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Review

Grazing of crop residues: Impacts on soils and crop production

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ABSTRACT

Integration of crops with livestock is receiving increased attention to improve soil productivity and environmental quality. Grazing of crop residues is an important practice, particularly under the current scenarios of decreasing grassland areas and increasing feed costs. While many have discussed the implications of grazing grasslands on soil properties and productivity, impacts of grazing crop residues on soil and crop productivity have not been widely discussed. We reviewed and synthesized published research information on the impacts of crop residue grazing on soil properties and crop yields, discussed factors influencing grazing effects, and identified research gaps. Our review indicates that residue grazing can increase penetration resistance (compaction parameter) by 0.27–0.84 MPa in the upper 25 cm soil depth, but this increase in compaction does not generally result in reduced crop yields. Residue grazing has small or no effect on soil bulk density, wind and water erosion, and hydraulic properties. Residue grazing generally has a positive impact on soil nutrients. Indeed, moderate grazing may increase soil organic matter concentration, in some cases, compared to no grazing. Overgrazing can, however, reduce organic matter concentration in the long term. Crop residue grazing, in general, does not affect crop yields unless grazing occurs when the soil is wet. Information is limited on the impact of residue grazing on water and wind erosion, greenhouse gas emissions, and soil biological properties. Further studies should compare grazing effects on soils and crop production under different cropping systems, animal stocking rates, soil types, residue production levels, and climatic zones. Overall, grazing of crop residues appears to have small or no negative effects on soil and crop production, which suggests that crop residue grazing can be a viable component of integrated crop-livestock systems to sustain overall agricultural production.

1. Introduction

Use of crop residues as animal feed is not a new concept. About half of the world's food production comes from such integrated crop-livestock systems (Herrero et al., 2010). In developing countries, it is a common practice to use crop residues as livestock feed and in return use manure as an organic amendment to produce crops. However, in developed countries, the livestock and crop production systems have been mostly de-coupled under specialized agriculture (Franzluebbers and Stuedemann, 2006; Martin et al., 2016). This specialized system often causes environmental concerns (Peyraud et al., 2014; Regan et al., 2017). Thus, integration of crops with livestock is being considered for efficient utilization of resources, increased soil productivity, and improved environmental quality (Sulc and Franzluebbers, 2014; Nie et al., 2016).

Grazing crop residues can be an important component in integrated crop-livestock systems. It can be a low-cost feed for livestock while diversifying agricultural systems. However, the implications of such integrated crop-livestock systems on soils and crop production, particularly those of grazing crop residues are not well understood. While some have reviewed effects of grassland grazing on soil properties (Bilotta et al., 2007; McSherry and Ritchie, 2013), a specific review on the effects of crop residue grazing on soil properties and crop yields is lacking. Past reviews have mainly focused on examining the social, geographical and economic viability of integrated crop-livestock system in different parts of the world (Peyraud et al., 2014; Sulc and Franzluebbers, 2014). Bell et al. (2011) discussed some impacts of livestock grazing on soils and crop productivity with emphasis on experiments in Australia. Also, some studies reported limited or no effects of crop productivity residue grazing on soils and crop production (Russel et al., 2007; Sulc and Tracy, 2007; Hilimire, 2011; Lemaire et al., 2014; Sulc and Franzluebbers, 2014), while others cautioned about potential compaction and erosion caused by grazing cattle (Clark et al., 2004; Blanco-Canqui et al., 2016b; Rakkar et al., 2017). This warrants a more comprehensive review of the global literature to better understand the positive and negative implications of crop residue grazing. Thus, the objectives of this review were to synthesize and discuss published information on the impacts of crop residue grazing on

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Table 1
The residue production of major cereal crops in the world and livestock statistics.
Source: adapted from Unkovich et al., 2010; Yang and Zhang, 2010; FAO, 2015.

	2000	2013
Residue production[a]	*(million Mg)*	
Corn	525	902
Rice (*Oryza spp.* L.)	623	776
Wheat	809	985
Livestock	*(million heads)*	
Cattle	1302	1494
Sheep	1059	1173
Goats	751	1006
Buffalo	164	200

[a] Estimated residue production using harvest index of 0.53 for corn, 0.49 for rice, 0.42 for wheat.

soil properties and crop production and identify opportunities and research gaps of crop residue grazing across different world regions.

2. Crop residues as a potential livestock feed

2.1. Residue production

World-level residue production is presented in Table 1. In the past decade, world-residue production has increased substantially due to increasing trend of grain production. In the US alone, over the past 20 yr, corn grain along with residue production has increased 1.6 fold due to improved agronomic practices and use of corn hybrids. It is estimated that 3.8×10^8 Mg of corn residue is produced in the US primarily in the Midwest and eastern Great Plains (USDA-NASS, 2017). A significant portion of this abundant residue produced can be available for livestock production. Particularly, in high-residue producing areas such as in irrigated regions, partial removal (~25%) of crop residues can facilitate planting operations and improve plant emergence without affecting the soil productivity and crop yields (Kirkegaard et al., 2014).

2.2. Livestock production

Similar to crop production, there is an increasing trend in livestock production across the globe to meet the increasing demands for meat and milk products (Table 1; FAO, 2015). In the US, the number of cattle and calves increased by 4% from 2015 (98.2 million head) to 2017 (103 million head). In addition, the 2007 census of agriculture in the US showed an increase of 24% in total goat inventory over the 2002 census. Similarly, the number of sheep and lamb in the US has increased by 1% with a total of 5.32 million heads over the same period of time (USDA-NASS, 2009).

In contrast, pastureland area is in a decreasing trend due to the expansion of cropland areas (Wright and Wimberly, 2013). To maintain the livestock production level under the diminishing trends in grassland areas, stocking rates could increase, which can result in reduced soil and environmental quality. One alternative is feeding cattle in feedlot with hay and grains, but the cost of such feed sources has increased in recent years (USDA-NASS, 2013). In this complex scenario, developing sustainable alternatives to maintain livestock production is emerging as a priority.

2.3. Rationale for integration of crops and livestock

An integrated crop-livestock system involves the inclusion of livestock and crop production systems in the same piece of land to achieve mutual benefits. Some types of integration include crop-pasture rotation, crop-pasture intercropping, dual-purpose crops, and stubble or residue grazing (Nie et al., 2016). As mentioned earlier, crop-livestock integration can be an effective way to increase the diversity at farm and landscape scales to improve agricultural productivity and environmental quality (Lemaire et al., 2014). Both livestock and cropping systems complement each other. For example, livestock enhance soil fertility through manure input while crop residues are valuable feed source (Rufino et al., 2011). A recent whole-farm analysis suggested that crop-livestock integration in Australia with dual-purpose crops can potentially increase farm profitability by 88% (Kingwell and Squibb, 2015). Sulc and Franzluebbers (2014) discussed that crop-livestock integration through crop residue grazing in some areas in the US Midwest and Great Plains can enhance ecosystem services from agriculture.

In the US, livestock consume nearly 47% of soybean and 60% of corn grain produced (Olson, 2006). Grain-fed cows gain weight quicker than grass-fed cows. Some studies have reported that the grass-fed beef is more nutritional as it can contain an additional amount of Omega-3 fatty acids compared to grain fed beef (Muir et al., 1998), while others have reported less fat quantities and lean animals due to residue grazing (Cox et al., 2016a, 2016b). Leheska et al. (2008) reported no difference in *trans* fatty acids, n-6 fatty acids, and cholesterol, however, the composition of fatty acids between grass and grain fed beef differed. Also, the grazed dairy system can be comparable or better than confinement system due to more reproductive success and additional market niches (free range labeling) available (Russel et al., 2007). Based on these considerations, recent studies have suggested that crop residue grazing at permissible stocking rates can be an important livestock feed source to maintain or enhance animal performance (Stalker et al., 2015). In addition, crop residue grazing could also reduce animal stocking pressure on pasturelands, improve overall soil productivity, and reduce soil erosion potential of pasturelands due to overgrazing (Blanco-Canqui and Lal, 2008; Moore, 2009; Hochman et al., 2013).

3. Crop residue grazing and amount of residue removed

The amount of residue removed by grazing livestock varies across the globe based on crop production levels, climatic conditions, and economic status of farmers. Land size, cattle ownership, and labor availability are other factors that determine the crop productivity and fate of crop residues. A survey by Schmer et al. (2017) in 2010 found that 4.06 million ha corn area was grazed in 19 of the US states with major grazing occurring in the western Corn Belt. For example, about 52% of total corn acreage is being grazed in Nebraska and Colorado (Schmer et al., 2017).

Rational grazing in the high-residue production areas does not remove more than 30% of the residue. Animal stocking rates and grazing days are adjusted with a target of removing 25% of the total residue produced to ensure that more than 50% residue cover is left on the soil to control erosion (Rasby et al., 2014). However, residue retention needed for soil conservation can compete with residue for livestock feed in regions with scarcity of feed resources (Hellin et al., 2013). In some parts of the world, such as in Australia, overgrazing of residues is common during the dry season or drought to sustain livestock production (Kirkegaard et al., 2014).

4. Impact of crop residue grazing on soil properties

The effect of crop residue grazing on soil properties deserves a detailed consideration under the increasing trend of crop-livestock integration, particularly in temperate regions. During grazing, livestock activities such as treading, residue removal, and the addition of manure are likely to affect the soil properties. Grazing animals spend considerable time in walking, resting, drinking, and ruminating. The grazing behavior of different animals mainly depends on the inherited attributes, individual and social learning systems, location of feed and water, and spatial memory (Launchbaugh and Howery, 2005;