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NEMATODES AND SOIL HEALTH INDICATORS

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ABSTRACT

Understanding soil health impacts in relation to climate change is possible through the use of indicators which relate soil physical, chemical and biological. Major soil health indicators are governed by climate change. Selection of indicators within a minimum data depends on their sensitivity to management and climate changes, capacity to integrate and relate to other soil functions, ease of use, repeatability and cost of measurement. In this paper impact of soil health indicators including drivers for climate change; Carbon dioxide, nitrogen deposition, temperature, rainfall, soil structure, bulk density, rooting depth, soil surface cover, soil pH, electrical conductivity, available nutrients to plants, soil organic matter, soil carbon, potentially mineralisable Carbon and Nitrogen, soil respiration, soil microbial biomass, soil enzyme activities, genetic and functional biodiversity of soils on nematodes and selection of soil health key indicators are briefly discussed.

Keywords: soil health, nematodes, climate change drivers.

Soil health indicators are a measurable composite of physical, chemical and biological attributes relate to functional soil processes and can be used to evaluate soil health status, affected by management and climate change drivers. Defining soil health in relation to climate change should consider the impacts of a range of predicted global change drivers such as rising atmospheric carbon dioxide levels, elevated temperature, altered rainfall and atmospheric nitrogen deposition, on soil chemical, physical and biological functions. Studies progressed to understand climate change drivers. Wixon and Balsler (2009) noted that “a comprehensive explanation of the factors at the heart of the issue is currently lacking”. Soil health will be dependent on soil properties and their relationship with specific soil functions, including complexity associated with interactive effects of climate change. The “soil health” and “soil quality” are often used synonymously, however, it is realized that the former term gives greater emphasis on soil biodiversity and ecological functions that make soil a dynamic living resource with capacity for self-organization.

Indicators, calculated values or estimated statistics relative to a threshold level are being increasingly used

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across biological, environmental, economic, social, institutional and political disciplines to assess the current condition or trend of soil health (Dalal *et al.*, 2003). Indicators may be used as an indirect measure of soil function, serving to assess soil quality or health and its direction of change with time, by linking functional relationships among measurable attributes and monitoring for sustainable land management, including environmental impacts. This proposes that soil health assessment involves an evaluation process consisting of a series of actions: (1) selection of soil health indicators, (2) determination of a minimum data set, (3) development of an interpretation scheme of indices, and (4) on-farm assessment and validation. While the use of integrative soil health tests is increasing, limited information exists to evaluate the applicability of soil health indicators for monitoring soil functions within the context of climate change.

Elevated CO₂ concentration, increasing temperature, atmospheric N deposition and changes in total and seasonal distribution of rainfall and extreme events such as droughts and floods will impact on soil biological processes, Carbon and Nitrogen cycle, and consequently on soil structure and erosion events, nutrient availability and plant diseases, and hence on ecosystem functionality and agricultural productivity. Soil physical properties

provide information related to water and air movement through soil, as well as conditions affecting germination, root growth and erosion processes. Many soil physical properties thus form the foundation of other chemical and biological processes, which may be further governed by climate, landscape position and land use. A range of soil physical properties are highlighted as potential soil health indicators, and key soil physical indicators in relation to climate change include soil structure, water infiltration, bulk density, rooting depth, and soil surface cover, which are discussed below.

Drivers of climate change

Carbon dioxide (CO₂): Net ecosystem responses to elevated CO₂ cannot be predicted solely from the physiological responses of plants because plant responses have ecological consequences that ramify throughout the ecosystem. Increased C fixation increases root production, exudation, root to shoot ratios, or fine root turnover. Nematodes are the most abundant and diverse groups of soil organisms. Nematodes were extracted from roots and soil emerged changes in population densities of specific genera. Nematode respiration, estimated as a function of average individual size and population density, showed larger impacts of CO₂ treatment than community structure. For example, elevated CO₂ decreased both respiration and biomass of herbivorous nematodes by 150%, and respiration of predaceous nematodes by 180%. These carbon subsidies can stimulate microbial activities in the rhizosphere that increase short-term, mineral nutrient availability. However, labile reservoirs of nitrogen (N) and phosphorus (P) will be depleted quickly unless the decomposition of dead organic matter also increases, soil processes may ultimately limit the responses of ecosystems to CO₂ enrichment. Nematodes are a particularly good choice for studies of soil food webs. They occupy at least five trophic roles, including herbivores or plant-parasites, fungivores, bacterivores, omnivores and predators (Yeates *et al.*, 1993). Their taxonomy, life-histories, metabolism and feeding characteristics are better understood than any other group of soil invertebrates. They are small (0.3 to 2.5 mm length) animals with short generation times (7 to 9 generations per year) and respond quickly to changes in resources and conditions. They are abundant, typically ranging from 10⁵ -10⁷ m⁻² in the upper 15 cm of forest soils (Sohlenius 1980). They are likely to respond to elevated CO₂, because 37-59% of the total soil nematode

population is herbivorous and sensitive to changes in plant production (McClure 1997). Finally, efficient techniques have been developed to extract nematodes from soils (Neher 2001). Elevated CO₂ increased the number of nematode-induced galls on defence-dominated genotypes but not on the roots of wild-types or defence-recessive genotypes (Sun *et al.*, 2010). Elevated CO₂ and N fertilisation had significant effects on the abundance and diversity of soil nematodes. Elevated CO₂ increased the abundance of omnivores-predators, the values of maturity index (MI) and structural index (SI) of nematode assemblage at the jointing stage of wheat. Two levels of N fertilization had significant effects on the abundance of fungivores at the wheat jointing stage, while nematode channel ratio (NCR) showed responses to different N fertilization and the interaction effects of elevated CO₂ and N fertilization at the wheat ripening stage (Li *et al.*, 2007). Since root development and soil enzyme activities are closely related to soil porosity and pore size distribution and because future climate change scenarios viz., elevated CO₂ and temperature, and variable and extreme rainfall events may alter root development and soil biological activities soil porosity and pore size distribution and consequently soil functions are likely to be affected in unexpected directions; this aspect needs attention in future studies on the relationship of soil health and climate change. Elevated CO₂ and nematode infection did not qualitatively change the volatile organic compounds (VOC) emitted from plants. Elevated CO₂ increased the VOC emission rate only for defence-dominated genotypes that were not infected with nematodes.

Nitrogen (N) deposition: Nematodes are proposed as useful indicators for shifts in soil ecosystem functioning under N enrichment. Generally, N addition decreased total nematode abundance and diversity, but responses varied among trophic groups. Reduction in the population of herbivores, fungivores, omnivores and predators and increased of some opportunistic bacterivores in response to N addition in forests, grasslands and croplands has been established. Moreover, responses of soil nematodes to N addition often vary with time after application. Soil acidification following N addition has been proposed as one of the important factors inhibiting soil nematode abundance after N addition, NO₃⁻ N and NH₄⁺ N concentrations were found negatively correlated with root herbivores and fungivores suggesting direct effects

of N addition on soil nematodes. Importantly, soil nematodes may not only be influenced by changes in physicochemical soil conditions but also indirectly by shifts in plant community composition. Nematode trophic groups showed a diverse response to the N addition. N addition negatively affected the abundance of fungivores; their numbers linearly decreased with N addition. The abundance of fungivores was on average higher in August than in September. Root herbivores were strongly negatively affected by N addition in August, then September. Ammonium has been documented toxic to a wide range of organisms. However, ammonium toxicity could not explain the responses of microbial-feeding and omnivorous-predatory nematodes.

Temperature: *Rotylenchulus reniformis* is notorious for its ability to survive without a host. It is a broadly distributed in tropical, subtropical, and some regions of temperate of the world. Nematode affects a large number of cultivated plants. The parasitic behavior of the nematode on roots is obligate, sedentary, semi-endoparasitic. The life cycle of *R. reniformis* is very short at ambient temperature. Mature females lay one-celled eggs into a gelatinous matrix, where the embryo develops into a first-stage juvenile (J₁). The first cuticle molt occurs while the nematode is still in the egg. The second-stage juvenile (J₂) emerges from the egg, and subsequent juvenile stages (J₃ and J₄) remain in the soil until adulthood is reached. Eggs are able to hatch in water without the influence of a host plant and juveniles will develop into males and pre-adult females without feeding. On induction of anhydrobiosis, *R. reniformis* in direct response to elevated relative humidity (RH) condition resembling natural dehydration regimes. All larvae and pre-adults were unable to survive direct short-term exposure to 97 % RH. However, dehydration of larvae on model substrates (0.5% agar: 1.0% agarose) that mimic the natural rate of soil moisture loss, induced coiling and successful entry into anhydrobiosis. Coiling was maximized at 10-12 days and only coiled larvae survived dehydration, emerging as the preadult form. Larvae could withstand severe dehydration at 80 and 40% RH after the induction of coiling but were unable to withstand direct exposure to 0% relative humidity.

Rainfall: There is evidence that soil biodiversity does confer stability to stress and disturbance, but the mechanism is not yet fully understood. It appears to depend on the kind of stress and disturbance and on the combination of stress and disturbance effects.

Alternatively, community structure may play a role. The available evidence suggests that mycorrhizal diversity positively contributes to nutrient and, possibly, water use efficiency. Soil fauna effects on nutrient and water use efficiencies are also apparent, but diversity effects may be indirect, through effects on soil structure. In the area of sugar beet in England affected with Docking disorder widespread after heavy rain. *Trichodorus* spp. and *Longidorus* spp. cause the primary damage to seedling roots. Root shape was worst in sites with persistent symptoms. Atmospheric CO₂ has increased and temperature has risen (0.3 to 0.6°C). Climate change could have positive, negative or no impact on individual plant diseases. The effect of desiccation treatment on gene expression was measured by putting a 200 µl suspension containing approximately 1000 nematodes in a 35 mm Petri dish and exposing them to different RH. Treatments consisted of pretreatment (exposure to 98% RH followed by 85% RH for 12 h each), pre-treat + desiccation (exposure to 75% RH for 3 days after pretreatment), desiccation (direct exposure to 75% RH for 3 days without pretreatment), pre-treat+ rehydration (rehydration in water at 4°C after pre-treat + desiccation) and rehydration.

Soil Structure: Nematode and microbial communities vary between soil aggregate fractions due to variations in physical and/or resource constraints associated with each fraction and this contributes to management impacts on whole soil food webs. Phospholipid fatty acid (PLFA) analysis suggested that the LM fraction contained greater microbial biomass, gram positive bacteria, and eukaryotes than the IS fraction, while SM contained intermediate PLFA associated with these groups. Total PLFA was greater under RC and ORG than under CC or CON. Total PLFA was positively correlated with % C in soil fractions while nematode abundance exhibited no such relationship.

The soil is a complex habitat for diverse biota: size and arrangement of sand, silt, and clay particles; pores; and organic matter in a typical soil aggregate. It is considered a useful soil health indicator since it is involved in maintaining important ecosystem functions in soil including organic carbon accumulation, infiltration capacity, movement and storage of water, and root and microbial community activity; it can also be used to measure soil resistance to erosion and management changes (Rimal and Lal 2009). Because of its association with the storage of soil organic carbon (SOC) and water,

its measurement can be useful to guide climate adaptation strategies, especially in areas that are likely to experience high and intense rainfall and consequently increased erosion events. Pore characteristics are strongly linked to soil physical quality; bulk density and macroporosity are functions of pore volume, while soil porosity and water release characteristics directly influence a range of soil physical indices including soil aeration capacity, plant available water capacity and relative field capacity (Reynolds *et al.*, 2009). Aggregate stability, the resistance of soil aggregates to external energy such as high intensity rainfall and cultivation, is determined by soil structure, as well as a range of chemical and biological properties and management practices. Improvement in the soil physical properties impacted positively on the N and organic carbon contents. *P. phaseoloides* could be used as one component for the biological control of *Helicotylenchus multicinctus*, a phytopathogenic nematode (Banful and Hauser, 2011). Fertilization alters the composition of soil nematode and microbial communities in soil aggregates, and the interaction between nematodes and microbes can stimulate or inhibit microbial activity. Aggregate fractions affect the total number of nematodes and the abundance of *Protorhabditis* and *Pratylenchus*. Aggregate fractions also influenced microbial biomass and diversity. Only fertilization had a significant effect on the compositions of nematode groups, while both fertilization and aggregate fractions significantly affected microbial community composition. Aggregated boosted trees (ABT) analysis indicated that total C exerted the strongest influence on microbial biomass, while pH influenced the total number of nematodes. The grazing on microbes by microbivores may decrease microbial activity.

Bulk Density: Bulk density is considered as a useful indicator for the assessment of soil health with respect to soil functions (aeration and infiltration). Since bulk density is in general negatively correlated with soil organic matter (SOM) or soil organic content (Weil and Magdoff 2004), loss of organic C from increased decomposition due to elevated temperatures (Davidson and Janssens 2006) may lead to increase in bulk density and hence making soil more prone to compaction (land management activities and climate change stresses), variable and high intensity rainfall and drought events (Birka's *et al.*, 2009). Total nematodes population were not affected by compaction, but their distribution over

the various feeding types shifted towards a population with increased numbers of herbivores and decreased numbers of bacterivores and omnivores/predators. This change in the structure of the nematode assemblage is associated with poorer conditions for crop growth. The influence of continuous cropping (CC), intermittent fallow (F), standard tillage (ST) and no tillage (NT) on the nematode assemblage and the soil food web.

Rooting Depth: Rooting depth is considered an important indicator of soil health since changes in this property are likely to affect plant available water capacity, subsoil salinity, SOC content or other properties to indicate physicochemical constraints in the soil profile (Birka's *et al.*, 2009). Under prolonged drought, the impact of subsoil constraints such as salinity and high chloride concentrations (Rengasamy 2010) is likely to be greater on plant available water and hence plant productivity. Nematode density and root mass decreased with depth. Lesion Nematodes were higher at the 30–60 cm depth than from the shallower layer, but it was decided to take the repeated bimonthly samples from a depth of about 30 cm to accommodate areas of shallower sandy clay loam soil. *Meloidogyne* spp. and *Tylenchulus semipenetrans* were higher at depth 30-60 cm, however, this did not apply to all nematodes especially *Criconebella xenoplax*.

Soil Surface Cover: A layer of crop residues or biological soil crust provides a range of important ecological functions. Protection of soil surface by dissipating raindrop impact energy, soil stabilisation, reduction in erodible surface area, water and nutrient retention, C fixation, N fixation and support of native seed germination etc., affect ecosystem functions and plant productivity, and evaluate their role in mitigating adverse climate change impacts, thereby These parameters assist in climate change adaptation. Nematodes directly influence soil processes and reflect the structure and function of many other taxa within the soil food web. Nematode indices allow us to determine the effects of environmental stress, dominant decomposition channels and may reflect soil suppressive to plant parasites and pathogens. Cover crops provide an attractive alternative, reducing erosion, decreasing soil compaction, and building soil organic matter, as well as influencing soil organisms. Nematodes provide useful indicators of soil food web dynamics.

Soil pH: Soil pH, a function of parent material, time of weathering, vegetation and climate, is considered as one

of the dominant chemical indicators of soil health. The greatest numbers of *Pratylenchus alleni*, *Hoplolaimus galeatus* colonized soybean roots at pH 6.0, best survival of Tylenchinae-Psilenchinae (pH 6.0), while Dorylaimoidea number were greatest at between pH 6.0 and 8.0. The non-stylet nematodes were recovered in greater numbers from pH 8.0 soil. Soil pH has thus been included in integrative soil health tests to assess impacts of land use change and agricultural practices (Gil *et al.*, 2009). Brinkman and Sombroek (1999) suggested that most soils would not be subjected to rapid pH changes resulting from drivers of climate change such as elevated temperatures, CO₂ fertilization, variable precipitation and atmospheric N deposition are the drivers of climate changes and these affect organic matter status, C and nutrient cycling, plant available water resulting plant productivity.

Electrical Conductivity: Soil electrical conductivity informs trends in salinity, crop performance, nutrient cycling and biological activity and, along with pH, can act as a surrogate measure of soil structural decline especially in sodic soils. Nematodes are a greater problem in sandy soils. Investigations on the spatial relationship between soil texture, EC and nematode population densities have been established by many workers in the past. Electrical conductivity has been used as a chemical indicator to inform soil biological quality in response to crop management practices (Gil *et al.*, 2009). Smith *et al.* (2002) found that EC decreased and pH increased in a semi-arid environment.

Plant Available Nutrients: Nutrient cycling, especially N, is intimately linked with soil organic C cycling as well as drivers of climate change such as elevated temperatures, variable precipitation and atmospheric N deposition. Chemistry of the soil system provides the context; soil biota is adaptive to changes in environmental circumstances (Kibblewhite *et al.*, 2008). Under conditions of climate change, biological indicators form an integral component in soil health assessment, since, by virtue, they involve complex adaptive systems. Ritz *et al.* (2009) published information that potential biological indicators have shown an almost exponential increase since the 1970s.

Soil Organic Matter: It comprises an extensive range of living and non-living components; it has been widely acknowledged that SOM is one of the most complex and heterogeneous components of soils, which vary in their properties, functions and turnover rates. Main indicators

for evaluating SOM status include SOC, since it comprises about 50% of soil organic matter; organic N, since it is closely associated with organic carbon and is the most important nutrient for plant productivity; and readily mineralisable C and N (Haynes, 2008). SOM drives the majority of soil functions. Decreases in soil organic matter can lead to a decrease in fertility and biodiversity, as well as a loss of soil structure, resulting in the reduced water holding capacity, increased risk of erosion and increased bulk density and hence soil compaction. Land use and management practices that lead to building up of SOM will help in absorbing CO₂ from the atmosphere, thus mitigating global warming.

Soil Carbon: Soil carbon can be used as an indicator of change for a number of reasons: it is familiar, direct, linked to ecosystem performance and it has “memory”, that is, changes across time. (Janzen 2005). While soil contains carbon in diverse forms and residence times, considerable research attention has focused on the SOC form, since it (1) has been largely modified through human activities, and (2) is predicted to decline with increase in mean global temperatures, which would have adverse effects on important soil functions and processes and soil quality/health (Lal *et al.*, 2007).

Potentially Mineralisable Carbon (C) and Nitrogen (N): The amount of mineralisable organic matter in the soil is an indicator of organic matter quality, acting as the interface between autotrophic and heterotrophic organisms during the nutrient cycling process. The mineralisable organic matter may be a useful indicator to assess soil health under climate change, since it affects nutrient dynamics within single growing seasons, and may be used to compare management regimes and C sequestration over extended periods of time (Gregorich *et al.*, 1994).

Soil Respiration: Soil respiration is often used as a biological indicator for soil health since it is positively correlated with soil organic matter content and can be determined as either CO₂ production or O₂ consumption (Haynes 2008). Soil respiration, particularly its temperature response, is widely acknowledged to be a critical link between climate change and the global carbon cycle (Wixon and Balser 2009), although the nature of this relationship is under current scientific debate (Kuzyakov and Gavrichkova 2010).

Soil Microbial Biomass: Microbial biomass is the living component of soil organic matter and should be considered as the most labile carbon pool in soils and a

sensitive indicator of changes in soil processes, with links to soil nutrient and energy dynamics, including mediating the transfer between soil organic carbon fractions (Saha and Mandal 2009). When combined with ^{13}C isotope labelling technique, the shift in microbial biomass ^{13}C may provide a more sensitive measure of changes in soil carbon processes in response to climate and land use changes than the total microbial biomass carbon (Paterson *et al.*, 2009). Bacteria and fungi both have more ammonium than what the nematode needs so the extra is released in a plant available form.

Enzyme Activity: Soil enzyme activities may serve to indicate change within the plant-soil system, since these (1) are closely linked to the cycling of nutrients and soil biology, (2) are easily measured, (3) integrate information on both the microbial status and the physicochemical soil conditions, and (4) show rapid response to changes in soil management (García-Ruiz *et al.*, 2009). Dorodnikov *et al.* (2009) showed that by altering the quantity and quality of belowground carbon input by plants, elevated CO_2 may stimulate microbial enzyme activities. In addition, atmospheric N deposition may affect extracellular enzymes. Homogenates and extracts of *Ditylenchus iriformis*, *D. dipsaci* and *Pratylenchus zae* were assayed for hydrolytic, respiratory and terminal oxidative enzymes by viscosity, titration, colorimetric and spectrophotometric techniques identified that lactic dehydrogenase activity was present in extracts from *D. triforrmis* but doubtful in *D. dipsaci*. Fumarase and cytochrome oxidase were detected in extracts from *D. iriformis*. Variable protease and no polygalacturonase activity were found in homogenates of the above nematode species.

Other microbiological indicators as integrative: Soil microbial properties need to be considered with soil health indicators. *Scottinema lindsayae*, *Plectus murrayi*, *Eudorylaimus antarcticus* and *Monhystera villosa* were suitable for their habituated under influenced soil moisture, carbon and salinity in Antarctic regions.

Genetic and functional biodiversity of soils: Changing climatic factors is also of concern due to possible evolutionary changes, which allow the spread of virulence factors and genes that aid in environmental survival (French *et al.*, 2009). Soil nematode species diversity is often high, both at ecosystem and single soil-core scales. Soil nematode diversity is important for the long-term stability of soil functioning. The relationships

between functional genes of soil microbial communities and environmental variables, including greenhouse gas fluxes were also observed by various Nematologists.

WHAT DO THE NEMATODES DO?

Nematodes are not the highest organism in the soil food web. As stated earlier there are also predatory nematodes in the soil that consume nematodes. A major function of soil nematodes is that they are biocontrol agents, meaning they can be used to eliminate disease causing nematodes and other organisms. Tropic groups do not act in a unitary manner with respect to altered environmental, the species-level analysis is more meaningful and preferred for investigations. Nematodes are tremendous diverse groups, most participate in many functions at different levels of the soil food web. Nematode diversity in natural and agro-ecosystems are based on both species-level taxonomy and trophic-level guilds. Several researchers have proposed approaches to assessing the status of soil quality by counting the number of nematodes in different families or trophic groups. In addition to their diversity, their populations are relatively stable in response to changes in moisture and temperature. They are useful indicators being quite small, live in a water film and provide durable soil microenvironments. Nematodes enhance soil quality, mineralize nutrients into plant-available forms, provide a food source for other soil organisms and consume disease-causing organisms. Nematodes are considered grazers. They move through the soil profile devouring smaller organisms as well as distributing any bacteria or fungi that are on them as well as any that are in their digestive system. If the nematode population is low, they will stimulate the growth rate of prey populations. If the nematode population is high, they have the potential to have a negative impact on soil health. Predatory nematodes balance the population of other nematodes. When nematodes consume bacteria or fungi they release excess ammonium (NH_4^+). Soil microarthropods and insects, as well as bacteria and fungi, feed on nematodes. *Helicotylenchus* and *Paratylenchus* feed shallowly on root cortex or epidermis seem to have less effect on plants as compare to *Meloidogyne* and *Heterodera* which are vascular parasites. Nematodes are important in mineralizing or releasing, nutrients in plant-available forms. When nematodes eat bacteria or fungi, ammonium (NH_4^+) is released because bacteria and fungi contain much more nitrogen than the nematodes require. Feeding by nematodes stimulates the growth rate of prey

populations at low nematode densities. Bacterial-feeders stimulate bacterial growth, plant-feeders stimulate plant growth, and so on. Nematodes will reduce the population of their prey at higher densities. This may decrease plant productivity, negatively impact on mycorrhizal fungi and can reduce decomposition and immobilization rates by bacteria and fungi. Predatory nematodes may regulate populations of bacterial-and fungal-feeding nematodes, thus preventing over-grazing by those groups. Nematode grazing may control the balance between bacteria and fungi, and the species composition of the microbial community. Nematodes help distribute bacteria and fungi through the soil and along roots by carrying live and dormant microbes on their surfaces and in their digestive systems. Nematodes are food for higher level predators, predatory nematodes, soil microarthropods, and soil insects. They are also parasitized by bacteria and fungi. Some nematodes cause disease. Others consume disease-causing organisms, such as root-feeding nematodes, or prevent their access to roots.

SELECTION OF SOIL HEALTH KEY INDICATORS

Many soil health indicators predict climate change scenarios. The indicators of soil health are interlinked with global change. Conceptualization of interactions between climate change, land management and soil health indicators (Balsler 2006). Major soil health indicators, their processes and functions under projected climate change scenarios, their relevance to climate change impacts and their frequency of inclusion within a minimum data set for soil health assessment. Most studies agree that a minimum data set for the assessment of soil health should include key indicators that: (1) Sensitive to changes due to management and climate variations, (2) Integrated soil properties, (3) Relatable to important soil functions, (4) Applicable to field conditions and (5) Accessible to many users (Idowu *et al.*, 2009).

SUMMARY AND FUTURE PROSPECTS

Understanding soil health impacts in relation to climate change is possible through the use of indicators which relate soil physical, chemical and biological. Major soil health indicators are governed by climate change. Selection of indicators within a minimum data depends on their sensitivity to management and climate changes, capacity to integrate and relate to other soil functions, ease of use, repeatability and cost of measurement.

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