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Effect of animal manure application on sustainable potato production and soil structure management

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Abstract
Historically animal manure has been the most valuable and accessible source of plant nutrients across the globe. Potato is worldwide important food, feed and industrial crop with the highest provision of calories, vitamins and nutrients compared to other crops. The aim of the review is therefore to assess the current state of knowledge about the effects of the use of animal manure on sustainable potato production and soil structure. It also briefly discusses the results of research on the benefits of animal manure on the physical properties of soil and the general management of soil health. The overview of sustainable crop production, types and profiles of animal manure, their benefits on the soil structure enhancement and potato yield increment have been briefly reviewed. Many literatures have narrated that animal manure could boost the productivity and yield of potato in the different parts of the world either solely or in combination with inorganic fertilizers. Similarly, facts have been unfolded about the merits of animal manure on the improvement of soil physical properties which in turn improves the agronomic and ecological services of the soil. Misuses of animal manure can lead to possible contamination of the water bodies and the atmosphere. It has been suggested that the application of manure at the right time right dose, either solely or in combination with inorganic fertilizers, are thought to alleviate related challenges while sustaining potato production.

Keywords: animal manure, sustainable crop production, potato, soil structure

Introduction
The world potato production in 2019 was 423 MT, and potatoes can nourish higher calories, vitamins and nutrients per unit area of land sown than other stable crops. Due to its multiple usage in the food, feed and industrial inputs, it is a plant of a great economic importance globally (FAOSTAT, 2019) [13]. Mixed crop-livestock systems have merits over crop enterprise alone. According to Entz and Martens (2009) [11] integrated crop-livestock systems have the potential to maintain and boost soil fertility levels. Similarly, organic C and soil N were increased, and leachable N decreased under the integrated crop-livestock enterprise compared to sole crop enterprise as reviewed by (Kumar *et al*., 2019) [23]. As a result, the inclusion of livestock in crop schemes has improved overall crop yields and economic profits (Kumar *et al*., 2019) [23]. For decades, animal manure has been recognized as the ultimate source for the soil nutrients, with a contribution scale up to about 37-61% of total nitrogen input to the land surface (Bouwman *et al*., 2013) [5]. Predictions are that demand for the animal population will increase as a result of an increase in the human population and changes in dietary structure, so that as meat consumption increases in the coming decades, nitrogen production from animal manure will increase (Herrero and Thornton, 2013) [18]. Potatoes area generally one of the important foods, feed and industrial crops. Soil organic matter levels and their biological activity is one of the most important and decisive factors in ensuring and maintaining high yield potential in the world's potato production system (FAO, 2009) [12]. The aim of the review is therefore to assess the current state of knowledge about the effects of the use of animal manure on sustainable potato production and soil structure. It also briefly discusses the results of research on the benefits of animal manure on the physical properties of soil and the general management of soil health.

Overview of sustainable crop production
Agricultural productivity has been increased and food security was also achieved via the green revolution interventions.

However, through time it was evident that the green revolution eventually led to top soil deterioration, pollution of ground water, production cost increment and decline of the organic farms (Pimentel *et al*., 2005) [32]. On top of that, it is predicted that the world population will shoot to 8.9 billion by the 2050 and demand for agricultural products, especially food will reach climax (Lichtfouse *et al*., 2009) [26]. This ignites the need for twofold crop yields compare to the present by applying sustainable crop production means. The central focus of sustainable crop production is to enhance soil organic matter content and reduce soil erosion via various management options (Doran, 2002) [10].

Soil organic matter management, lowering of chemical pesticide application, safeguarding of biodiversity, integrated pest management, ameliorating nutrient quality, ensuring food health and quality and eventually boosting the profitability of the crop sector are the most pillar principles of sustainable crop production; and this secures the share of the upcoming generations without polluting the environment (Imadi *et al*., 2016) [20]. In line with 2009 FAO's report the level of soil organic matter and its biological activity is one of the most vital and decisive factors for ensuring and maintaining high yielding potential in global potato production system (FAO, 2009) [12]. A similar report had appreciated the importance of animal manure as organic fertilizer for sustainable potato production not only by increasing its yield, but also improving the efficiency of chemical fertilizers; and it is realized that potato is the best responsive of all other crops to animal manure application. The 21 years long study has revealed that organic plots have shown a higher biodiversity and could boost soil fertility than conventional plots (Fig 1).

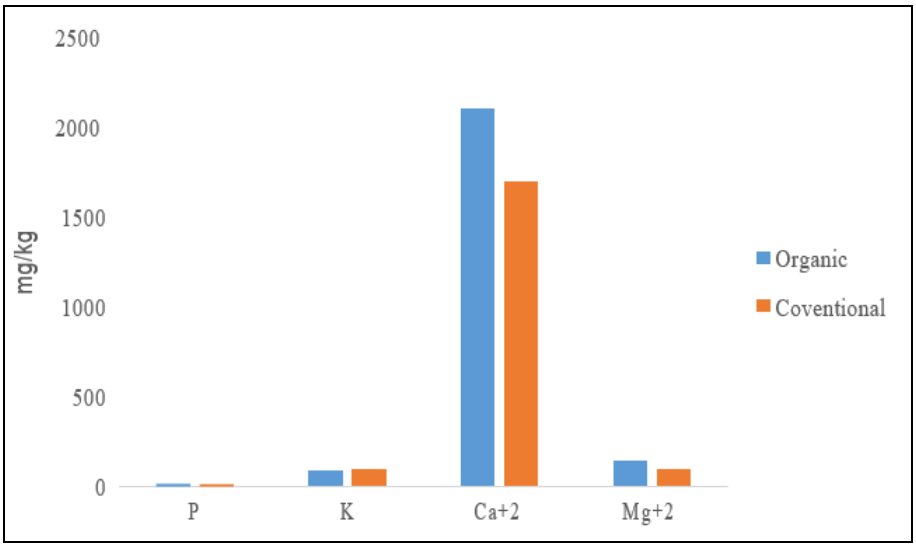

Fig 1: Mean values of selected soil minerals from organic and conventional farm of potato studied for 21 years (Mader *et al*., 2002) [29].

Organic farming

In a broader sense organic farming utilizes various eco-friendly pest control methods and huge amount of animal and plant based organic fertilizers, and nitrogen fixing cover /green crops. It uses fewer chemical inputs (fertilizer and pesticide), while reducing soil erosion and nitrate leaching into the water bodies, eventually recycles animal waste back into the farm (Admachak, 2008) [1].

Types of animal manure and their nutrient profiles

Soil productivity can be sustainably ameliorated by the important source of plant nutrients so- called animal manure. The inherent characteristics animal manure can be varied based on animal species, ages of animal, nutrition, protein and fiber content, digestibility of the diet, environment, housing and time of production (Lorimor *et al* ., 2004) [27]. In a general term, many scholars have agreed that cattle, poultry and pig manures are the most stable organic fertilizers after being applied to the soil respectively (Dendooven *et al*., 1998; Kirchman and Bernal, 1997) [22]. Pulleman *et al*. (2003) [33] have found that increments in total soil organic matter (SOM), earthworm activity, water stable macro-aggregation, and N mineralization in field where manure was used as compared with conventional field. The properties of this soil are the most important indicator of soil quality. The basic philosophy, in which all organic certification bodies operate, is to create and maintain underlying soil fertility through the use of biological processes, rather than importing short-term fertility in the form of soluble mineral fertilizers and pesticides, such as conventional agriculture (Derfa, 2002).

Table 1: Total nutrient contents of various livestock manures based on their fresh weight

Manure type	Contents					
	Dry matter (%)	Nitrogen N	Phosphate P2 O5	Potash K2O	Sulfur SO3	Magnesium MgO
		Kg/t- Solid manure				
Cattle	25	6.0	3.5	8.0	1.8	0.7
Pig	25	7.0	7.0	5.0	1.8	0.7
Sheep	25	6.0	2.0	3.0	ND	ND
Duck	25	6.5	5.5	7.5	2.7	1.2
Layer	30	16	13	9.0	3.8	2.2.
Broiler	60	30	25	18	8.3	4.2
Kg/m3 – Liquid manure						
Dairy	6	2.8	1.3	3.5	0.8	0.7
Beef	6	2.3	1.3	2.7	0.8	0.7
Pig	4	4	2	2.5	0.7	0.4

(Adapted from Chambers *et al*., 2001) [6].

Yield responses to the addition of S fertilizer are increasingly common in raped seed and grains in soil types that are deficient in Sulfur (S), generally sandy and shallow soils are with low S deposition. The animal manure provides a useful amount of S and magnesium (Mg) (Table 1). Soil bioactivity can be stimulated by adding manure, which can increase the number of

worms in some soils. Such improvements in the physical and biological fertility of the soil are more likely to be achieved with regular application of animal manure (Chambers *et al*., 2001) [6].

Benefits of sustainable potato production using animal manure

Previously, animal manure was an important source of plant nutrients. Its value in maintaining and improving soil productivity has been known since ancient times (Nowak *et al*., 1998) [31]. Fertilizing crops with nutrients for cattle dung began several millennia ago and is mentioned in the Old Testament Bible and other ancient documents. Recent Michigan studies have shown that applying poultry manure with a low dose of fertilizer can increase potato tuber yields by 30 to 60 cwt per hectare in some places (Snape *et al*., 2003) [35]. The key indicators for sustainable potato production are biodiversity and diversity, seed and seed quality, soil health and fertility management, nutrient supply and nutrient imbalance, soil protection, pest and water management, post-harvest management value creation and marketing farmers' health, safety and well-being (Lutaladio *et al*., 2009) [28].

Table 2: Mean yield of potato under the animal manure and NPSZnB fertilizer application in Awi Zone, Ethiopia, 2017.

NPSZnB (kg/ha)	Animal manure (t/ha)	Yields (t/ha)		
		Marketable yield	Total yield	Total dry biomass yield
0	0	15.3	18.5	122.8
65.7	10	18.7	23.9	147.4
133	20	20.5	24.6	155
199	30	22.7	26.2	161.7

(Data adapted from Bewket *et al*., 2018)

This research has shown the importance of animal manure in the boosting potato yield. Furthermore, it explicitly depicts NPSZnB fertilizer in combination with animal manure results in high yield and better performance of yield components than applying alone (Bewket *et al*., 2018) [4]. Application of cattle manure from zero to 30 t ha-1 had also resulted in statistically significant incremental effect in average tuber weight, marketable and total tuber yield and total dry biomass yield (Table 2). Similarly, the application of 20 to 30 t ha -1 FYM + 66.6% of the recommended chemical NP fertilizers provide higher total tuber yield as compared to the full dose of NP fertilizers without FYM in vertisol (Balemi, 2012) [2]. Therefore, it can be advised that this research output can benefit farmers, researchers, investors and others considering the agro-ecological requirement of the crop.

Effects of animal manure on soil structure

Soil physical properties include characteristics related to particle size distribution, particle arrangement (structure), volume and porosity, density, hydraulic conductivity, water holding capacity, soil temperature, soil air and erodibility. The main processes strongly influence ecological, pedological and agronomic processes at the soil, landscape and watershed scale, with consequences for ecosystem services and ecological processes (Fig 2) and soil organic matter and its dynamics (Reynolds *et al*., 2002) [34]. Among the main ecological processes, the physical properties of soil determines gas flow, elemental circulation, biodiversity, net primary productivity (NPP). Similarly, soil formation, humification, illuviation, horizonazation and transformations, and rate of leaching are examples of soil processes that are affected by the physical properties of the soil (Fig 2). Therefore, the physical properties of soil affect agricultural yield and productivity. Adaptation to climate change, seasonal change, and the parameters that affect it is mediated by the physical properties of the soil and related processes (Fig 2). Changes in soil properties, in turn, affect the content of organic matter (SOM) in the soil and its cycle. For example, SOMs affect soil properties (structure, porosity, density, hydraulic conductivity, water retention capacity, thermal conductivity etc) (Fig 2) that affect the basin and dynamics of SOMs. The content of SOM and its quality affect the physical properties and processes of the soil (Fig 2). SOM content is an important indicator of soil quality that strongly influences the formation and stabilization of soil aggregates (Franzluebbers, 2002) [15].

Walsh *et al*. (2012) [38] have pointed out the organic soil plays an important and multifaceted role in the earth. Physically, organic soil affects the structure of the soil and all its related properties while chemically, the organic matter of the soil affects its ability to catalyze exchange and its ability to inhibit changes in the soil pH (Walsh *et al*., 2012) [38]. Biological, organic matter is present in most plants acts as microbial biomass and nutrient and energy supply (Fig 2). Soils that are biologically and chemically fertile but not physically conducive to crop growth do not meet their agricultural potential (Fig 2). Soil productivity is determined by the combination of the influence of organic matter on physical, chemical and biological properties of soil (Walsh *et al*., 2012) [38].

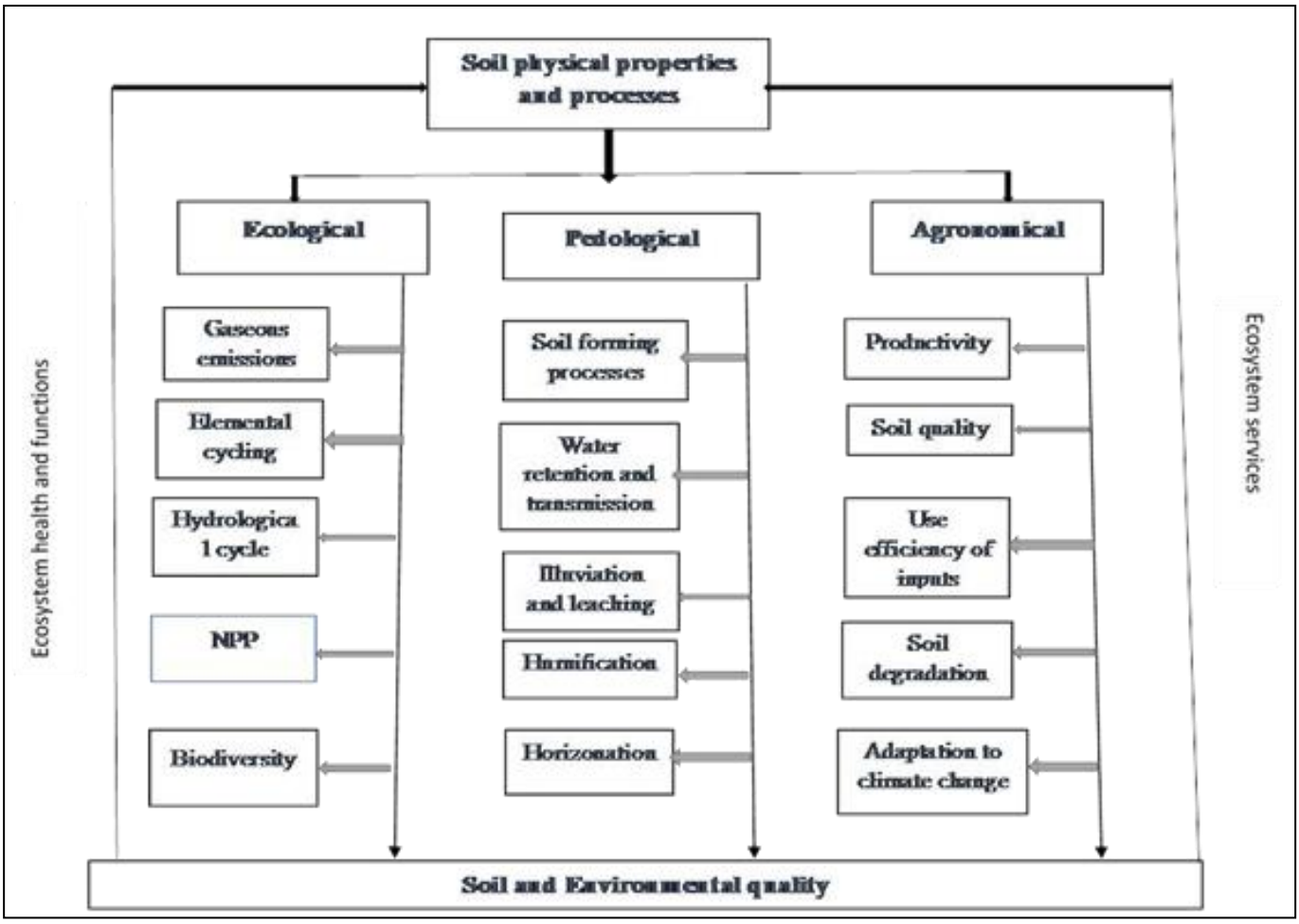

Fig 2: Schematic representation of ecological, pedological and agronomical impacts of soil physical properties and process as conditioned by soil organic matter as adapted from (Lal, 2011) [24].

Challenges associated with animal manure

The excessive use of fertilizes can result in the distribution and leaching of N and other nutrients, leading to contamination of surface and groundwater. If the crop is based on N requirements, the use of animal manure can be a major cause of excess P, as animal manure usually contains a smaller amount of N compared to P to meet crop needs (Toth *et al*., 2006). Adjusting the rate of application so that the manure provides sufficient P reduced the risk of P outflow from the field (Toth *et al*., 2006). However, it is also more likely to not meet the nitrogen requirements of the crop. Some excess nitrogen can accumulate in nitrogen reservoirs in the soil. Nitric oxide (N2O) from manure accounts for 44% of the total anthropogenic emissions of N2O, the largest anthropogenic stratospheric ozone-depleting substance and the third most important anthropogenic greenhouse gas (Tian *et al*., 2016) [37]. Excess nitrogen and phosphorus stimulate eutrophication of inland waters (Conley *et al*., 2009) [7] and are transported far from their original sources, degrading coastal water quality and even hypoxia (Yang *et al*., 2016) [38]. Manure production is more than 66% of NH3 emissions from the agricultural systems (Beusen *et al*., 2008) [3]. Thus, an increase in manure production may lead to an increase in NH3 emissions which harms public health and the environment (Sutton *et al*., 2013) [36]. The remaining excess nitrogen can zoom out of the soil profile and contaminate groundwater in the form of nitrates (Ju *et al*., 2006) [21]. It has been suggested that animal manure was the most important source of anthropogenic N 2O emissions in the 2000s (Davidson and Kanter, 2014) [8]. In some farms weed infestation would be a problem when not well decomposed animal manure is used as an organic fertilizer (Miller *et al*., 2015) [30].

Conclusion and future prospects

Historically animal manure has been the most valuable and accessible source of plant nutrients across the globe. Briefly discussed the results of research on the benefits of animal manure on the physical properties of soil and the general management of soil health. The overview of sustainable crop production, types and profiles of animal manure, their benefits of on the soil structure enhancement and potato yield increment has been reviewed. Many literatures have narrated that animal manure could boost the productivity and yield of potato in the different parts of the world either solely or in a combination with inorganic fertilizers. Similarly, facts have been unfolded about the merits of animal manure on the improvement of soil physical properties which in turn improves the agronomic and ecological services of the soil. Misuses of animal manure can lead to possible contamination of the water bodies and the atmosphere. It is suggested that application animal manure to potato at the right time and right dose either solely or in combination of the inorganic fertilizers are believed to lessen the associated challenges while sustaining potato production.

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