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Positive impact of moderate stubble grazing on soil quality and organic carbon pool in dryland wheat agro-pastoral systems

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ABSTRACT

Stubble grazing by livestock in post-harvest wheat fields is common in drylands. Previous studies have shown that this practice causes land degradation. Therefore, the objective of this study was to examine the effect of long-term stubble grazing, by comparing soil quality indicators in continuous wheat croplands of two rain-fed farming systems: with moderate stubble grazing during the summer (GR) vs. entire stubble retention (NO). Multi-annual averaged dry organic matter residue retained on the ground surface was ~0.8 Mg ha^{-1} in NO, as opposed to ~0.3 Mg ha^{-1} in GR. the same soil characteristics were also studied in 'natural' lands (NAT), to assess land-use change impact. The study was implemented in the semi-arid, northern Negev of Israel. Sampling of soil at depths of 0–5 and 5–10 cm was conducted in summer 2013. Some of the results suggest the degradation of soil quality following land-use change from NAT to croplands, as well as in GR, compared to NO. This included the coarse root biomass, which was 67% to ~two times greater under NAT than that under NO and GR. This impact was also revealed by the aggregate slaking index which was 18% to two times greater under the two cropland treatments than that under NO, as well as for the clay dispersion index which was ~two to three times greater under the two cropland treatments than that under NO. At the same time, unexpectedly, the majority of soil characteristics showed better soil quality under GR than that under NO. For example, hygroscopic moisture content under NAT was only 10% greater than that under GR, but 22% greater than that under NO. Also, the soil organic carbon pool was similar between NAT and GR, which had 16–22% greater value than that under NO. Overall, soil aggregation properties also suggested negative impact of land-use change, but, at the same time, showed a positive impact on soil quality by GR compared to that under NO. These aggregation properties included the micro-aggregate content, stable aggregate content, contents of the aggregates >2000 μm, the aggregate size fraction 1000–5000 μm, mean weight diameter of aggregates, and mean weight diameter of the 1000–5000 μm aggregate size fraction. An unexpected effect was recorded for the content of clods >8000 μm, which was ~two times greater under NAT than that under the two cropland treatments. The soil organic carbon's stratification ratio was marginally affected by treatment ($P = 0.1015$), and was 4% and 17% greater under NAT than that under NO and GR, respectively, revealing the clearest layering of soil organic carbon under NAT and the least clear layering under the GR. This suggests that mixing of organic residues in soil is smallest under NAT and greatest under GR. It is proposed that, in the long term, together with the input of animal excretion, the mixing of stubble residue in soil imposed by the livestock trampling compensates for the quantitative loss of stubble (through its consumption by the grazing animals), increasing soil organic carbon pool, and improving macro-aggregation processes and overall soil quality. A conceptual model is proposed to summarize these effects and relate them to soil conservation issues.

1. Introduction

Wheat (*Triticum aestivum* L.) grown under rainfed systems is one of the most dominant crops in the Middle Eastern drylands. Currently, wheat cropping systems cover ~18 million ha across this region (USDA, 2011), filling an important role in regional food security (Ahmed et al., 2013). In the Israeli drylands alone, these types of agrosystems cover ~75,000 ha.

Raising livestock has also been prevalent across Middle Eastern drylands. Natural rangelands provide the basis to feed the majority of these animals, with additional and considerable dependence on grazing wheat and barley stubble in post-harvest croplands, and also on serving supplementary feed such as grains and hay. Yet, because of the direct and much higher cost of supplementary feed, the desire is always to reduce its share in the overall animal diet (Benin and Pender, 2002). In the

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semi-arid Israeli Negev region, the livestock sector comprises mostly sheep and goats, reaching an overall number of 375,000 animals, relying on similar sources of feed as elsewhere in Middle Eastern drylands.

As elsewhere in the world, and similarly to other crops, irrational management practices, such as intensive and highly frequent tillage, massive removal of crop residues, and non-replenishment of soil organic matter stocks, have been causing the degradation of extensive croplands throughout the Middle East (Hobbs, 2007). Similarly, in the Israeli drylands, cropland degradation has become prominent, covering extensive lands of previously productive natural ecosystems (Blaustein Institute for Desert Research, 2000). Among other indices of land and soil degradation, predominant are the deterioration of soil structure formation and stability, the depletion of soil organic carbon stocks, the increase in magnitude and severity of erosional processes, and the general decrease in productivity and functioning (Stavi and Lal, 2015).

Overall, common perception suggests that stubble grazing adversely affects the soil quality and production capacity, resulting in degradation of extensive croplands around the world. Among the adverse effects associated with stubble grazing is the removal of organic residues (Rasby et al., 2014), which could otherwise been incorporated in the soil and sustain its organic carbon stocks (Ryan et al., 2008). Further, a special concern was alerted regarding the risk of soil compaction by livestock hoof action (Dimos, 2009; de los Agostini et al., 2012; Rasby et al., 2014). For example, for the Australian Northern Grain Zone it was reported that stubble grazing by cows has decreased the soil's porosity and infiltration rate, and increased its bulk density and strength, potentially reducing wheat crop yields (Bell, 2010). However, it was reported for the Australian Central Queensland that stubble grazing on saturated soil increased soil shear strength and cone index, with the resultant decreased yields of subsequent crops. At the same time, no adverse effects were reported for stubble grazing when applied on dry soil (Radford et al., 2008). Consequently, it seems that the effects of stubble grazing on the physical properties of soil, and particularly on aggregation characteristics, are not yet clear and thereby require further investigation.

Therefore, the objective of this study was to assess the long-term effect of stubble grazing on the soil organic carbon dynamics, soil aggregation properties and related quality indices in continuous wheat agro-ecosystems. The study was implemented in the semi-arid north-western Negev of Israel, where we examined the long-term effect of stubble grazing on a range of soil quality indices of croplands which have experienced moderate stubble grazing each summer, and other croplands which have experienced an entire stubble retention regime. In addition, we also studied the same indices for nearby natural lands, as a reference treatment to both of the wheat treatments. It was hypothesized that the moderate rate of stubble removal would decrease the soil organic carbon pool, deteriorating aggregation properties, and degrading the soil physical quality.

2. Materials and methods

2.1. Regional settings

The study was implemented in the Migda Experimental Farm (31°20′ N, 34°39′ E) of the Agricultural Research Organization, the Ministry of Agriculture and Rural Development, which is located in the semi-arid, north-western Negev of Israel. Mean daily temperature across the region ranges between 12 °C in January and 26 °C in July. The rainy season spans between October and March, yielding mean cumulative annual precipitations of approximately 230 mm (Bitan and Rubin, 1991). The predominant soil type is Loessial Serozems (Calcic Xerosol) with sandy loam texture. The farm itself has encompassed continuous wheat cropping agro-ecosystems since 1995. Also, starting in 1995, some of the fields have faced — every year — the retention of the entire stubble following the wheat harvest (NO, for no grazing). At the same time, every year since then other fields have experienced a moderate rate of grazing of stubble, after which, approximately 0.3 Mg ha^{-1} dry matter has remained on the ground surface (GR, for grazing). Excluding the stubble management practices, the remainder of the applied practices has been identical across all of the farm's fields. In order to imitate the prevailing management practices in the region, the applied practices included annual shallow disk-plowing to a 5-cm depth, and no application of any chemical or organic fertilizer. Regardless, since 2008, the entire farm has been converted to an organic system, with no pesticide or herbicide application. One way or another, this platform of field settings provided a unique opportunity to study the long-term impact of moderate stubble grazing vs. entire stubble retention on the functioning of dryland wheat agro-ecosystems. In addition to the GR and NO fields, an additional field has been utilized as a detention site, where livestock is held for longer periods, with the resultant high pressure from stubble grazing (Fig. 1).

2.2. Sampling scheme and laboratory analyses

Sampling was conducted at the end of summer 2013 when the soil was dry and reaching hygroscopic moisture content level. This took place after the completion of stubble grazing (in the GR plots), and before seedbed preparation for the subsequent growing season (in both of the wheat treatments). For each of the wheat treatments, three separate fields were utilized, each having an area of approximately five ha. In addition, three plots of 10 × 10 m were utilized for the reference treatment comprising a nearby 'natural' land, which is fully covered by a range of native herbaceous vegetation species, including grasses, forbs, and legumes (NAT, for natural) (Fig. 1). In each of the sampling fields (for each of the GR and NO treatments) and plots (for the NAT treatment), soil was sampled in seven randomly selected spots. At each spot, samples were obtained from two soil depths: 0–5 and 5–10 cm. From each spot and each depth, we obtained both a soil core of 5 cm diameter × 5 cm height, as well as a half-kg bag of whole soil.

Laboratory analyses included: hygroscopic moisture content (Gardner, 1965); dry coarse root biomass (Böhm, 1979); dry aggregate size distribution (by the dry sieving method: Kemper and Chepil, 1965), stable aggregate content (by using an aggregate stability apparatus: Eijkelkamp®, the Netherlands); aggregate slaking index (1 through 6: the higher the index, the greater the slaking. Modified from: Herrick et al., 2001); and clay dispersion index (by putting an aggregate of 3–5 mm diameter on a plate with distilled water, and observing the rate of milkiness (cloudiness) after 10 min and after 120 min. Scores for clay dispersion index ranged between 0 for no milkiness; 1 for slight milkiness; 2 for moderate milkiness; 3 for strong milkiness, and 4 for complete milkiness of the aggregate's clays (modified from: USDA-NRCS, EFH NOTICE 210-WI-62). In addition, based on data of the soil's total organic carbon concentration and bulk density (see: Stavi et al., 2015), the carbon's stratification ratio (Franzluebbers, 2002) and pool (stock) were also calculated.

2.3. Statistical analysis

Analysis of variance (ANOVA) was conducted with the GLM procedure of SAS (SAS Institute, 1990) to study the effect of treatment and depth on the measured soil characteristics. Factors in the model were treatment (2 df), plot within treatment (6 df; error term for plot), depth (1 df), and the interaction treatment × depth (2 df). Statistically significant interactions were further analyzed with the GLM's Slice command. Separation of means was implemented by Tukey's HSD at the 0.05 probability level. Pearson correlation coefficients were calculated to assess the relations between each pair of characteristics.

3. Results and discussion

3.1. Root biomass, soil organic carbon pool, and carbon stratification ratio

Growth rate and biomass production of vegetation root systems are determined by the soil conditions, of which, the soil structure is