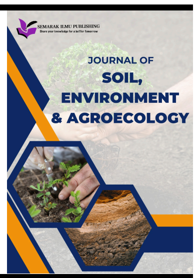
SEMARAK ILMU
PUBLISHING

Journal of Soil, Environment & Agroecology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/sea/index
ISSN: 3030-5697



Factors Affecting Soil Bulk Density: A Conceptual Model

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ARTICLE INFO

Article history:
Received 2 April 2024
Received in revised form 1 May 2024
Accepted 7 May 2024
Available online 16 May 2024

Keywords:
Soil compaction; compacted soil; soil hardpan; soil organic carbon; soil physical properties

ABSTRACT

Soil bulk density is an important aspect of soil properties, and it can affect agroecology as in diversity, synergies, efficiency, recycling, and resilience. Diversity as in soil low in bulk density allows greater penetration of plant roots allow better access of water and nutrients. The synergistic effect of adequate supply of soil moisture content in forming moderately low soil bulk density for deeper plant roots for better access to water and nutrients. Agroecology efficiency reduces the need of external inputs to reduce environmental impact related to the resulted excessive pollution and wastage. Ultimately, an improved soil bulk density may increase the overall agroecosystem resilience and output, thus, improving the efficiency. Recycling in agroecology involved mass recycling and heat circulation as in nutrient, water, and waste reduction. A high soil bulk density will impede the recycling process the soil. Resilience as in drought resistance is for soil not too loosely packed that cannot hold water or too compacted until flooding water occurs at the surface and too little water infiltrates the soil. In addition, soil bulk density can affect the estimation of soil moisture content and temperature distribution. The ability to understand the factors that influence changes in soil bulk density would improve the predictive ability of the current model. The current study conducts a review on factors affecting the soil bulk density that is divided into soil physical, chemical, biological, environmental, and management practices. A cumulative of more than 50 factors are discussed in the review on how it affects the change in soil bulk density. The current review illustrates the conceptual relation of these factors on soil bulk density. Also, the result of the current work can be used to support future endeavour by turning the conceptual relation into quantifiable predictive model.

1. Introduction

Agroecology has ten elements, and it covers a wide range of concern from social, economic to various environmental aspects. The term agroecology may sound alien to agricultural practitioners, but its ten elements of concern are built upon the already well-known aspects of agricultural activities and food production systems, and they are in line with the United Nations' sustainable development goals. It is important to state that agroecology place a strong emphasis in ecological principles while conducting farming activities. Place (or location) is one of the principles in ecology which includes local climate, hydrologic, soil, and geomorphologic factors. Soil physically can be changed by human

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activity like in agricultural practices. An important aspect of soil physical parameters is soil bulk density, which can be described by the mass of soil over the volume of the soil, and it has the unit of mass (kg) over volume (m^3). Soil bulk density affecting and affected by a few elements of agroecology, and they are diversity, synergies, efficiency, recycling, and resilience.

Diversity is an element of agroecology. It includes various plants, animals, microorganism, including genetic diversity in the ecosystem. Diversity can be achieved through crop diversity such as polycultures and crop rotation, genetic diversity by using indigenous varieties, soil biodiversity as in diversity in soil life, agroforestry that integrate trees and shrubs, animal integration in mixed farming systems, ecological services that provide natural pest management and pollination, and socio-economic diversity with traditional knowledge and practices. In soil microbial diversity, low in soil bulk density has more air space to improve the presence of oxygen gas, including soil moisture retention, for better microbial activity [1]. High soil bulk density limits the air space for the oxygen presence and water availability, and it may impede microbial activity. For plant diversity, soil low (intermediate) in bulk density allows greater penetration of plant roots allow better access of water and nutrients [2]. When soil is high in bulk density, plant roots growth might be restricted, then only plant with short root system can thrive in low air space condition that access to water and nutrients in proximity. Low soil bulk density (intermediate) support diverse range of habitat and living organisms within and above the soil. Increasing habitat diversity increases species diversity [3]. The diversity of species increases interaction may support co-existence and benefit from potential synergistic effects that has a broader ecological impact [4].

Like diversity, synergy is also an element of agroecology. Synergy involves the interactions of components that the resulted effects as a whole is greater than the summation of individual effects by individual components [5]. Synergy appears in diverse crop polycultures, integrated pest management, agroforestry system, soil health management, and water management. Synergy effect has some interlaps with diversity. The synergistic effect of soil particles and pore spaces can create a good soil structure [6] which may result in an optimum level of soil bulk density that allow plant roots to grow deep and wide for better access of water and nutrients. Also, optimum level of soil bulk density results in better water retention and improve water infiltration and soil drainage [7]. Thus, it prevents waterlogging, and improve air circulation in the soil for plant roots respiration and microbes in the soil. Optimum soil bulk density that has better retention of water and air circulation create a condition which enhance microbes' activities for nutrient cycling and availability [8].

Efficiency covers an important element in agroecology. In an agricultural system, efficiency refers to productive agricultural system with limited usage of resources with emphasis on sustainability [9]. Efficiency includes resource use, energy usage, biological and ecological, economics, and social and cultural efficiency. A less dense soil bulk density enable plants roots to have greater access to soil depth and width for better efficiency, thus enhancing root growth [10]. A less dense soil bulk density improves water mobility, and in the presence of organic matter it improves water retention, hence, improve soil aeration and water availability for better efficiency in agricultural field. The loose soil bulk density creates a conducive condition for microbes for nutrient cycling and retention [11] such as nitrogen, phosphorus, and potassium for better plant growth. Also, efficiency in agroecology reduces the need of external inputs such as water and nutrient [12], thereby it helps to reduce environmental impact related to those excessive pollution and wastage resulted by fertilizer and water. Ultimately, an improved soil bulk density may increase the overall agroecosystem resilience and output.

Recycling is a step above beyond reusing. While reusing is repurposing the use of items and products for extended usage, recycling involves reprocessing which may involve chemically for the items or products to be used again. Recycling in agroecology involved nutrient, water, energy flow, ecological interaction, and waste reduction. A compacted soil has a high soil bulk density will limit the water and air circulation in the soil [13], hence, it reduces the recycling process the soil. Also, the compacted soil limits the availability of pore space that limit expansion of root growth [14]. A compacted soil with limited water and air circulation will limit microbial activity and slowing nutrient recycling and availability [15]. Under such limited oxygen condition, reducing environment tend to develop that could produce reduce elements such as iron, manganese, methane, and hydrogen sulphide that could be toxic [16]. Unwantedly, soil high soil bulk density can also alter soil pH that changes nutrient recycling and soil fertility.

Resilience is referred to the basic functions and services of ecosystem to withstand environmental variability and shocks, social-political change, and economic uncertainty. The resilience of agroecology includes biodiversity, soil health, water management, agroforestry, local knowledge and practices, social and economic networks, and adaptive management. A resilience soil condition has an optimal soil bulk density that withstand surrounding stress to sustain its bulk density to allow enough pore space for water and air for plant root and microbial activity. Resilience soil bulk density can withstand erosion [17] that the soil is neither too compact nor too loose, and it could withstand wind erosion and erosion by heavy rainfall. Drought resistance is another resilience that the soil is not too loosely packed that cannot hold water or too compacted until flooding water occur at the surface and too little water infiltrate the soil [18]. A balance soil bulk density has the ability to sustain soil biota for nutrient recycling as in organic matter decomposition that contribute to soil fertility and sustaining soil structure for better resilience. Thus, these abilities significantly improve the soil resilience in handling climate variability.

Knowing soil bulk density is important in contributing to the success of elements in agroecology, an in-depth review of factors affecting soil bulk density is necessary. In addition, the review below explains the influence of soil bulk density on the derivative soil physical parameters to estimate the soil moisture content. The review then proceeds to divide the review into categories of factors and discuss the individual factors affecting soil bulk density.

2. The Effect of Soil Bulk Density on Soil Moisture Content

An important aspect of soil bulk density is that it represents a physical aspect of soil that is closely related to soil pore space. When the pore space is limited, so thus the space available to hold air and water. A limited space comes with increasing resistance to flow of liquid and air through the empty space. Such influence can also affect heat transfer in the soil.

Below is a typical equation used to govern mass transport of liquid water and vapor in the soil:

$$\left(1+\frac{\theta_a}{\rho_L}\frac{\partial\rho_v}{\partial\psi_m}\frac{\partial\psi_m}{\partial\theta_L}-\frac{\rho_v}{\rho_L}\right)\frac{\partial\theta_L}{\partial t}+\frac{\theta_a}{\rho_L}\left(\frac{\partial\rho_v}{\partial T}+\frac{\partial\rho_v}{\partial\psi_m}\frac{\partial\psi_m}{\partial T}\right)\frac{\partial T}{\partial t}$$
$$=\frac{\partial}{\partial z}\left[\left(D_{Tv}+D_{TL}\right)\frac{\partial T}{\partial z}+\left(D_{mv}+K\frac{\partial\psi_m}{\partial\theta_L}\right)\frac{\partial\theta_L}{\partial z}-K\vec{k}\,\right] \quad (1)$$

where ψ_m is matric suction (m), θ_a is volumetric air content (m^3 m^{-3}), ρ_L is liquid water density (kg m^{-3}), ρ_v is water vapor density (kg m^{-3}), θ_L is volumetric water content (m^3 m^{-3}), t is time (s), T is temperature (K), z is vertical distance (m), D_{Tv} is thermal vapor diffusivity (m^2 s^{-1} K^{-1}), D_{TL} is thermal liquid diffusivity (m^2 s^{-1} K^{-1}), D_{mv} is isothermal vapor diffusivity (m s^{-1}), K is hydraulic conductivity (m s^{-1}), and $\vec{k}$ is vector unit with a value of positive one when it is vertically downwards. Equation 1 was adapted from Heitman [19].

The term $\frac{\partial \psi_m}{\partial \theta_L}$ is the variation of soil matric suction with soil moisture content. It is referred to as characteristic curve relation in derivative form. The relation implies the soil moisture content changes with soil matric suction, and it can be affected by soil bulk density. When the soil is compressed, the parameters used in the empirical relation will change according to the level of compression. For physical expression, the compression reduces the moisture content in the soil [20]. The hydraulic conductivity K is normally derived from the soil characteristic curve, and it refers to as the ease of water passing through the soil. As such, it is similarly affected by the change in the soil bulk density [21]. The isothermal vapor diffusivity D_{mv} is given by several parameters such as volumetric air content, and the characteristic curve a function of soil matric suction. These parameters are readily affecting vapor density, hence, changing the soil moisture content. Since the characteristic curve is affected by soil bulk density, the change in the soil bulk density changes the air content and vapor density to affect the soil moisture content [22]. The same goes for the thermal liquid diffusivity D_{TL}, and thermal vapor diffusivity D_{Tv}. Figure 1 summarizes the effect of soil bulk density on soil parameters, which are then affecting the variation of soil moisture content as mathematically described in Eq. 1.

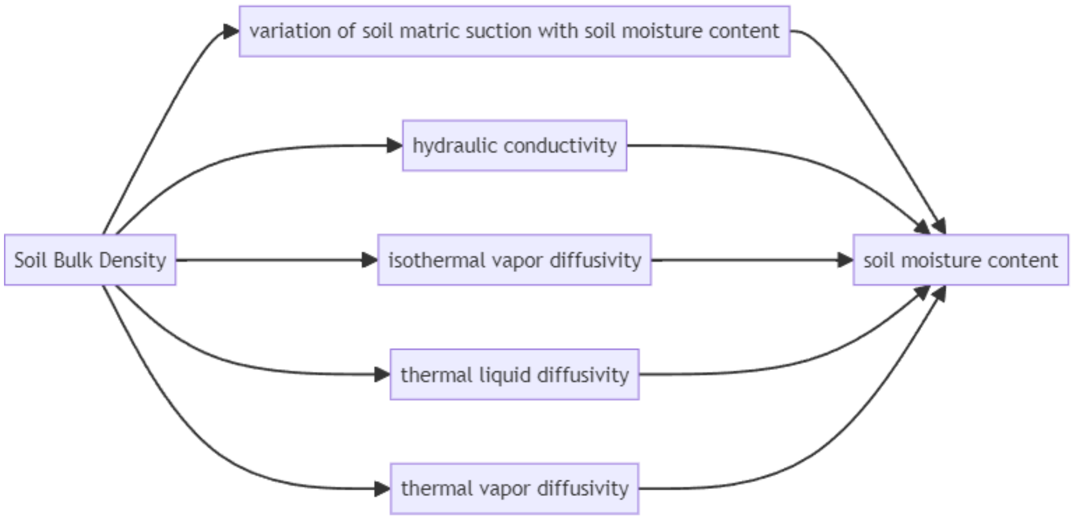

Fig. 1. The soil bulk density is affecting various parameters in the soil that leads to the changes in soil moisture content

3. Review Aim and Objectives

Even though the soil bulk density is known to affect water and vapor movement, and even heat transfer in the soil, the mechanistic (theoretical) process guiding the mechanism is not established. As such, the soil bulk density must be measured directly from the field. And the relation of the soil bulk density on those stated derived physical parameters (e.g. hydraulic conductivity, and so on) above were empirically described, which indicates the lack of theoretical understanding on the foundation of the mechanism(s) involved.

Such limitations inspire the current review to look for factors affecting soil bulk density in the hope that subsequent work come after the current work would help to establish a better understanding of the inter- and intra-relationship between soil bulk density and other physical parameters. Thus, the current objectives are: (1) identify factors affecting soil bulk density, (2) group those factors into categories for adequate discussion, and (3) describe the relationship between those factors.

4. Groups of Factors Affecting Soil Bulk Density

Basically, five groups of factors affecting the soil bulk density, and they are physical, biological, chemical, environmental, and management factors (Fig. 2). Soil physical factors [23], for example, include soil texture, soil structure, soil porosity, and soil moisture content. Soil texture consists of the composition of sand, silt, and clay). Soil texture is the arrangement of soil particles to results in, for instance, granular, blocky, prismatic, and so on. Soil porosity refers to the space between soil particles, and the space is available for occupation of water and gas. Soil moisture content is the amount of water contained in the empty of the soil. Collectively, these and some other factors not stated here are responsible for the changes in soil bulk density.

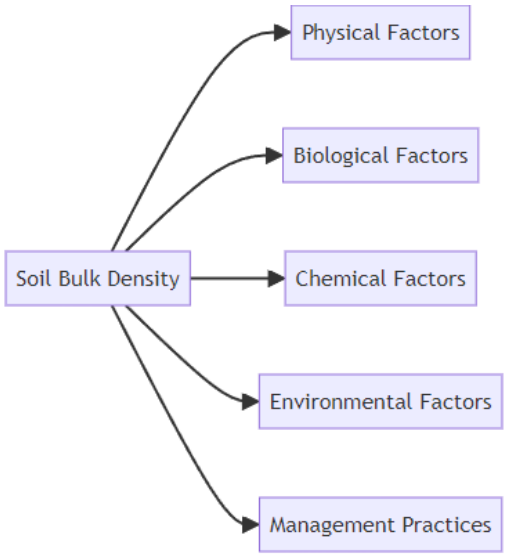

Fig. 2. The influence of physical, biological, chemical, environmental, and management factors in affecting the soil bulk density

Soil biological factors include soil fauna, microorganisms, and plant roots. Soil fauna may include earthworms, ants, beetles, and so on. Soil microorganisms like bacteria [24], actinomycetes, fungi, protozoa. In the simplest description, soil organic matter, plant roots, fungi, and bacteria work collectively to affect the formation of soil aggregates, then on soil structures that affect soil bulk density.

Soil chemical factors are soil pH, salinity, cation exchange capacity, and nutrient content [25]. These factors combined to affect the closeness of soil particles coming together to create tightness of reduce air space or repelling each other that could be the result of dispersion to create loose space within the soil.

Some other factors such as the environment play an important part as well. The factor is a presentation of surrounding factor other than the soil itself. The environmental factors could manifest themselves in the form of natural events like earthquakes, flooding, drought, weather patterns, or even climate such as heat and precipitation. These factors do not occur within the soil, but the influence on the soil bulk density is significant whether in the short or long terms [26].

Another external factor could be coming from human intervention like land or soil management practices. Management practices could manifest in the form of soil tillage [27], land-use practices, agricultural practices like crop rotation, irrigation, and fertilization. These management practices could influence physical, biological, and chemical properties of the soil that could change the formation of soil aggregate, soil structure, soil compaction, and ultimately, changes the soil bulk density.

5. Soil Physical Factors on Soil Bulk Density

There are many physical factors contributing to the variation in the soil bulk density in the field. Refer to Figs. 3 and 4 for soil physical factors responsible for increasing or decreasing the soil bulk density, respectively.

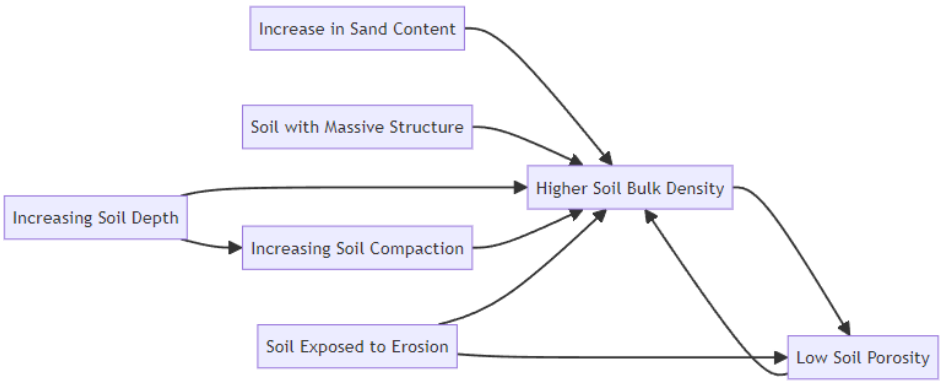

Fig. 3. Change in the soil physical factors increasing the soil bulk density

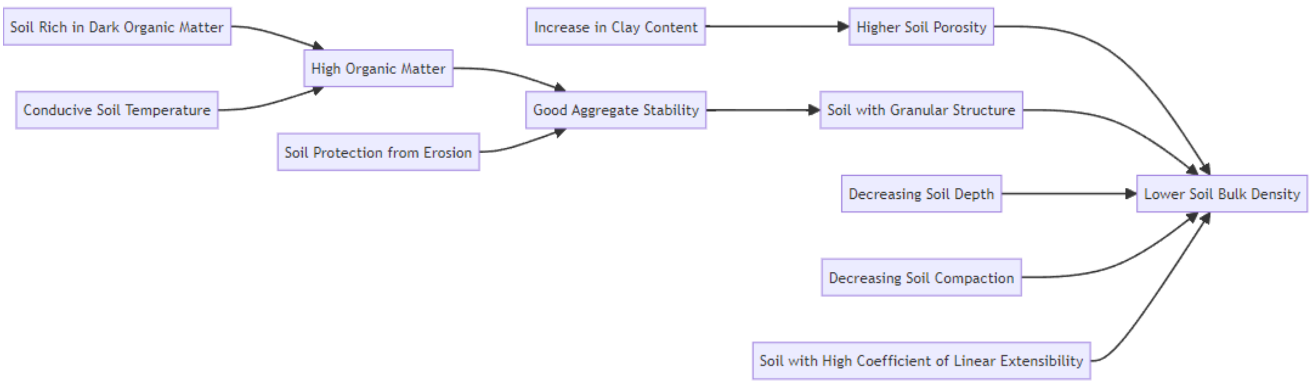

Fig. 4. Change in the soil physical factors decreasing the soil bulk density

As soil texture depends on the composition of sand, silt, and clay, different composition resulted in different soil textures. Increase in sand content in the soil appears to increase soil bulk density [28]. A soil high in bulk density tends to exhibit soil property as having a lower soil porosity [29], [30]. Conversely, soil high in clay content, increases the soil porosity, while reduces the soil bulk density [28].

Soil structure affects soil bulk density. Soil with aggregation such as granular structure tend to have lower soil bulk density due to more pore space available [31]. However, soil with aggregation results in massive structure will result in high bulk density.

Soil porosity is strongly associated with the soil bulk density, and its quantification is referred to as air space volume over total soil volume. A low soil porosity is often associated with high soil bulk density [30]. The relationship between them can be described physically, as highly compressed soil is giving high soil bulk density that also has very low air space for gas and water. Hence, low in soil porosity.

Particle size distribution is associated with soil texture prediction. Particle size distribution with high sand content tends to give high soil bulk density [28], whereas soil high in clay and silt content incline towards lower soil bulk density [32].

Aggregate stability refers to the ability of the soil to resist disintegration and avoid the collapse of air space within the soil body. Soil with good aggregate stability is often associated with soil amended by soil organic matter that helps to maintain the soil aggregation, thus decreasing its soil bulk density [33]. Whereas soil that has a poor soil aggregate stability tends to disintegrate under external force could result in the collapse of air space that led to increasing soil bulk density.

Soil depth is another physical parameter that influences soil bulk density. Increasing soil depth often reported with increasing soil bulk density [34]. The increasing soil bulk density can be explained due to increasing compaction with soil depth. Also, noticeable is the decreasing soil organic matter with soil depth. Since soil organic matter is often associated with good soil aggregate stability with low bulk density, the often-higher soil organic matter at the surface layer of soil exhibiting a low soil bulk density.

Soil color may not directly affect the change in soil bulk density. The physical appearance of the soil color may be a good indication of the presence of soil organic matter in the soil. Soil rich in soil organic matter is often reported as having dark soil color [35], which can be used to infer soil with low bulk density.

Moisture content of soil is an indication of wetness level of soil. A desirable soil is associated with its ability to retain water for plant roots absorption. The soil moisture content is also useful for cooling soil temperature as it evaporated from the soil surface. When the soil moisture content enters the plant root it is also responsible for transporting nutrients for plant growth. Since soil moisture occupied the pore space between soil particles, the mass of soil (water plus soil particles) over soil volume (solid, gas, water) to give the wet soil bulk density increases with increasing soil moisture content. Similarly, soil low in moisture content exhibits low wet soil bulk density. It is important to distinguish wet soil bulk density from (dry) soil bulk density [36]. The (dry) soil bulk density does not change with the changing soil moisture content, because it does not include water content in its calculation. All the discussion in this study refers to soil bulk density that does not change with soil moisture content, i.e. dry soil bulk density.

Soil temperature does not have an immediate effect on soil bulk density. However, the change in soil temperature changes the soil moisture content and the rate of soil organic matter production and degradation. When the change in soil temperature is conducive for soil organic matter production as a byproduct of tree growth and organisms living in the soil, soil temperature will indeed improve the soil bulk density by lowering its value. The apparent evident would be the natural forest area expansion [37,38]. However, the opposite is true when the temperature is extremely hot and not conducive for production rather favoring soil organic matter degradation [39]. Thus, soil bulk density increment could be resulted.

Soil compaction has direction relation to soil bulk density. Soil compaction is associated with high soil bulk density [40]. A low compaction soil can be found in soil of high organic matter with good soil aggregate and soil structure. Soil compaction is often found with increasing soil depth.

Parent materials are partly responsible for the soil bulk density as reported in the literature. Alnaimy *et al*., [41] has reported that the soil bulk density of alluvial- and lacustrine-derived soils is lower than that of the marine- and aeolian-derived soils. The soil organic matter is also negatively correlated with the soil bulk density.

Erosion and sedimentation can influence the soil bulk density. Erosion can remove the lighter soil organic matter from the soil surface [42], exposing the soil particles and weaken the soil particles aggregate leading to increasing soil bulk density. While sedimentation of different particle sizes and organic matter occurring at the soil surface potentially changing the soil surface bulk density.

Clay minerals may have influence on soil bulk density when it exposes to soil moisture content. Soil which has a high coefficient of linear extensibility is associated with the ability to swell or expansion [43]. Smectite clay content maybe often relates to the soil that has high coefficient of linear extensibility [44].

6. Soil Biological Factors on Soil Bulk Density

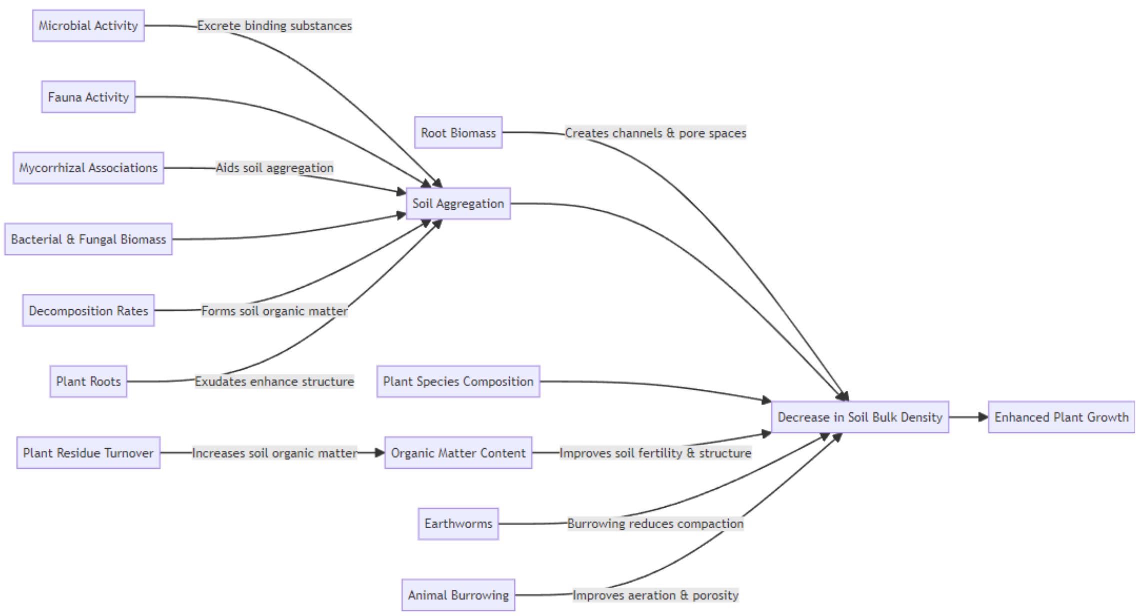

Fig. 5. Change in the soil biological factors decreasing the soil bulk density

There are numerous biological factors affecting soil bulk density. Figure 5 shows the impact of plant roots, microbial activity, root biomass, fauna activity, plant species, and so on, in changing the soil bulk density. An expanded discussion is presented below.

Root biomass is well known to affect the soil bulk density. Root growth in the soil vertically and horizontally. The root penetration into the soil can be impeded by high compacted soil [14] like soil high in soil bulk density. Soil in moderate soil bulk density allowed plant root penetration. Plant root growth creates channels and pore spaces that potentially [45] leads to lowering the soil bulk density, also improving the soil structure and soil porosity.

Microbial activity is present in the soil. They live and thrive when conditions are favorable. Microbes can excrete extracellular substances (polysaccharides, humic substances, and microbial biomass are sticky and act as natural glues or binding agents) that are effective in binding soil particles together in forming soil aggregates [46]. The aggregates are instrumental as an organic matter that contributes to the reduction in soil bulk density.

Fauna activity is also instrumental for soil bulk density reduction. There are soil dwelling living organisms such as insects and worms. They live, breed, excreting organic matter and expanding the territories by making channels and pores in the soil [47]. Thus, soil bulk density is reduced with improved soil aggregation and improved air spaces within the soil.

Plant species composition has varieties plant roots growing in the soil. Some plant roots may grow to a few centimeters of depth [48], while others may growth deep and even up to 1.5 m depth or more [49]. It is understood that plant root growth could lower the soil bulk density due to the channel and pores created as it growth and spread into the soil body, which contradict the general understanding that the compacted soil impedes root growth [50]. Nonetheless, having a composite of plant roots may play an important role in shaping soil aggregate formation and affecting the soil bulk density is something that needs further research.

Organic matter content in the soil has an important role in shaping the soil bulk density. At high soil organic matter is commonly associated with low soil bulk density [51]. To have a low bulk density that is good for plant root growth and soil water retention, an adequate amount of soil organic matter present in the soil is necessary. In addition, it contributes to cation exchange capacity and it increases the soil moisture retention [52]. Also, soil organic matter can improve the soil fertility [53].

Mycorrhizal associations refer to as the association between higher plant roots and fungi. It is known as symbiosis or mutualism that about 90% of all plants experiencing this relation. The relation allows the fungal hyphae live and thrive where it excretes extracellular biopolymers that can act to cement and seal surface aiding soil aggregation [54]. The soil aggregation is known to assist macropores formation, modify pore size distribution, and thus reducing soil bulk density [55].

Earthworms are known to improve soil structure and fertility. Earthworms burrowing aerates the soil, and it also increases soil macropores. The burrowing activity reduces soil compaction that reduces the soil bulk density. The earthworm casts is shown to help in soil aggregation [56]. Soil aggregation is often found to improve soil condition by lowering its soil bulk density.

Bacterial and fungal biomass are closely related to that of microbial activity and mycorrhizal associations. As stated, both the bacterial and fungal biomass accumulation lead to the high excretion of organic matter that form better soil aggregation with low soil bulk density [57]. Apart from bacterial and fungal, there are also insects like ants, beetles, termites, crickets, earwigs, cockroaches, etc. actively working on the soil. Their individual contributions towards collective effect on soil bulk density is up for further research, though generally they are believed to lower the soil bulk density.

Decomposition rates are another factor of consideration on soil bulk density. Organic matter piles up on the topsoil by plants or carried over by wind will go through a degradation process. The degradation process converting residues into simpler organic and mineral forms [58]. The degradation being worked on by organisms in the soil by generating degraded soil organic matter that can help in soil aggregation to result in lowering the soil bulk density.

Animal burrowing is like that described in the fauna activity. Animals such as rodents can affect soil compaction, soil aeration, increase soil porosity, and improving water circulation [59]. They live, consume, and excrete wastes that help to speed up the soil organic matter generation that eventually lowering the soil bulk density for better plant growth.

Plant residue turnover is part of the description in decomposition rate, and it helps to increase the soil organic matter that is essential for soil fertility. Organic matter helps to improve soil structure for better water retention and nutrient retention. It promotes soil nutrient recycling that helps the system to retain essential nutrients with little need of external inputs. The pilling up of organic matter acts as carbon sequestration capturing atmospheric carbon dioxides to combat climate change [60]. Ultimately, soil organic matter reduces the soil bulk density for better plant growth.

Plant roots are known to exudates substances such as amino, sugars, organic acids, and other compounds [61]. These substances improve soil structure through soil aggregation formation which the soil physical condition with the presence of soil organic matter increase the soil water retention. Like other descriptions in soil organic matter, it reduces the soil bulk density. The presence of exudates substances serves as the food source for microorganisms. Result from the interaction of microbial activities form biofilm to assist in soil aggregation and reduces the soil bulk density.

7. Soil Chemical Factors on Soil Bulk Density

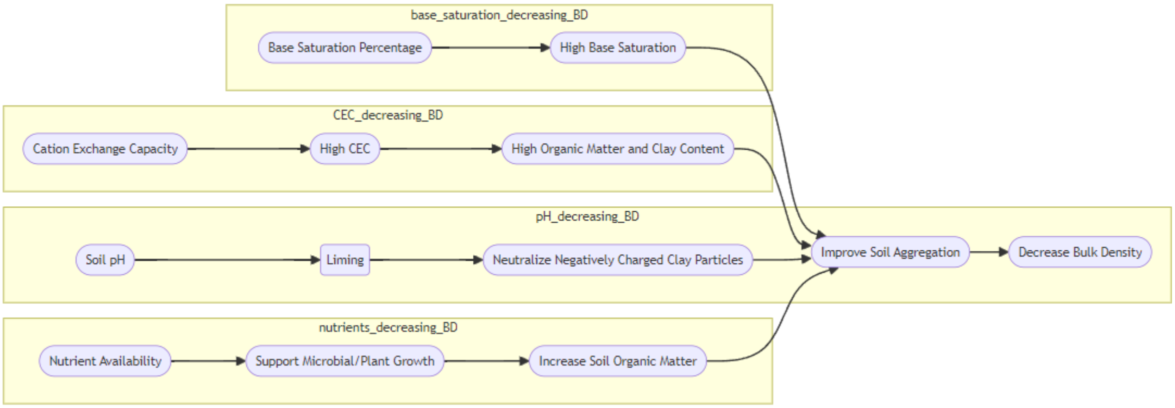

Fig. 6. Change in the soil chemical factors decreasing the soil bulk density

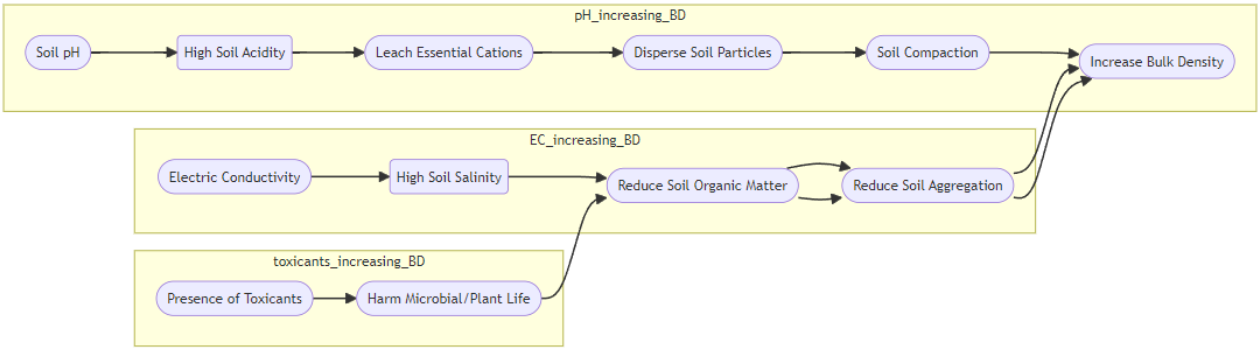

Fig. 7. Change in the soil chemical factors increasing the soil bulk density

Figures 6 and 7 show the impact of soil pH, electric conductivity, cation exchange capacity, soil salinity, and so on, in decreasing or decreasing the soil bulk density. An expanded discussion is presented below.

Soil pH can affect soil bulk density. pH varies from very acidic (pH=0) to neutral (pH=7) to very alkaline (pH=14). Soil pH at any extreme acidity or alkalinity can negatively impact soil structure. At high soil acidity, soil structure stability reduces [62]. For instance, extreme pH in high acidity leaches essential cations like calcium and magnesium, which are necessary for sustaining soil aggregation. Otherwise, soil particles will disperse, disintegration of soil structure, and soil compaction will occur. Similarly, soil pH at the other extreme condition. It desirable to maintain soil pH above 6.0 by limestone [63].

Electric conductivity (EC) is an indication of the ability of the material in conducting electric current. Soil electric conductivity refers to the ion concentration of the soil solution. When the ion concentration is high, it refers to the presence of salts, fertilizers, or other potential dissolved minerals [64]. Sodic soil result in the loss of soil organic carbon through degrading soil structure, causes soil aggregation dispersion, and also increase the soil bulk density [65].

Cation exchange capacity (CEC) is another chemical factor affecting soil bulk density. Soil CEC refers to the ability of the soil to hold positively charged ions (cation), for instance, potassium, calcium, and magnesium. The soil CEC is governed by the presence of soil colloids, soil organic matter and clay content because of their negative charge [66]. The higher the organic matter and clay content, the higher the soil CEC ability, thus, also indicates its ability to hold positively charged ions (cation) (forms of nutrient elements) like calcium, magnesium, potassium, ammonium, hydrogen, and sodium [67], and to supply to plant roots. Both the clay and organic matter aid soil aggregate formation for better soil structure less susceptible to compaction and erosion, ultimately, reduces the soil bulk density.

Base saturation percentage affects soil bulk density. Base saturation percentage refers to the portion of soil CEC occupied by base cations like calcium, magnesium, potassium, ammonium, hydrogen, and sodium. A soil low in base saturation percentage can lead to low soil pH [68]. A high base saturation percentage indicates a large proportion of the soil CEC occupied, thus, reflecting better soil aggregation and lower soil bulk density.

Nutrient availability can affect soil bulk density indirectly. This is because nutrients like N, P, and K are important to support microbes and plant growth [69], which then responsible for increasing soil organic matter in supporting soil aggregate formation, subsequently leading to low soil bulk density.

Soil salinity is an indication for EC [70], and it does affect the soil bulk density. When the soil salinity is high it results in the loss of soil organic carbon by reducing the plant productivity, and microbial activity. The organic matter that is required for soil aggregate formation is reduced as a result. Subsequently, it will be increasing the soil bulk density.

Toxicant presence like heavy metals could affect the microbial and plant life [71]. Heavy metals can be toxic to organisms in the soil affecting the soil health and fertility that involve in decomposition and nutrient recycling. Heavy metals are known to reduce seed germination, changing enzyme reaction, limiting plant growth and photosynthesis, and affect nutrient uptake [72]. Since the soil organic matter generated from this process is essential for soil aggregation and sustaining soil structure, the soil bulk density could be increased with the increasing toxic substances in the soil.

Liming is another process chemistry to improve soil. Lime consists of calcium and magnesium of many forms such as burnt lime, hydrated lime, chalk, marl, and even limestone. Liming increases soil pH making soil less acidic and make available essential nutrients. Lime substances like calcium and magnesium neutralize negatively charged surface of clay particles so that particles could come in contact. Liming improves soil aggregation and soil porosity that can improve soil structure [73]. Hence, soil bulk density can be improved as a result.

8. Environmental Factors on Soil Bulk Density

Figure 8 is a schematic diagram showing the effect of environmental factors either increasing or decreasing the soil bulk density. There are many factors involved, and they are climate patterns, precipitation rate, drought frequency, warm climate, wind erosion, solar radiation, atmospheric carbon dioxide, fire, and so on.

Climate patterns could affect soil moisture and temperature which then affect biological activity and soil bulk density. Climate drives rainfall frequency and amount on receiving land [74]. Soil moisture from rainfall is used for microbial [75] and fauna activity that can be used for degradation of organic material. The abundance of soil organic matter will improve soil aggregation, soil structure, and also it reduces the soil bulk density.

Precipitation rate is an important aspect of climate parameters, and it is essential to support biological reactions in the soil. However, excessive precipitation rates until it increases in the event of flood [76], surface runoff [77], or exceptionally high groundwater level [78] could contribute to the reduction of soil organic matter production. Because fauna and microbe activity requiring continued access to oxygen level will be impeded under fully saturation condition, it results in the reduction of soil organic matter as the soil bulk density increases.

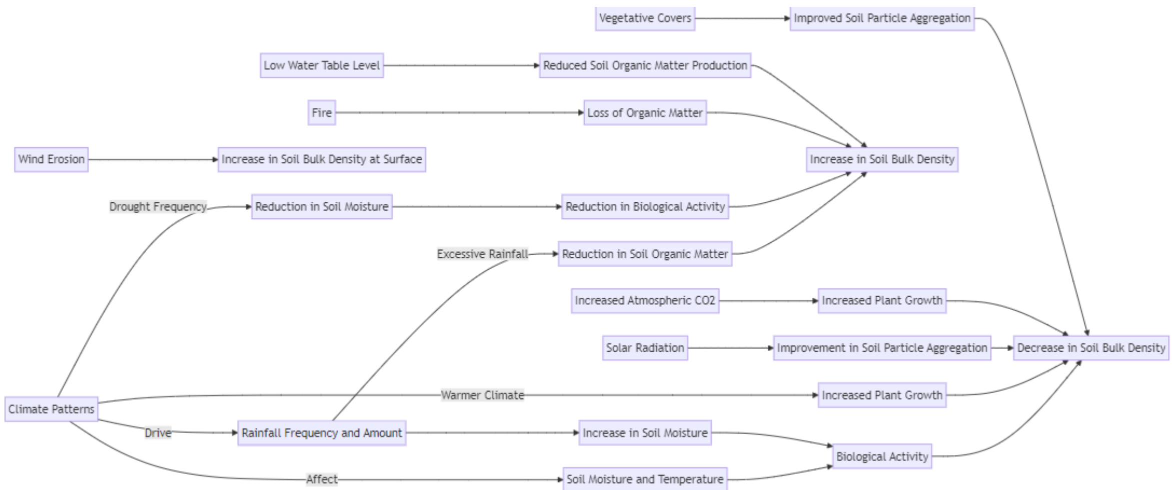

Fig. 8. Change in the environmental factors increasing or decreasing the soil bulk density

Drought frequency is another climate parameter that affects soil. Excessive droughts deprive the soil of sufficient soil moisture content for fauna and microbe activity in the soil [79]. Adding to the damage is the soil temperature tends to increase in dry weather conditions [80] giving another external pressure to the soil. As a result, soil organic matter production is retarded, and it is subjected to decline in this condition. Thus, potentially it increases the soil bulk density.

A warmer climate but not extreme temperature is suitable for plant growth in general. Hatfield et al. [81] shows plants like maize, sorghum, bean, cotton, cotton, rice, soybean, and wheat to have vegetative development and reproductive development positively with increasing temperature. Therefore, the temperature increases the plant biological activity will give rise to soil organic matter as expected that will influence the soil aggregation and porosity improvement, and subsequently on reducing the soil bulk density.

Wind erosion can change the soil bulk density at the soil surface level. This is because wind can erode or lift soil particles that are lighter, for instance silt and clay including some organic matters that are light in mass [82]. In doing so, the soil surface will be leftover with coarse materials like sand, which can raise the overall soil bulk density at the surface level.

Solar radiation has an impact on soil bulk density. Solar radiation exposure at the soil surface increases the soil temperature leading to evaporation and also it stimulates transpiration and photosynthesis on the plant for growth supporting plant roots exudation for better soil aggregation. Also, solar radiation increments on soil temperature support microbial activity in decomposing the organic matter to produce polysaccharides, humic substances, and microbial biomass, and the substances are sticky and act as natural glues or binding agents may improve soil particle aggregation.

Atmospheric carbon dioxide level is known to have increased the plant growth [81]. As such a thriving and growing plant will contribute to soil organic carbon in the soil, which then can be degraded by bacteria to form stick and natural glues as degraded substrates to aid in soil particles aggregation and lowering the soil bulk density.

Fire is becoming an important phenomenon for concern in the environment. When fire occurs, organic matter is burnt and reduced, such as leaf litter, fallen branches, and other plant materials. Lossing the organic matter will result in reduce volume of light materials, nutrient volatilization, disintegration of soil aggregate stability, which then increasing the soil bulk density [83].

Water table level has an indirect impact on soil bulk density. When the water table level is low, soil near the soil surface will be drier resulting in insufficient water for evaporation to cool down the soil body. This condition could result in excessively high temperature in tropical countries [84], hence, it can be detrimental to impedes plant growth and reduce the production of soil organic matter.

Vegetative covers provide land surface protection from direct sunlight and also rainfall [85]. While protection from rainfall is beneficial to avoid soil erosion, protection from sunlight avoids the soil from heating up too high. In addition, vegetative cover enhances provide conducive temperature and contain sufficient soil moisture content to support soil organic matter formation [86] and degradation to form sticky materials to support particle aggregate formation, which will reduce the soil bulk density.

9. Management Practices on Soil Bulk Density

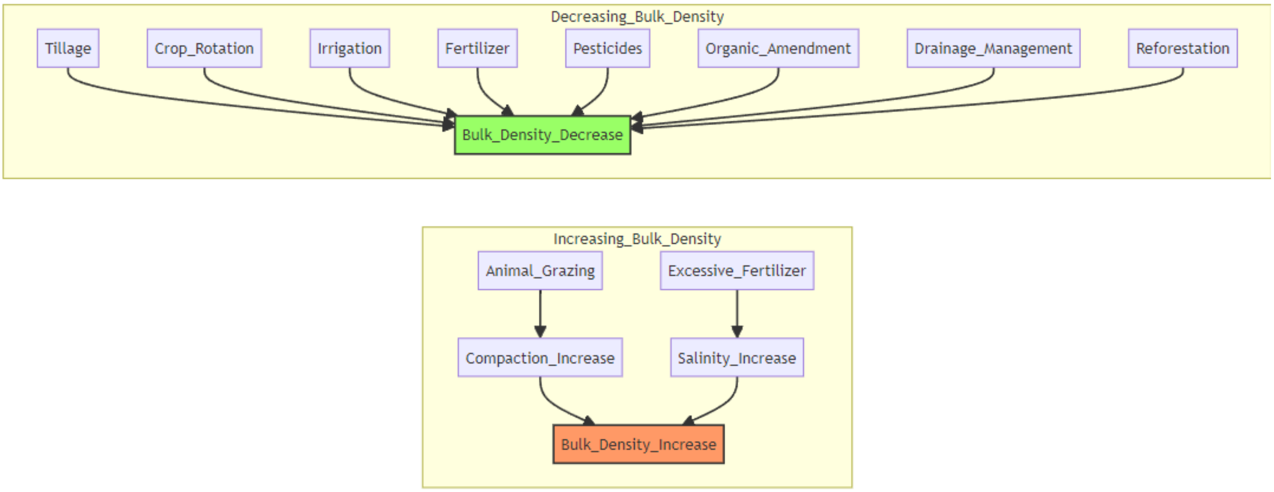

Fig. 9. Change in the management practices increasing or decreasing the soil bulk density

Figure 9 shows the management practices that can have an impact on soil bulk density, which either increase or decrease in value. The management practices are tillage, crop rotation, irrigation practice, fertilizer application, pesticides, organic amendments, and others.

Tillage is a method traditionally done by mechanical agitation of the soil which involves digging, stirring, and overturning the soil, primarily at the soil surface. Tillage is necessary to prepare the soil for planting by loosening compacted soil. Although this method is effective in reducing the soil bulk density, excessive usage over time will lead to reduction in soil organic matter [87] because of constantly exposing soil fauna to direct sunlight, increase aeration for degradation with limited organic matter produce on-site by mechanical method, and gradually breaking of soil aggregates over time impedes the soil ability to retain water and nutrients.

Crop rotation is another soil management practice that has an effect on soil bulk density. Crop rotation can include deep rooted legumes like beans to increase soil aeration due to its deep penetration into the soil. It helps plant roots and organisms in the soil to access oxygen for growth. Also, some rotated crops can include those with fibrous roots like grasses can create a dense network small roots give good grip on soil particles [88] potentially forming stable soil structure. Taproot crop like carrot is effective in penetrating hardpans. Crop rotation adds diversity in the root system to improve the overall soil organic matter for better soil structure and collectively reduces the soil bulk density [89].

Irrigation practice is essential for sustaining soil moisture, which is necessary for microbe, soil fauna activity and plant root water absorption [90]. They collectively produce organic substances effective in sticking soil particles to form stable soil structure that increases soil porosity by reducing its soil bulk density.

Fertilizer application can have a positive impact on plant growth. The nutrient from fertilizer is necessary for plant root growth and develop strong and extensive root systems [91], effective in providing aeration and more extensive access to soil moisture. Like the effect of irrigation, soil fauna and microbe activity would benefit from the nutrients, together with thriving plant roots, they will improve the soil structure, while reducing the soil bulk density. However, excessive usage of fertilizer could be detrimental to the soil because of salt accumulation in the soil increasing the soil salinity.

Pesticides are generally believed to protect plants from diseases or pests. Thus, using it will improve plant health and growth. The root biomass will also become more extensively widespread. A good root growth supports the supply of organic matter in the soil that will help reduce soil bulk density. However, the effect of pesticides on soil microbial community, which is also importantly impacting soil bulk density, is case specific that a pesticide type might be stimulating a type of bacteria population growth, but when a different pesticide is used it suppress the population of that bacteria [92]. Therefore, the impact of pesticides on plants is certain, while that on microbe is case-by-case.

Organic amendment is an effective way of providing external sources of organic matter to the soil to reduce soil bulk density [93]. Soil organic matter will go through the process of degradation to further enhance the soil structure. Although this method is effective to reduce soil bulk density, it costs overhead, time and the expenses in obtaining the organic matter. Even if it is cost-free, still it requires the transportation fuel and vehicle maintenance.

Drainage management is an effective way to prevent water accumulation or to increase the surface runoff, so that water is removed from the soil to prevent unwanted soil saturation [94]. This is because unsaturated soil condition is needed for plant root respiration and growth, including supporting soil fauna and microbe activity in the soil. Excessive amount of water for long time may lead to weakening of soil structure [95] that increases the soil bulk density.

Animal grazing on land affects soil compaction. Increase in animal grazing intensity will increase the soil compaction [96]. The compaction is expected because the heavy animal stepping on the soil surface that their body weight is distributed over the four legs areas touching the ground level. Adding to the soil compaction is the loss of cover crop by grazing on top of the soil that is necessary in sustaining the soil organic matter for reducing compaction. However, the manure from the grazing animal will act as support for nutrients and soil organic matter, but the combined effect with physical compaction by animal feet could be heading towards land degradation, especially when over grazing occurs.

Reforestation is an effective method to repopulate the field with trees and forest plants that ultimately will give positive impact on soil organic matter and soil structure [97] by the tree leaf litter, fallen branches, and other plant materials. Also, the plant roots will create extensive grip on the soil and vertical penetration into the soil to improve aeration and soil moisture present in the soil. This will contribute to reducing the soil bulk density.

10. Conclusion

Soil bulk density is affected by physical, biological, chemical, environmental factors, and also management practices in the soil. The review in this study has shown that there are multiple factors come into play to result in low soil bulk density. It is important to stress that those factors covered in the current study are not exhaustive but reveal the most known influence that could have on the soil bulk density. Soil bulk density when it is low in density in the natural environment with flourishing plants growth on top of it indicates the soil suitability for planting, high in soil organic matter, rich in soil fauna and microbe activity, resilience to soil erosion, ability to retain soil moisture plant roots, capable of providing partial heat insulation, effective in removing soil heat to lower soil temperature, moderately high water infiltration, natural service of soil nutrient recycling and high capacity in storing nutrients. In this study, we also revealed the soil bulk density influence on the soil physical parameters that are commonly employed in the governing equation in predicting soil moisture content distribution. Also, the change in soil bulk density is expected to affect the soil temperature distribution, but it is beyond the scope of the current review. The current study reveals the conceptual relationship of parameters on either increasing or decreasing the soil bulk density, supported by past literature reviews, which provide the theoretical fundamental knowledge that can be used to support the establishment of a working deterministic model to predict the change of soil bulk density.

Acknowledgements
We appreciate the constructive feedback from the reviewers, who assist us in enhancing the quality of our work.

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