February 28, 2021

Influence of Soil Ph and Microbes on Mineral Solubility and Plant Nutrition: A Review

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Received Date: 09-Feb-2021 Accepted Date: 27-Feb-2021 Published Date: 28-Feb-2021

Abstract

Soil pH is one of the essential vital features that increases or decreases the nutrient availability in soil. The lower pH lessens the secondary macronutrient availability while higher pH limits the available micronutrient in soil. Furthermore, the pesticides efficiency, use of organic and inorganic fertilizers sources to soil also required proper pH for maximum utilization by plants. Therefore, soil pH is termed as "principal soil indicator" that affect the biogeochemical cycles and has broader effects on the soil microbial community. Mineral approaches used to alter the soil pH had demonstrated drawbacks that it is too difficult to change. That's why alteration in rhizospheric pH can be a practical approach. Hence, a microbial-breeding technique such as genome replication of microbes may be a suitable approach to alter rhizospheric pH. It might be possible that microbes genetic product releases too much acidic or basic compounds that increase or decrease the pH of rhizosphere. Greater exploitation of microbes in this respect would be essential to pursue, as they have the ability to resolve several stresses in a more sustainable manner. In order to breed the microbes selectively for optimal nutritional interactions with plants, the genetic components of different traits must first be practiced.

Keywords: *Soil pH, Rhizosphere, Organic acids, Basic compounds, Nutrient availability, Growth promotion, Soil health, Genes transfer*

INTRODUCTION

Soil is the essential component of life support systems since it supplies several goods and services that have positive or negative impacts on human well-being such as water regulation, carbon preservation, food production, and soil fertility including pH (FAO, 2015; FAO and ITPS, 2015; Jones et al., 2013). The pH is a negative logarithm of hydrogen ion activity in the soil-water continuum (Hong et al., 2018) and is a critical component of nutrient availability. Hydrogen ion activity in soil is considered as the dominant phenomenon; at elevated pH value, the hydrogen ion concentration is low and vice versa (Cushman, 2015). A logarithmic pH scale is used when hydrogen ion concentration ranges over a broad range; with a pH decrease of 1, the acidity increases by a factor of 10 (Gethin, 2007). The pH scale varies between 0-14 (Schneider et al., 2007) and differentiates the soil types with different ranges of pH worldwide. For instance, the pH value of ordinary soil ranges from 3.5 to 9 and in precipitated areas ranges from 5 to 7 and in dry regions varies between 6.5 to 9 (Queensland Government, 2016).

Upper and lower level of pH in soil solution significantly affect the nutrient uptake and all other phenomenon's that occurred in soil. Soil pH directly influences the cation exchange capacity (CEC) (Sparks, 2003). The presence of negative charges on soil colloids tends to develop the CEC of the soil, and the CEC of soil fluctuate significantly due to change in negative charge (Weil and Brady, 2017). Negative charges on soil particles (allophones, organic colloids, sequiooxides, and 1:1 types silicates) are increased due to an increase in pH that also tends to increase the CEC of soil and vice versa (Sollins et al., 1988). Commonly, variable and permanent charges are the two types of soil charges (Cunha et al., 2014). Variable charges are completely pH-dependent (vary with variation in pH), while permanent charges are independent (constant) (Cunha et al., 2014). Furthermore, the pH explains the chemical behaviour of protons, the main player in redox reactions, and precipitation, surface complexion, crystal degradation, and other geochemical processes (Bethke et al., 2011). These processes determine the factors such as salinity, nutrients avaibility, pH, and micronutrients association in soil solution. It also affect the enzymatic activities, and organic matter (Lauber et al., 2009). However, increase or decrease in pH significantly influence the crop growth, quality and yield in terms minimum nutrient uptake.

Furthermore, each pesticide has its prerequisite for proper functioning. Simultaneously, the soil pH reaches the inappropriate standard; it may either become ineffective and may not degrade as expected (Nicholls, 1988), resulting in difficulties for the subsequent crop growth period. The intensive cultivation and climatic changes significantly modify the soil characteristics including pH (Guo et al., 2010; Yang et al., 2012). Hence, plant growth, pesticide efficacy, soil productivity, microbial activity, and nutrient availability are adversely affected by soil pH; plant growth problems are common in too alkaline or too basic soils. Besides, many heavy metals become more water-soluble under acidic conditions and can move down to the soil with water and, in some instances, move to aquifers, surface streams or reservoirs and soils with a pH of 5.5 or less are likely to be incredibly corrosive to concrete (USDA Natural Resources Conservation Service, 1998).

Various mineral soil conditioners such as limestone, dolomite, and potassium feldspar etc. are generally used to overcome the problem of soil acidity and these conditioners are rich source of calcium (Ca+2), silicon (Si), magnesium (Mg+2), and potassium (K) (Yang et al., 2020). Addition of sulfur (S) may acidify the alkaline soil to the desirable pH range (McCauley et al., 2009). In addition, natural community disrupt the pH significantly because of their metabolism (Ye et al., 2012). Microbial population change their metabolism in several ways. Various microbes such as acidophilic (Thiobacillus acidophilus (a type of bacteria), Vorticella (a type of eukaryote), and Crenarchaeota (a type of archaea)) maintain the pH towards neutral by secreting basic compounds in the soil solution (Gemmell and Knowles, 2000) and are resistant to salinity and other abiotic stresses as prescribed in Table 1. Similarly, Alkaliphilic (Thiohalospira alkaliphila) microbes released acidic compounds to adjust the pH towards neutral and are also resistant to stresses by adopting various mechanisms (Kulshreshtha et al., 2012). For instance, the applied S is converted into hydrogen sulfate or sulfuric acid by particular kind of microbes that helps the soils to bring the pH down a bit (Kopecky, 2014).

Table 1. Tolerance of microbes in acidic and basic environment;

Microbe	Acidity Tolerant	Alkalinity Tolerant	Reference
Rhizobia	yes	-	(Watkin et al., 2003).
Rhizobium tropici	yes	-	(Muglia et al., 2007; Wang et al., 2018)
Arbuscular mycorrhiza (AM) Fungi	yes	-	(Clark, 1997; Bloom et al., 2006)
Alkaliphilic Bacteria	-	yes	(Torbaghan et al., 2017)
Bacillus	yes	-	(Shin et al., 2017)
Paenibacillus	yes	-	(Shin et al., 2017)
Alicyclobacillus	Yes	-	(Shin et al., 2017)
Burkholderia bannensis sp.	yes	-	(Aizawa et al., 2011)
Sulphur oxidizing bacteria		yes	(Bao et al., 2016)

– sign show that data is not available.

Fragile effects of the acidic soil environment

The soil acidity influence plant development in several ways. Hydrogen (H^+), iron (Fe^{+2} or Fe^{+3}), and aluminum (Al^{+3}) are common acid-forming cations, while sodium (Na^+), K^+, Ca^{+2}, and magnesium Mg^{+2} are base-forming cations (Diriba, 2018). The solubility of manganese (Mn), Al, and Fe become maximum at lower pH. The excessive soluble Al in soil solution restricts root growth, reduces the supply of macronutrients, which also affects microbial development (Cornell University, 2010). These nutrients, however, become too poisonous for plants when their volume reaches the cap. On the other hand, the availability of macronutrients increases as certain micronutrients and phosphorus decrease. The lower level of these primary and secondary nutrients negatively affects plant growth, especially by disrupting the many plant characteristics such as biomass, flower size and number, lateral spread, and pH-induced pollen production (Jiang et al., 2017). Higher amounts of H^+ ions dissolve basic cations at a lower pH level, remove them from exchange sites, release them into the soil solution, and very small concentration of these nutrients is utilized by plant and remaining is lost by leaching (University of Hawai'i, 2021). In acidic conditions, microbes and their counts are responsible for transforming nitrogen (N), phosphorus (P), and sulfur (S) into the usable type of plants (Jacoby et al., 2017), thus reducing the concentration of minerals. In acidic soils, Mg^{+2}, Ca^{+2}, nitrate ions of nitrogen (N), boron (B), P, and molybdenum (Mo) availability is reduced (Extension Service of Mississippi State University, 1914; Maathuis, 2009; McCauley et al., 2009). The Ca^{+2} and Mg^{+2} ions become inaccessible to the plants by reacting with soil matrix or adsorption by clay particles and leached to some extent (Maathuis, 2009; McCauley et al, 2009). The symbiotic nitrogen fixation may be impaired in legume crops after alteration in soil pH. *Rhizobium* is mainly responsible for N fixation in legumes, which demands more N (Mabrouk et al., 2018), and its activities have decreased under acidic conditions.

Fragile effects of the alkaline soil environment

At very alkaline pH levels, mineralization of organic matter is delayed or halted due to weak microbial behavior (Diriba, 2018) associated with nitrification and nitrogen fixation that is also hindered. The pH of soil influence the degradation and mobility of insectides and hercides and also influence the heavy metals solubility (Smith and Doran, 1996). The pH affects cation exchange reactions that modify soil aggregation (Sumner and Miller, 1996), e.g. Ca^{+2} ions serve as a barrier between clay particles and organic colloids in alkaline or acidic environments. In addition, the *Gaeumannomyces graminis* fungus grows well at alkaline pH and thus affects barley, rye, wheat and various other grasses (Smith and Doran. 1996). At higher pH, denitrification process become limited due to inhibition in microbial community and accumulation of nitrite (NO_2^-) occur (Albina et al., 2019). Mineralization of organic matter is slowed down at alkaline pH and organic matter is pH dependent (McCauley et al., 2009).

Correlation of soil nutrients and pH

Soil nutrients are essential for vigorous plant growth. Macronutrients (potassium (K), P, and N) are needed by crop pants in greater quantity and can be handled and applied by fertilizers on crop-based requirements (Rosse et al., 2011). Fertilizers (organic and inorganic) are a more incredible nutrient source and are pH-dependent (Neina, 2019). Furthermore, pesticides stability is adversely affected by pH (Schilder, 2008). Soil pH can change the available type of nutrients in soil solution (Jensen and Thomas, 2010). Changing pH to the indicated value greatly influences the essential plant nutrient, and plants typically grow well above 5.5 pH. As a rule, 6.5 is the most appropriate pH level for optimum nutrient absorption (Cornell University, 2010). The supply of nutrients, solubility, microbial population, and various other processes depend on pH. For instance, a higher pH value promotes micronutrient availability than neutral or alkaline soils that favour plant growth (Lončarić et al., 2008). Similarly, soil chemical, biological, physical, and other processes are closely interlinked with biogeochemical cycles and positively affected by soil pH, which eventually influences plant growth, yield, and biomass (Neina, 2019; Minasny et al., 2016).

pH specification of macro and micronutrients

A pH range of either 7 or nearly 7 is most suitable for plant growth, since all plant nutrients are readily available (Hayman and Tavares, 1985) and at pH 5.5 poor solubility of phosphorus, molybdenum, calcium, and magnesium while solubility of Fe, Al, and B is high. Furthermore, calcium and magnesium become more abundant at pH 7.8 and pH of 6.6 to 7.3 is optimal for microbial activities that contributes towards plant available nutrients (N, S, and P) (USDA Natural Resources Conservation Service, 1998). The availability of B to the plants decreases with an increase in soil pH (Marx et al., 1996), particularly above pH 6.5. However, highly acidic soils (pH less than 5.0) often appear to be poor in usable soil B due to boron sorption of iron and aluminium oxide on the soil mineral surfaces (Goldberg, 1997). The K fixation between clay layers tends to be lower under acidic conditions and is believed to be attributed to the presence of soluble Al occupying the binding sites, while the accessible type of S had no effect on soil pH (Stanford, 1947). The pH had a crucial impact on the solubility of Fe (Lindsay and Schwab, 1982). Less than 50% of Fe is available to the plants at pH 7 and due to the precipitation of iron hydroxide at pH 8; none of the Fe is to be found in the soil solution. More than 90% of Fe become accessible to plant as pH tends toward acidic (< 6.5) (Fageria et al., 2014). With each unit rise in pH lessens the solubility of Fe approximately by 1000-fold (Lindsay, 1979; Fageria et al., 2014). The activity of Mn, Cu, and Zn is decreased by 100-fold approximately with increase in each unit of pH in the range of 4-9 (Lindsay, 1979). Hydrated copper (Cu) exhibit the process of hydrolysis as the pH of soil increases (pH >6.0), that tends to increase the adsorption of Cu to the organic matter (OM) and clay minerals (Fageria and Nascente, 2014).

Role of pH in microbial growth

In natural environments, microbes are widespread biota; from hot springs to deep aquifers, in the natural habitats and also commonly support the microbes in ocean floor (Edwards et al., 2012). They modify a number of biogeochemical cycles ranging from global carbon cycling and redox reaction to weathering (Maguffin et al., 2015). A wide variety of environmental factors such as temperature, supply of nutrients, salinity and pH regulate their metabolism (Amend et al., 2013). Among these factors, pH has greater influence (Chen et al., 2004). The pH is the indication of managing the microbial community, their activities, and composition (Lauber et al., 2009). On maximum basis, microbes are classified into three groups namely, alkaliphiles grow fastest above pH 9, acidophiles grow best at pH <5, neutrophils grow optimally at pH between 5 to 7 (Baker-Austin and Dopson, 2007). One unit increase or decrease the pH reduce the microbial growth 50% (O'Flaherty et al., 1998; Kotsyurbenko et al., 2004).

Management of soil pH

Various approaches, methods, and strategies are being used to mitigate the problem of soil pH. Generally for the management of acidic soils, calcitic limestone is used to maintain the pH towards neutral and is more effective than the dolomitic limestone (Pennisi and Thomas, 2015) and for high pH elemental sulfur is recommended in certain cases. Gypsum is more effective to enhance electrical conductivity (EC) of soil than S but S is effective to reduce the pH of soil than that of gypsum (Turan et al., 2013). Both application pulls the pH towards neutral as shown in **Figure 1.** Unfortunately, to change the soil pH is a complicated phenomenon because of all the artificially applied nutrients sources are pH dependent. Therefore, management of soil pH is necessary to achieve successful production of horticultural and agronomic crops (Shober et al., 2019). The microbial breeding approaches can be suitable alternative.

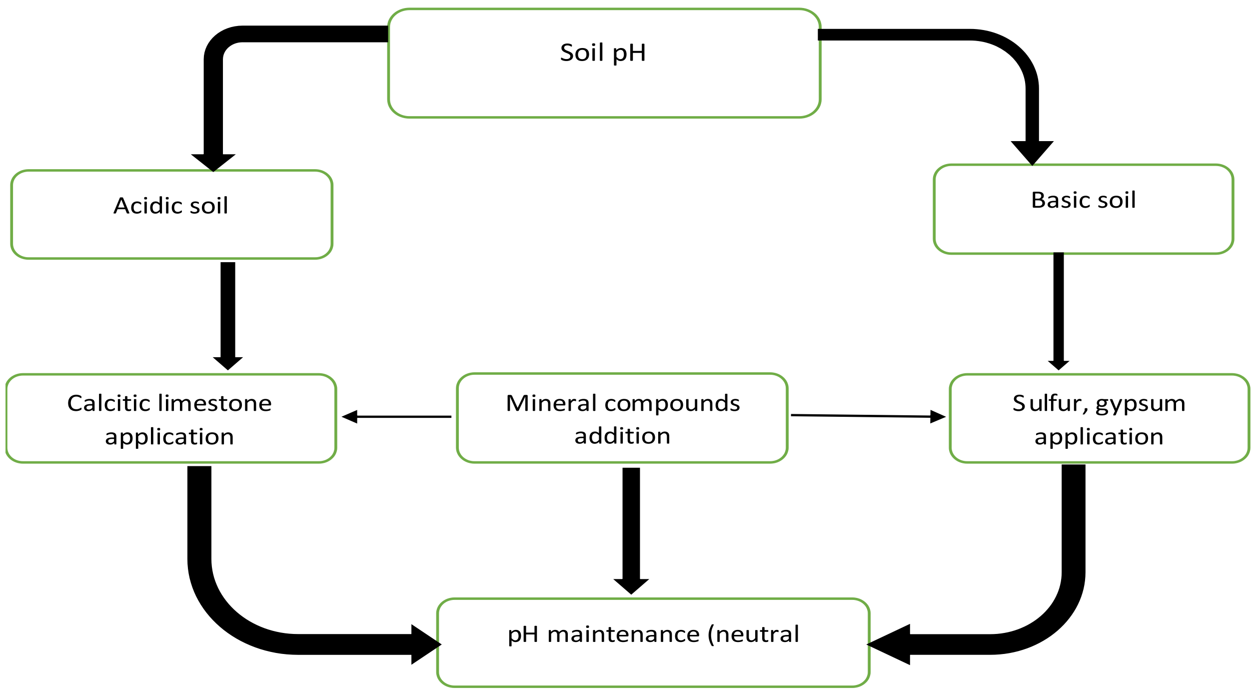

Figure 1. The mineral application drag the pH towards neutral.

Mechanism of innovative microbial approach

The fluctuation of pH in rhizosphere could be a suitable phenomenon that increase or decrease the pH by several folds in rhizosphere. The microbial approach can be beneficial if manage properly. In this technique, the collected microbes (that release organic acids or essential compounds) may be multiplied through genome transferring until their characteristics become too acidic or basic in rhizosphere to help to alter soil pH where nutrients are readily available to the plants. The microbial community collected from different sites, alkaline and acidic medium can be helpful for this purpose because every bacteria has its own characteristics collected from various locations. The **Figure 2** clearly explains the innovative mechanism. Furthermore, in recent years, this view has helped to begin to answer some common evolutionary concerns regarding how bacteria, along with their host species, have evolved from their early ancestors. Furthermore, it is of vital significance to consider how plant tolerance has been affected by their encounters with microbes, although much remains unclear.

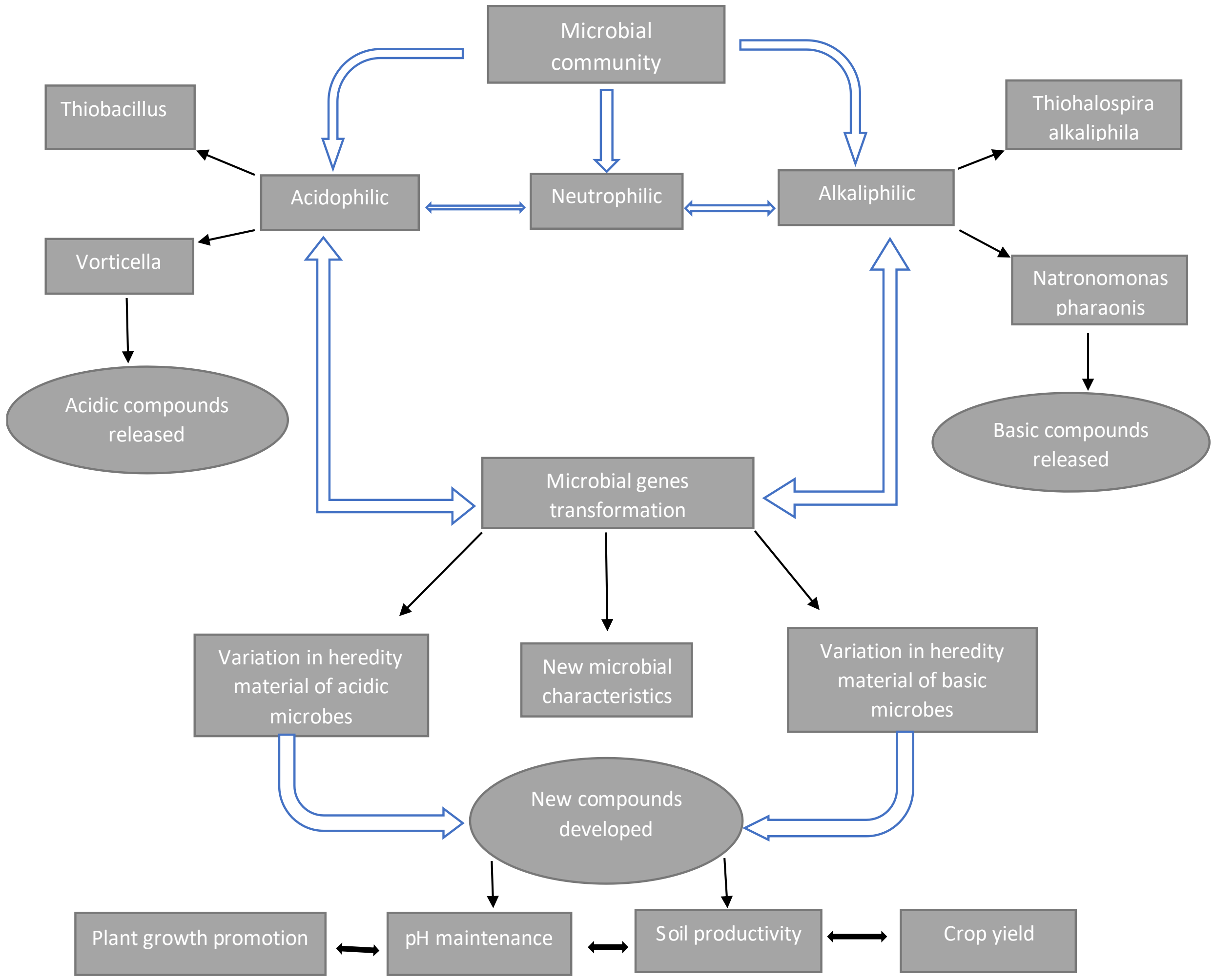

Figure 2. Innovative microbial approach towards neutral soil pH.

In addition, the next challenge is to identify the primary genetic elements that support how different plant genotypes interact with rhizospheric bacteria. Decades of study have shown that the vulnerability to pathogenic microorganisms is heavily dependent on the genome of plants, between various species as well as on accessions of the same species (Zhang et al., 2013). Similarly, Arabidopsis accessions have demonstrated considerable variance in support for the development of the rhizospheric bacterium *Pseudomonas fluorescens* in the hydroponic system (Haney et al., 2015).

Microbial efficiency towards soil pH

Plants do not live on their own; they still have dynamic relationships with microbes (Knack et al., 2015). Plants allow the microbes (fungi, archaea and bacteria) in all over their tissue and the subsequent accumulation of microbes is called as phytomicrobiome (Knack et al., 2015; Smith et al., 2017). Various organic acids such as malic acid, gluconic acid, citric acid, oxalic acid, tartaric acid, lactic acid, and succinic acid are produced by microbial biota in which both anions and cations serve as chelating agents and anions trap positively charged ions (Ca^{+2}, Al^{+3}, and Fe^{+3}) present in the soil (Mardad et al., 2013). Plant roots, decay of organic matter, and bacteria may be the cause of acids in the soil. Previous studies agreed that microbes are the primary cause of soil organic acid production and therefore the problems associated with the formation of organic acids are becoming important (Adeleke et al., 2017). From wider variety of ecosystem, the organic acids concentration varies between 0 to 50 μM for tri or dicarboxylic acids such as tartaric acid, citric acid oxalic acid, malic, and succinic acid while these concentrations varies greatly ranging from 0 to 1 mM in monocarboxylic acids including formic, valeric, lactic acid, acetic acid, propionic acid, and butyric acids. (Strobel, 2001). However, it should be focused that these concentrations are extremely variable based on the soil composition, organic matter degradation, root exudates, and microbes. Microorganisms including bacteria, fungi, and lichen species contain large quantities of soil organic acids (Ryan et al., 2001, Lian et al., 2008, Aoki et al., 2012).

Conclusions

Increasing or decreasing pH significantly influence the nutrients in soil and ultimately affect the growth and yield of plants. Various methods are used to solve these problems but it is very complex phenomenon. Therefore, breeding of microbes may be suitable option. Microbes release organic acids that take part in much of the physico-chemical processes that make the soil ecological system working. Future crop production may entail more breeding for pH stress resistance and the introduction of microbial technologies that have improved tolerance to pH stress. However, the underlining theory that organic acids synthesis in the soil setting is one process involved in the mineralization and solublization of poorly available and complex minerals, and that it leads to the carbon cycle, the detoxification of soil metals, among other functions, is possible, although it also needs further study. Comparing of current and previous genes characteristics by these microbes should be checked through experiments. In order to selectively breed the microbes for optimal nutritional interactions for plants, the genetic components of this trait must first be established.

Conflict of interest

The authors do not have any conflict of interest with each other.

Acknowledgment

All the authors are highly thankfull to Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Punjab, Pakistan and College of Agriculture, University of Sargodha, Sargodha Punjab, Pakistan.

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