveness in broad-scale inoculation. More recently, it has been shown that using yeasts such *Metschnikowia, Pichia, Candid, Saccharomycopsis, Schwanniomyces,* and *Rhodotorula* can enhance soil quality and plant development (Freimoser et al., 2019; Wang et al., 2022).

Every aspect of the soil environment in the natural world have changed as a result of human activity, especially the use of chemical plant protection and the intensification of agriculture. The ability of the ecosystem to survive and operate properly may be impacted by this change (Nunes et al., 2020). Plant variety and productivity are impacted by changes in soil quality, and human activity aims to maximize the productive attributes of soil. The physiochemical and microbiological characteristics of the soil must be taken into account for appropriate agricultural management (Hernández-Fernández et al., 2021). The sensitivity of soil quality, as shown by the activity and variety of microorganisms, is a subject of inquiry for various experts. It has been discovered that anthropogenic factors—particularly agricultural practices—have a major influence on the quantity and quality of organisms that live in soil environments (Frey-Klett et al., 2011).

CONCLUSION

In the upcoming years, the large expansion in the world population is predicted to drive up demand for agricultural methods, including the use of conventional fertilizers. This growth produces and accumulates residues in addition to the depletion of organic matter in soils. The levels of microbial populations are impacted by changes in physicochemical qualities, underscoring the necessity for creative and long-term agricultural solutions. In lieu of synthetic fertilizers, especially in acidic soils, this paper suggests using yeasts as plant promoters to increase agricultural output both directly and indirectly. Yeasts are a useful microorganism for agriculture because of their natural qualities and practical applications. They are the perfect platform for evolutionary study applicable in field studies because of their variety of species, simplicity of laboratory cultivation, and fast adaptation for experimental testing, including reverse genetics approaches. Future biofertilizers may be based on the discovery, creation, and refinement of efficient yeast inoculant consortia that are tolerant of different plant species and environmental conditions. These biofertilizers have the ability to provide a steady supply of food, help save the environment, and provide a workable solution since they are affordable, useful, and socially acceptable.

ACKNOWLEDGEMENT

The authors acknowledge the Universiti Putra Malaysia (UPM) supported my candidature by providing support for this study. The author thanked to friends, colleagues, and staff of the Department of Land Management, UPM for their moral support, technical assistance, and contribution in various aspects.

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