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Research priorities for applied soil science

Prioridades de pesquisa para ciência aplicada do solo
Prioridades de investigación para la ciencia aplicada del suelo

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Abstract

Much has been done to promote soil health and conservation and to safeguard the future of humanity. Much more remains to be done. The importance of soil health as the foundation for sustainable agriculture and other ecosystems continues unperceived. This paper reviews recent literature on research priorities for sustainable soil use and involves interdisciplinary teams to set pathways for research needs. We show the urgent need to restore soil health and promote the independence on foreign agricultural inputs in Brazil, potential for soil carbon to be included in voluntary carbon market and potential of biochar to sequester carbon in soil in the long term. We also highlight the need for bottom-up approach, inclusiveness, creativity and innovation in the search for equitable sustainable development.

Keywords: Research priorities, Brazil, sustainability.

Resumo

Muito tem sido feito para e promover a saúde e conservação do solo e salvaguardar o futuro da humanidade. Muito mais resta a ser feito. A importância da saúde do solo como base para a agricultura sustentável e outros ecossistemas continua despercebida. Este artigo revisa a literatura recente sobre prioridades de pesquisa para o uso sustentável do solo e envolve equipes interdisciplinares para definir caminhos para as necessidades de pesquisa. Mostramos a necessidade urgente de restaurar a saúde dos solos e promover a independência dos insumos agrícolas internacionais no Brasil, o potencial do carbono do solo para ser incluído no mercado voluntário de carbono e o potencial do biocarvão para sequestrar carbono no solo a longo prazo. Também destacamos a necessidade de abordagem de baixo para cima, inclusão, criatividade e inovação na busca do desenvolvimento equitativo e sustentável.

Palavras-chave: Prioridades para pesquisa, Brasil, sustentabilidade.

Resumen

Se ha hecho mucho para promover la salud y la conservación del suelo y salvaguardar el futuro de la humanidad. Aún queda mucho por hacer. La importancia de la salud del suelo como base para la agricultura sostenible y otros ecosistemas pasa desapercibida. Este artículo revisa la literatura reciente sobre las prioridades de investigación para el uso sostenible de la tierra e involucra a equipos interdisciplinarios para definir vías para las necesidades de investigación. Mostramos la necesidad urgente de restaurar la salud del suelo y promover la independencia de los insumos agrícolas internacionales en Brasil, el potencial del carbono del suelo para ser incluido en el mercado voluntario de carbono y el potencial del biocarbón para secuestrar carbono en el suelo a largo plazo. También destacamos la necesidad de un enfoque ascendente, inclusión, creatividad e innovación en la búsqueda de un desarrollo equitativo y sostenible.

Palabras-clave: Prioridades de investigación, Brasil, sostenibilidad.

INTRODUCTION

Soils are complex systems that provide a range of ecosystem services fundamental for life on Earth. They are formed at the intersection of the atmosphere, biosphere, hydrosphere, and lithosphere, regulating many ecosystem processes in landscapes and is home to a large proportion of earth's biodiversity, providing the physical foundation for numerous human activities (PEREIRA et al., 2018). Thus, the study of soils naturally involves an inter- and transdisciplinary approaches (BREVIK et al., 2015), as well as the Sustainability Science, with its systemic, transdisciplinary approach searches pragmatic solutions to complex problems and most urgent challenges. This includes how soil health could influence or aid in achieving inclusive and equitable sustainable development (BRANDT et al., 2013; LAL et al., 2021).

Soil health, defined as the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans (NRCS, 2022) and soil conservation are paramount for effectively and adequately realizing the objectives of Sustainable Development Goals (BORTHAKUR; SINGH, 2020). Soils are however overlooked and under-researched in the tropics (LATAWIEC et al., 2022; MENDES et al., 2018; RODRIGUES et al., 2021). There is often lack of recognition of the critical role of soils for human well-being (LATAWIEC et al., 2021), little education on specific role of soils (LATAWIEC et al., 2022) and therefore lack of prioritization of soil degradation among environmental problems (LATAWIEC et al., 2020).

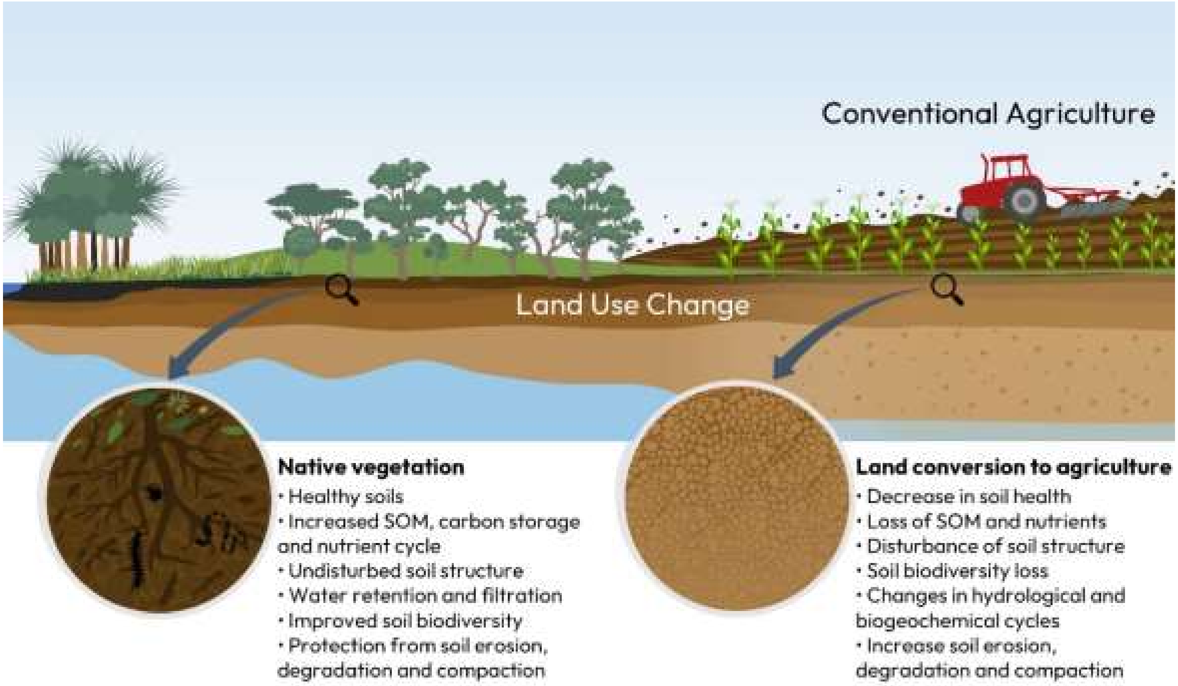
In this context, we adopted transdisciplinary approach within Sustainability Science to arrive at new priority research topics for soil sustainability in Brazil. To this end, we conducted a two-day workshop entitled 'New Frontiers in Sustainable Soil Use' (Novas Fronteiras no Uso Sustentável do Solo, in Portuguese - full recording available on request). The event was held between August 26-27 at Embrapa Agrobiology, Seropédica, Rio de Janeiro. The participants included local farmers, academics, researchers, undergraduate and postgraduate students in Sustainability Science, Sustainable Development, and Agriculture, totalling 27 participants. Based on the most urgent challenges to sustainable food production and a mind-mapping exercise, here we report the frontiers in applied soil science which were depicted as most impactful for soil sustainability.

Brazilian soils and agricultural sustainability

Brazil is currently one of the largest food producers and by 2030, the country will be the largest producer and supplier of agricultural products in the world (OECD-FAO, 2015), 77% of agricultural establishments are classified as family farming, employing 67% of the population that works with agriculture in the country (IBGE, 2017). Family farming is responsible for 70% of the food consumed in Brazil and in 2017, this contribution was more than 22 billion dollars (IBGE, 2017; NETO et al., 2020). Family farm account for 77% of the number and 23% of the total area of the rural establishments in Brazil. Family farming also accounts for 48% of the gross production value of coffee and banana, 80% of the production value of cassava, 69% of pineapple and 42% of bean production (IBGE, 2017). The impact of family farming and agribusiness on the Brazilian Gross Domestic Product approximately 25% (CEPEA, 2022).

Sustainability of Brazilian conventional agriculture (Figure 1) may however be questionable. Most Brazilian soils are classified as Latossolos (Ferralsols) and Argissolos (Acrisols, Lixisols, and Alisols) (SANTOS et al., 2018; WRB, 2022) which are acidic, weathered and with low levels of nitrogen (N), phosphorus (P) and potassium (K). Food production in Brazil depends therefore on the input of nutrients imported from a limited number of countries (ANDA, 2020; EMBRAPA, 2022). Soil fertilization consists in addition nutrients and substances that improve the structure of the soil or support appropriate microbiota, these treatments improve the physical, chemical, and biological properties of arable soils, indirectly affecting their fertility which has a significant impact for development of plants (ROMBEL et al., 2022).

Figure 1. Schematic representation of soil changes in a conventional agriculture model.



Regarding N, in 2020, Brazilian production supplied only 4% of demand and imported the equivalent to 96% of demand of N fertilizers (Plano Nacional de Fertilizantes - PNF, 2021). The main problem is the low competitiveness linked to the high cost of the natural gas used in the production process, where Brazilian urea costs about U$ 280.00/ton, being more than 400% higher than the price of urea produced in Canada, for example, where the price is only US$ 54.00/ton. In addition, Brazil has a low installed capacity for production of basic N fertilizers. As for P fertilizers, production is concentrated in a few countries, where China, Morocco and the United States of America are responsible for producing approximately 60% of world production. The current dependence on imports of phosphate fertilizers is 72% (in terms of contained P2O5; PNF, 2021). Potassium is the nutrient whose Brazilian dependence is the most critical, where national production corresponds to only 3% of domestic demand. It is worth mentioning that the geographic distribution of K reserves is restricted to a few countries, especially Canada, the largest producer, with about 30% of world production.

The way forward and soil research priorities

Notwithstanding the shortage of delivery of organic minerals crucial for agriculture, the potential in Brazil is huge. According to the PNF, Brazilian official reserves correspond to about 5.2 billion tons, which is equivalent to 460 million tons of P2O5. The mineable reserve is 2.9 billion tons (with an average content around 10%), comprising 317 million tons of P2O5. Considering consumption similar to that of 2019, which was 5.2 million tons of P2O5, our reserve has the potential to serve around 60 years with agricultural production maintained at current levels. Brazilian reserves of K correspond to 3% of the world reserves (or 0.1% in terms of K2O). Given this scenario, an alternative is to invest in agrogeological research to advance in the use of potassium sources in silicate rocks. These are abundant rocks in the country and are formed by varying proportions of silicate minerals, such as feldspar, mica, amphibole, etc.) and siliceous (quartz), or just silica, covering materials commercially classified or identified as granite, pegmatite and shale. Although there are already materials on the market, there is still no consensus on the agronomic efficiency of silicate rocks. Therefore, investment in scientific research is necessary to ensure increased soil fertility using more sustainable ways of agricultural practices, such as reducing the use of chemical fertilizers, providing increased food production without compromising soil productivity and health (NEOGI et al., 2022).

To supply most of the nutrients, farmers can use agrosilvopastoral residues (BRASIL, 2010). Among these residues, agricultural residues stand out (coffee, cocoa, bananas, oranges, coconuts, cashews, grapes, soybeans, corn, sugar cane, beans, rice, wheat and corn); livestock residues (broilers, laying hens, beef cattle, dairy cattle and swine), forestry residues (eucalyptus, pine, acacia, rubber tree, paricá, teak, araucaria and populus), in addition to residues derived from fish and of agribusinesses. In the state of Rio de Janeiro alone, there are more than 30 different types of waste with potential for use in agriculture (EMBRAPA, 2021). According to the Institute of Economic and Applied Research (IPEA, 2012), around 400 million tons of agricultural waste are produced annually in Brazil in animal confinement systems alone. This represents, considering an average content of 2% N, more than double the total N imported annually by Brazil. The amount of waste available in Brazil has the potential to reduce, especially with regard to family farming, the dependence on fertilizer imports. The rational use of waste, using the composting process (Ferreira et al., 2021), allows for the recycling of nutrients and the sustainability of family farming. For this, it is essential to work within the logic of the circular economy.

Another strategy to reduce dependence on imported nitrogen fertilizers is biological nitrogen fixation (BNF). Plant species of the Fabaceae family (legumes), such as jack bean (*Canavalia ensiformis*), forage peanut (*Arachis pintoi*), velvet bean (*Mucuna pruriens*) and sunn hemp (*Crotalaria juncea*), inoculated with strains of bacteria of the genera *Rhizobium* and *Bradyrhizobium*, collectively known like rhizobia, they can supply nitrogen derived from BNF through the technique of green manuring for various crops (ARAÚJO et al., 2011; ARAÚJO et al., 2019; GOULART et al., 2021; MEDEIROS et al., 2019; ROCHA et al., 2019). Green manuring is an old technique with proven efficiency, capable of inserting more than 300 kg N ha-1 year-1, however, for its application it requires planning and technical knowledge. Considering that there is a low rate of technical assistance in Brazil, the use of green manure is incipient, currently restricted to a few farmers. However, green manure has a high potential to reduce dependence on imports of nitrogen fertilizers.

Nitrogen (N) deficiency is the main limiting factor to pasture-based cattle production systems, particularly due to the high adoption cost of this practice (GURGEL et al., 2020; XU et al., 2018). Forage legumes have the capacity to fix air N by association with soil bacteria of the Rhizobium genus (RAZA et al., 2020). Successful experiences of mixing forage legumes into grass pastures has been pointed out as a low-cost and low carbon option to reclaim and maintain pasture productivity, thus contributing to increase productivity and profitability of cattle productions systems (BODDEY et al., 2020; ERMGASSEN et al., 2018; LATAWIEC et al., 2014; SHELTON et al., 2005; VALENTIM; ANDRADE, 2004; VALENTIM et al., 2021), while reducing methane emissions per unit of product and contributing to reduce deforestation pressures (BODDEY et al., 2020; STRASSBURG et al., 2014).

Another crucial component for soil sustainability is organic matter. Due to the intense weathering conditions to which most Brazilian soils were subjected in their formation, iron and aluminum oxides and kaolinite are the main constituents of the clay fraction of

Latossolos and Argissolos (SANTOS et al., 2018). These minerals have low cation exchange capacity and can sometimes exhibit anion exchange capacity. Thus, management systems that contribute to an increase in the organic matter content in soils are of fundamental importance.

Soils and carbon sequestration

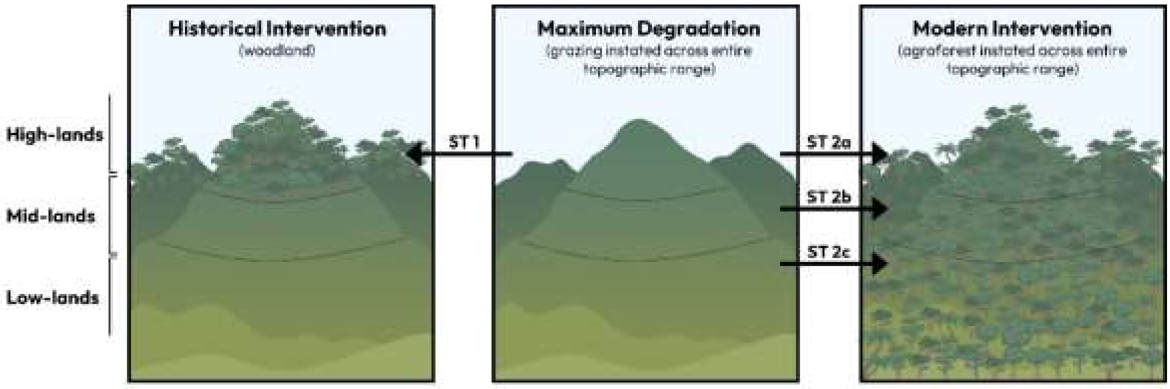
Soil C is crucial for sustaining human life and ecosystem health and functions. The C cycle in soils is very complex including biological, physical, and chemical processes that are influenced by climate and cultivation practices. Adequate soil management can increase soil C sequestration, mitigate climate change, and improve the soil ecosystem service (BATJES, 2019; IPCC, 2019; LAL et al., 2018). Although several efforts have been made to monitor the loss of vegetation cover throughout different biomes (e.g., MAPBIOMAS, 2022), the understanding of the current soil C stock in the different Brazilian biomes is limited. Also, assessments of soil C dynamics are generally focused on shallow soil layers (0–30 cm depth). Current broad estimates of soil C stocks in Brazil rely on historic nationwide data from surveys from earlier decades that span several land use systems across the entire country (BATJES, 2005; BERNOUX et al., 2002; GOMES et al., 2019). While these national- scale studies are extremely valuable and rich, regional-scale soil C assessments with spatial explicitly ground-based measurements are highly necessary to increase accuracy. Improvements in the soil C understanding, in terms of quantity and quality of C, and the uncertainty around these stocks is necessary for national C inventories.

The intrinsic capacity of a mature forest to sequester and store carbon is different to that of a pasture, or crop land. Equally, highlands will differ to lowlands by virtue of their productivity capacity and dissimilar soils that underpin their vegetation. It is essential to appreciate the magnitude of net-gain opportunity represented by a land use change transition. Natural capital assets are most likely to be traded as net-gains. Without appreciation of the baseline, it is impossible to evidence the net-gain. The rural poor need support to ensure they are not disenfranchised from emerging natural capital markets. Intervention is needed by government to deliver a framework wherein natural capital credits and be ascribed and verified across a landscape. local government should finance the benchmarking of natural capital assets under contrasting land use regimes.

Soil carbon, and specifically opportunities to re-carbonize soils emerged as priorities in need of urgent action. Globally, an estimated 135 Pg C of soil organic carbon (SOC) has been lost from soil due to land use change and agricultural interventions (LAL, 2018). Viewed from the opposing standpoint soil have 135 Pg C technical capacity to re-sequester this "lost" carbon. Lal (2018) reported SOC re-sequestration to be feasible across 4,900 Mha of agricultural land; including ~2,000 Mha of degraded lands. Of the 160.9 million hectares of existing pastures in Brazil, 39.39% are in an intermediate degradation phase and 15.99% are severely degraded (LAPIG, 2022). These lands identified as strong candidates to support meaningful re-carbonisation efforts. Opportunities to encourage soil recarbonization through financial reward were identified as a likely powerful lever to facilitate the adoption of strategies to increase SOC (KEENOR et al., 2021). However, robustly assessing baseline SOC stocks, increases in SOC stocks following a regime of intervention and the permanence of SOC carbon storage were highlighted as significant challenges. This is further confounded in tropical regions where environmental conditions favor continuous and faster organic matter decomposition (FAO, 2005). Thus, biomass decomposing contributes to CO2 emissions alongside sequestration potential.

There is pressing need to benchmark carbon stocks represented across a topographic sequence and how land use interventions (again across a topographic sequence) deliver demonstrable uplifts in above and below ground carbon stocks (Figure 2). With regards to the exemplar Atlantic Forest biome, data is needed to quantify the magnitude of change, as delivered through policies to afforest hilltops, in terms of carbon uplifts realized (Sustainability Transition 1 - ST1; Figure 2). In compliment, the success of agroforestry (or afforestation per se) in terms of carbon socks uplift is also needed (ST2; Figure 2). Such assessment should evaluate temporal changes to assess speed of carbon uplift and how topographic position influences the carbon stock outcome. With regards to the latter, soil types can be expected to vary across topographic sequences and thus their influence on productivity and carbon fixing will also vary (ST2 a-c; Figure 2); this defining a Carbon Catena. Furthermore, the inherent capacity of contrasting soils to lock up carbon will also vary. A fuller appreciation of these interplays (forest type, soil type and elevation) will inform strategy/policy to optimize carbon gains. Finally, in relation to the "rural poor" (see below) this benchmarking of carbon asset, across topography and land use regime, will potentially support a rudimentary ("basic") carbon payment mechanism; wherewith, if bespoke assessment is precluded by a lack of assessment resource, precautionary estimates of carbon uplift can be made and the rural poor remunerated.

Figure 2. Framework to evaluate carbon assets under Sustainability Transitions (STs) as linked to historical high-land afforestation (ST1), and modern interventions, for example, agroforestry (ST2); with further evaluation of the influence of altitude and soil type on the Carbon Catena (ST2a-c).



High-lands	Old Woodland	Long-term Pasture	Recent Agroforest
Mid-lands	Long-term Pasture	Long-term Pasture	Recent Agroforest
Low-lands	Long-term Pasture	Long-term Pasture	Recent Agroforest

Biochar in soil

There is a global enhancive need of utilization organic by-products and wastes for production of materials such as biochar and composted, these materials have been suggested and are increasingly being used for soil improvement, landscaping and carbon sequestration to provide faster vegetation restoration on highly degraded lands (HEISKANEN et al., 2022).

In recent years, the application of biochar – product from pyrolysis of residues - has been investigated as a solution to improve the productivity of soils, increase carbon storage, reduce chemical fertilizer input, adsorb pollutants and has been proven to mitigate the effects of degraded soils by the adjustment of key physiochemical properties soil (JAMES et al., 2022). However, it is important to highlight that these positive effects depend on several factors such as the biochar raw material, application rate, pyrolysis temperature and soil properties (NOVOTNY et al., 2015).

In addition to the environmental benefits promoted by the sustainable use of biochar, production and commercialization have enormous economic and social potential that need more research. Many challenges need to be overcome, some specific barriers towards commercialization expansion of biochar are access to financing, technological constraints, regulatory issues, lack of education and awareness (SINGH et al., 2022). Furthermore, research related to the potential adverse impact of biochar on ecosystems can be encouraged, given the relatively small number of studies exploring its possible harmful effects and frequent disregard of such effects (BRTNICKY et al., 2021).

Given the economic aspect, biochar can also be considered as an important tool to promote a circular bioeconomy (DAHAL et al., 2018). Bioeconomy is a versatile, dynamically developing sector of the modern economy, covering the extraction and use of bio-based products, including organic waste from the agri-food industry and biotechnology to create new bioproducts with economic value (ADAMOWICZ, 2017; BUGGE et al., 2016).

Therefore, biochar production technology from biomass waste and its wide applications in agriculture, remediation and generation of energy, are considered as environmentally sustainable and economically viable intervention strategy for abating climate change promising fostering a circular bio-economy in context of climate amelioration (NEOGI et al., 2022).

Different biomass, which include but are not limited to agricultural residues, municipal solid wastes, and agroforestry residues, can be utilized how feedstocks for biochar (JAMES et al., 2022). Most of the countries hardly use these residues and therefore, they can be used as valuable feedstocks for producing biochar (SINGH et al., 2022). The easy accessibility of biomass for biochar productions that Brazil has offers a considerable advantage for the country.

However, variables associated with the cost benefit biochar production, scale up and others, need to be considered to evaluate the overall contribution of biochar to the environment. The development of biochar systems around the world can be at vastly different scales and uses depending on the feedstock, expected use for the biochar, production technology, local economics and setting (IBI, 2022). For Brazil, the scaling of biochar production is still a limiting factor. There is a lack of national technologies that supply the internal market. In order to scale up the production of biochar in Brazil, more investments and more research are still needed.

Soils and food security

Worldwide, the vulnerability of food supply chain when depending on imports has surfaced recently, socially and environmentally dependence on the supply of fertilizers and food on international market, its negative impact on food prices and poverty increase has become evident in various parts of the world (FAO, 2022). The disposition of contaminants in soil can be of geogenic and anthropogenic sources as numerous industrial contaminants inclusion and agricultural practices themselves add a number of contaminants into the soil primarily via fertilizer and pesticides applications (SARKAR et al., 2021).

There is also a need to increase healthy food production in accessible ways for the rural poorest. The rural poor, arguably most in need of food security and income diversification offered through the emerging mechanisms of payments for provision of environmental services (trade of biodiversity, nutrient, hydrological and carbon credits), is worst placed to access the market for these commodities. Specifically, this social group lacks the resource to credibly ascribe these credits and obtain verification for them. In addition, the transaction costs associated to such assessment and trading is disproportionate to modest income a small volume of credits might generate. If the rural poor are incentivized to produce food in a sustainable way, it will follow that access to such food would be facilitated for them as well as increasing food access by the poor population in neighboring urban areas. Furthermore, in relation to such an outlook, there is opportunity for collateral benefits, wherein a move to proactive SOC sequestration can support biodiversity and or conservation aspirations.

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Conflict of interest

The authors declare no conflicts of interest.

Ethics council approval

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