

Remediation of degraded arable steppe soils in Moldova

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Remediation of degraded arable steppe soils in Moldova using vetch as green manure

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Abstract

In the Republic of Moldova, non-sustainable arable farming led to severe degradation and erosion of fertile steppe soils (Chernozems). As a result, the Chernozems lost about 40 % of their initial amounts of soil organic carbon (SOC). Aim of this study was to remediate degraded arable soils and promote carbon sequestration by implementation of cover cropping and green manuring in Moldova. Thereby, the suitability of the legume hairy vetch (*Vicia sativa*) as cover crop under the dry, continental climate of Moldova was examined. At two experimental sites, the effect of cover cropping on chemical and physical soil properties as well as on yields of subsequent main crops was determined. The results showed a significant increase of SOC after incorporation of hairy vetch due to a high above- and belowground biomass production that was related with a high input of carbon and nitrogen. A calculation of SOC stocks based on equivalent soil masses revealed a sequestration of around $3\text{ tC ha}^{-1}\text{ yr}^{-1}$ as a result of hairy vetch cover cropping. The buildup of SOC was associated with an improvement of the soil structure as indicated by a distinct decrease of bulk density and a relative increase of macroaggregates at the expense of microaggregates and clods. As a result, yields of subsequent main crops increased by around 20 %. Our results indicated that hairy vetch is a promising cover crop to remediate degraded steppe soils, control soil erosion and sequester substantial amounts of atmospheric C in arable soils of Moldova.

1 Introduction

In the Republic of Moldova, located at the western edge of the Eurasian steppe belt, about 80 % of the land area is covered by thick, dark steppe soils, the Chernozems. These soils are characterized by an exceptional high amount of soil organic matter (SOM) and belong to the most fertile soils of the world. Due to their naturally high productivity, Chernozems were intensively used for agricultural production in Moldova since the end of the 19th century. Non-sustainable arable farming, particularly after

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the collapse of the Soviet Union, resulted in a severe degradation of these sensitive soils, which was associated with a deterioration of the soil structure, compaction of the plough layer and erosion of the topsoil (Krupenikov et al., 2011). Today, almost 40 % of agricultural land is eroded and 26 million tonnes of soil are lost every year (Andries et al., 2014; Kuharuk and Crivova, 2014). As a result, Chernozems lost approximately 40 % of their initial amount of SOM resulting in a strong decline of soil fertility and agricultural productivity (Krupenikov et al., 2011). Since the end of the 1980s, crop yields of Moldova are declining which entails economic losses of up to 260 million US\$ annually, not including environmental damages (Boincean, 2014; Kuharuk and Crivova, 2014). The detrimental effect of soil degradation might be aggravated by climate change, as mean annual temperature in Moldova has increased by 1.4 °C since 1970 (Vronskih, 2014). This could have contributed to the decline of agricultural productivity as summer temperatures are already beyond the optimum of most crops, the probability of droughts increased and the mineralization of SOM may be accelerated (Eitzinger et al., 2013; Supit et al., 2010; Trnka et al., 2012).

In order to restore fertility and productivity of Moldova's Chernozems, a sustainable way of arable farming is needed which should primarily aimed at erosion control and the build up of SOM. Several approaches were proposed to remediate degraded dry-land soils worldwide (e.g. Garcia-Orenes et al., 2012; Wiesmeier et al., 2012; Novara et al., 2011). A promising option is thereby an introduction of cover crops, particularly leguminous plants, for green manuring. Cover crops are frequently used in regions with sufficient precipitation in order to avoid soil erosion, control weeds, increase water infiltration, improve soil physical, chemical and biological properties, promote the formation of SOM and thus C sequestration and last but not least increase agricultural production (Dabney et al., 2001; Cherr et al., 2006; Fageria, 2007; Fageria et al., 2005; Bronick and Lal, 2005). In particular, legumes are used which additionally fix substantial amounts of atmospheric nitrogen (N). However, under a dry, continental climate as in Moldova, experience with cover crops is limited. It was hypothesized that in regions with low precipitation ($< 500 \text{ mm yr}^{-1}$), cover crops could have an adverse effect on

agricultural productivity as the water available for subsequent main crops may be reduced (Blanco-Canqui et al., 2011; Stavi and Lal, 2013; Wortman et al., 2012; Unger and Vigil, 1998; Cherr et al., 2006).

In this study, the suitability of the legume hairy vetch (*Vicia villosa*) as cover crop was investigated under the dry, continental climate in Moldova. Hairy vetch is known as a high yielding cover crop in temperate regions with a high potential for N fixation (Brandsaeter et al., 2008; Mirsky et al., 2012; Teasdale et al., 2004; Clark, 2007). Greenhouse experiments on the physiological response of the relative common vetch (*Vicia sativa*) to drought indicated that common and hairy vetch could be also useful in drylands (Tenopala et al., 2012). At two experimental sites in Central and Southern Moldova, mixtures of hairy vetch and winter wheat were sown which may be more advantageous than legume monocultures due to a more effective weed control, an increased biomass production, a decreased N leaching as well as an increased N availability for subsequent main crops (Sainju et al., 2002, 2005a; Mirsky et al., 2012; Dabney et al., 2010; Tosti et al., 2014). The main objectives of this study were to

1. evaluate the productivity and the N fixing potential of hairy vetch under continental climatic conditions of Moldova,
2. investigate the effect of cover cropping and green manuring on the physical and chemical quality of degraded arable Cherozems,
3. estimate the potential for an enhancement of C sequestration and agricultural productivity.

2 Materials and methods

2.1 Study sites and experimental design

The study was performed at two experimental sites in Southern Moldova in the Cahul district next to the village of Lebedenco (28°19' E, 45°51' N, 165 m a.s.l.) and in the in

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the central part of Moldova within the Orhei district in the vicinity of Ivancea village (28°53' E, 47°18' N, 173 m a.s.l.) (Fig. 1). The continental climate follows a north–south gradient with ranges of mean annual temperature from 7.5 to 10.5 °C and of mean annual precipitation from 550 to 380 mm from north to south. Summer droughts occur frequently, particularly in the south. The soils were classified as Calcic Chernozem at the Cahul site and Haplic Chernozem at the Orhei site, both derived from loess (IUSS Working Group WRB, 2006). Soils of both experimental sites were intensively used for agricultural production for several decades. In September 2010 (Orhei) and September 2012 (Cahul), a mixture of 80 % hairy vetch and 20 % winter wheat (*Triticum aestivum*) was sown at two experimental plots with a size of 1 ha at each study site. In April of the following year, hairy vetch was incorporated into the soil using a disk harrow. As subsequent main crops, sunflower (*Helianthus annuus*) in Orhei and corn (*Zea mays*) in Cahul were grown and harvested in September. Before the start of the experiment and again before sowing the main crops, a fertilizer rate of 17 kg ha⁻¹ N was applied. Topsoil horizons down to a depth of 47 cm were sampled using steel cylinders with a volume of 100 cm³ before the start of the experiment and again after harvesting the basic crops at five locations from each experimental plot as well as adjacent control plots, where main crops were grown without previous vetch cover cropping.

2.2 Determination of soil properties and crop biomass

Several physical and chemical soil properties were determined in order to characterize the soil status before and after the experiment. Soil texture was analyzed using the pipette method according to Gee et al. (1986). Bulk density (BD) was quantified from the mass of the oven-dry soil (105 °C) divided by the volume of the soil cores. The proportions of microaggregates (< 0.25 mm), macroaggregates (0.25–10 mm) and clods (> 10 mm) were quantified by dry sieving. Total N content was determined by the Kjeldahl method (Bremner, 1996) and soil pH was measured in H₂O. The content of SOM was determined by wet oxidation and divided by the factor 1.724 in order to obtain soil organic carbon (SOC) contents (Nelson and Sommers, 1996). SOC stocks were

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calculated on the basis of an equivalent soil mass (ESM) approach according to Ellert et al. (1995). As green manuring is often associated with a change of BD, constant investigation depths would result in a consideration of different soil masses for the quantification of SOC stocks. Thus, the investigation of the effect of cover cropping on SOC stocks has to be based on ESM (Post et al., 2001; Ellert and Bettany, 1995). For all topsoil horizons soil masses of vetch plots as well as soil masses of control plots were calculated after vetch incorporation and harvest of the subsequent main crop. The differences of soil masses were used to derive corrected depths of topsoil horizons, which are necessary to obtain ESM. Total topsoil SOC stocks were calculated on the basis of ESM using corrected (initial SOC stocks) and unchanged (SOC stocks after vetch) horizon depths:

$$\text{SOC}_{h_z} = \sum_i^{h_z} \text{SOC}_i \cdot \text{BD}_i \cdot h_i \quad (1)$$

where SOC_{h_z} is the total SOC stock (kg m^{-2}) of all topsoil horizons h_z , SOC_i is the SOC concentration (mg g^{-1}) of the fine earth of horizon i , BD_i is the BD (g cm^{-3}) of the fine earth of horizon i , h_i is the corrected/unchanged thickness (cm) of horizon i .

Total aboveground biomass of hairy vetch was determined at five randomly selected locations within an area of 1 m^2 at each experimental site. Root biomass was determined gravimetrically by washing soil monoliths (side length 15 cm) to a depth of 35 cm within the selected locations. Yields of main crops were determined at five randomly selected locations of 6 m^2 within control and experimental sites. The collected plant material was dried at 60°C for 24 h and yields were corrected for residual water at 105°C . To test the significance of green manure effects on the examined parameters, Student's t test were applied using the software IBM SPSS Statistics 19.

3 Results

3.1 Vetch biomass and main crop yields

The above- and belowground biomass of vetch as well as the related input of C and N is shown in Table 1. In total, dry masses of 7.2 and 8.0 t ha⁻¹ were incorporated at Orhei and Cahul, respectively, which was related to a total C input of 2.9 and 3.1 t ha⁻¹. At both study sites, total N amounts of 254 and 273 kg ha⁻¹ were incorporated in which 203 and 218 kg ha⁻¹ (80 % of total N) were biologically fixed according to Rochester et al. (2005). The incorporation of vetch as green manure showed a clear effect on the yields of the following main crops (Fig. 2). In Orhei, the yield of sunflower significantly ($P < 0.05$) increased by 22 % compared to the control site. Similarly, corn yields significantly ($P < 0.05$) increased by 18 % in Cahul.

3.2 The impact of vetch intercropping on physical and chemical soil properties

The topsoils (0–47 cm) of both study sites were characterized before the start of the experiment in terms of soil texture, pH and C/N ratios (Table 2). In Orhei, topsoil horizons revealed high proportions of silt (55 %) and clay (37 %) and relatively low sand contents (8 %). Topsoils from Cahul showed comparable sand contents of 7 % but higher proportions of silt (65 %) and lower contents of clay (28 %). The pH values were slightly higher in Cahul (7.0–7.3) compared to Orhei (6.5–6.6) and C/N ratios of both study sites were in a close range of 8.9–9.8.

After incorporation of one harvest of winter vetch and the subsequent main crop, a considerable improvement of physical soil parameters was observed at both study sites (Figs. 3 and 4). For BD, a significant ($P < 0.05$) decrease of 14 and 15 % was detected for the Ahp1 (0–12 cm) and of 4 and 9 % for Ahp2 (12–20 cm) at Orhei and Cahul, respectively. In Cahul, even BD of Ahp3 (20–35 cm) decreased by 6 %. Further indication for an enhanced soil structure after vetch intercropping was found by analysing the proportion of microaggregates (< 0.25 mm), macroaggregates (0.25–

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10 mm) and clods (> 10 mm). At Orhei, a significant ($P < 0.05$) increase of macroaggregates by 6–8% was determined in the two upmost horizons. In Cahul, the macroaggregate content increased by 22% in both topsoil horizons and by 10% in the Ahp3. Accordingly, the relative proportion of clods and to a lower amount of microaggregates decreased.

In addition to an enhanced soil structure, also an increase of SOM was determined as a result of hairy vetch cover cropping (Table 3, Fig. 3). At both study sites, SOC contents of Ahp1 and Ahp2 significantly ($P < 0.05$) increased by 7–9% and 4–6%, respectively. The associated decrease of BD required an ESM approach to quantify the effect of green manuring on SOC stocks (Table 3). Due to significantly ($P < 0.05$) different soil masses in topsoil horizons at vetch and control sites, the depth for the calculation of total SOC stocks in the topsoil was corrected by 2.3 cm at Orhei and 3.6 cm at Cahul. SOC stocks based on ESM significantly ($P < 0.05$) increased from 11.3 to 11.6 kg m⁻² at Orhei and from 10.2 to 10.5 kg m⁻² at Cahul due to vetch incorporation. Thus, an amount of 3 t C ha⁻¹ yr⁻¹ was sequestered in agricultural soils of Moldova as a result of hairy vetch intercropping and green manuring.

4 Discussion

4.1 Biomass of hairy vetch and C and N input

The cultivation of hairy vetch as cover crop in Moldova revealed a relatively high above- and belowground biomass production and related C and N input into soils compared to results from other studies worldwide (Table 4). The aboveground biomass was 27–37% higher compared to the global average and belowground biomass was even twice as high. However, only few studies investigated the root biomass of hairy vetch and the available results are hardly comparable due to different depths considered and general difficulties in root biomass determination. Remarkably, studies which applied mixtures of hairy vetch and cereals as in our study showed higher aboveground biomass sim-

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ilar to our results. This confirmed the assumption that hairy vetch/cereal-mixtures are more effective than monocultures for green manuring, particularly in terms of the C input (Dabney et al., 2010; Mirsky et al., 2012; Sainju et al., 2002; Tosti et al., 2014). According to the higher biomass production, the total C input of hairy vetch was 45–55 % higher compared to the average value from the literature. However, in the only study that investigated the C input of hairy vetch and a hairy vetch/rye mixture, the mixture revealed a substantially higher C input (67 %) in the range of our results, which can be attributed to the higher C/N ratio of cereals compared to hairy vetch (Sainju et al., 2005a, b). This clearly demonstrates the advantage of hairy vetch/cereal-mixtures for green manure approaches which are primarily aimed at increasing the amount of SOM in degraded soils and promoting C sequestration.

Furthermore, the detected N input of hairy vetch was distinctly higher than the global average. The aboveground N input was 56–64 % higher than the global mean value and the belowground N input was almost three times higher. Interestingly, the difference between the average N input derived from literature data and our results was much higher than the difference in terms of the biomass, which points towards a higher N concentration of hairy vetch biomass in Moldova. In fact, the determined N concentration of 4.1–4.2 % was higher than the mean N concentration of 3.5 ± 0.7 % estimated from data presented in Table 4. The effect of hairy vetch/cereal-mixtures on the N input was not as pronounced as for the C input due to the high C/N ratio of cereals.

4.2 Increase of SOM and carbon sequestration potential

The high above- and belowground biomass production of hairy vetch and the related high C input led to an increase of SOM even after incorporation of one harvest of hairy vetch. A significant increase of SOC contents by 7–9 % was found in the topsoil (Ahp1) of degraded arable soils. Incorporation of hairy vetch as green manure in temperate region of the USA had a negligible effect after one year and similar increases of SOC occurred only after several years (Sainju et al., 2002; Kuo et al., 1997). However, C input by hairy vetch was distinctly lower ($1.7\text{--}2.5 \text{ t ha}^{-1}$) compared to our study. The

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5 calculation of SOC stocks based on ESM revealed an increase of 5–9% in upmost
topsoil horizons (Ahp1 and Ahp2). Incorporation of one harvest of hairy vetch resulted
in a sequestration of 3tC ha^{-1} in topsoils (0–20 cm). This is in the upper part of the
range of observed C sequestration rates in humid regions. In the USA, the incorpora-
10 tion of hairy vetch as green manure in cereal, cotton and vegetable production resulted
in a wide range of SOC accumulation of $0.2\text{--}2.7\text{t ha}^{-1}\text{ yr}^{-1}$ in topsoils (0–30 cm) in the
first 3 to 7 years of the experiments (Sainju et al., 2002, 2003, 2005b). In Japan, C
sequestration ranges from 0.6 to $1.0\text{t ha}^{-1}\text{ yr}^{-1}$ were found in topsoils (0–30 cm) by
including hairy vetch as cover crop in rice and soybean cultivation under a humid sub-
15 tropical climate (Higashi et al., 2014). General estimations of C sequestration rates in
arable soils due to green manuring were also lower with a mean of $0.9\pm 1.3\text{C ha}^{-1}\text{ yr}^{-1}$
(Balkcom et al., 2013; Jarecki and Lal, 2003). The high variation of the effect of green
manuring on SOC sequestration is related to several environmental and management
factors. Besides growth conditions of cover crops (length of cultivation, soil status, cli-
matic conditions), N fertilization rate and the way of tillage seems to be crucial for SOC
20 accumulation. The relatively high amount of C that was sequestered in arable soils of
Moldova may be attributed on the one hand to the high biomass production of hairy
vetch and the related high C input into the soil.

On the other hand, the build up of SOC stocks largely depends on the C stabilization
mechanisms of the soil and the associated storage capacity. In arable soils, the occlu-
sion of SOM in soil aggregates and the interaction of SOM with mineral surfaces con-
stitute the dominant stabilization mechanisms (von Lützwow et al., 2006; Sollins et al.,
1996). Hassink (1997) found evidence for a worldwide strong correlation of the C stor-
age potential of arable soils with the proportion of silt and clay particles $< 20\ \mu\text{m}$. As
25 the studied steppe soils are characterized by exceptionally high proportions of silt and
clay ($> 90\%$), one can assume a high potential C storage capacity. In fact, early es-
timations in non-cultivated Chernozems in Moldova at the end of the 19th century re-
vealed SOC contents of $30\text{--}40\text{ mg g}^{-1}$ (Ursu et al., 2014). Due to the massive SOC
loss of 40% induced by non-sustainable arable farming in the 20th century, there is

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presumably a high C saturation deficit and thus a high C storage capacity in degraded arable soils of Moldova (Krupenikov et al., 2011). On a country basis, approximately 3.1 MtCyr⁻¹ could be sequestered in arable topsoils by green manuring over a period of 20–25 years. This amount corresponds to 11.4 MtCO₂-equivalents which almost equals Moldova's annual greenhouse gas emissions of 11.9 MtCO₂-equivalents (in 2005).

4.3 Improvement of soil structure

The buildup of SOM induced by green manuring was associated with an improvement of soil structure. This was indicated by an increase of macroaggregates (0.25–10 mm) at the expense of microaggregates (< 0.25 mm) and clods (> 10 mm). Generally, there is evidence for aggregate hierarchy in temperate soils: microaggregates (< 0.25 mm) are bound together into macroaggregates (> 0.25 mm) by organic binding agents like roots and hyphae (Oades, 1984; Tisdall and Oades, 1982; Six et al., 2004). As a result, macroaggregates are characterized by higher C contents compared to microaggregates (Gupta and Germida, 1988; Six et al., 2000). Intensive soil cultivation leads to a loss of C-rich macroaggregates and a concurrent increase of C-depleted microaggregates (Six et al., 2000). Therefore, the proportion of macroaggregates, particularly the aggregate size class of 0.25–10 mm, was proposed as suitable indicator for soil quality (Oades, 1984; Tisdall and Oades, 1982; Nichols and Toro, 2011). The cultivation of hairy vetch as cover crop apparently promoted the formation of macroaggregates due to an increased C input which probably stimulated microbial biomass and thus the formation of polymers that act as binding agents. Moreover, the increased root growth was presumably related with an enhanced enmeshing of microaggregates which directly promoted macroaggregate formation. In a study that investigated the dynamics of root- and shoot-derived carbon from hairy vetch, it was concluded that root-derived C plays an important role in the formation of aggregates (Puget and Drinkwater, 2001). Increased proportions of macroaggregates and a decrease of microaggregates and

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the soil (USD 110). This rough estimation does not account for savings in terms of reduced fertilizer application and environmental costs, e.g. expenses related with nitrate leaching and soil erosion.

5 Conclusions

5 Our results provided evidence that hairy vetch is a suitable cover crop under the continental climatic conditions of Moldova. A high above- and belowground biomass production was associated with a high input of C and N into arable soils resulting in a significant increase of SOM already after incorporation of one harvest. Thus, green manuring using hairy vetch is an effective option to sequester atmospheric C in degraded arable soils of Moldova, which have a high C sequestration potential. A countrywide
10 implementation of green manuring on SOM-depleted soils could roughly compensate Moldova’s annual greenhouse gas emissions in the next 20–25 years. The buildup of SOM was related with a substantial improvement of soil structure presumably leading to enhanced resistance to erosion, improved root growth of main crops and increased infiltration and water holding capacity. As a result, yields of subsequent main crops
15 increased by 20 %. Green manuring with hairy vetch is a promising method to improve the economic situation of farmers and to control soil degradation in Moldova. Further studies are needed that monitor the long-term effect of green manuring on the soil status and its feasibility on a country-scale.

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Table 1. Dry masses (above- and belowground) of vetch and related input of C and N at Orhei and Cahul (mean values \pm SD, $n = 3$).

study site		dry mass		C	N	N fixed*	
		(t ha ⁻¹)					
Orhei	aboveground	5.2 \pm 0.2	2.2 \pm 0.1	218 \pm 11	174 \pm 9		
	belowground	2.0 \pm 0.3	0.7 \pm 0.1			36 \pm 5	29 \pm 4
	total	7.2 \pm 0.5	2.9 \pm 0.2			254 \pm 16	203 \pm 13
Cahul	aboveground	5.6 \pm 0.2	2.2 \pm 0.1	230 \pm 12	184 \pm 9		
	belowground	2.4 \pm 0.2	0.9 \pm 0.1			43 \pm 4	34 \pm 3
	total	8.0 \pm 0.4	3.1 \pm 0.2			273 \pm 16	218 \pm 12

* Assuming a mean proportion of N₂ fixation on total N of 80 % according to Rochester et al. (2005).

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Table 2. Basic soil properties (soil texture, pH, C/N ratio) of topsoil horizons of experimental sites in Orhei and Cahul (mean values \pm SD, $n = 3$).

study site	horizon	depth (cm)	sand (%)	silt (%)	clay (%)	pH (H ₂ O)	C/N
Orhei	Ahp1	0–12	7.9 \pm 2.6	55.5 \pm 4.4	36.6 \pm 0.6	6.6 \pm 0.2	9.4 \pm 0.2
	Ahp2	12–20	7.8 \pm 1.9	55.5 \pm 3.9	36.7 \pm 0.6	6.6 \pm 0.2	9.2 \pm 0.2
	Ahp3	20–35	8.6 \pm 1.6	54.7 \pm 2.9	36.7 \pm 0.4	6.5 \pm 0.1	9.1 \pm 0.1
	Ah	35–47	8.5 \pm 2.0	54.6 \pm 4.3	36.9 \pm 1.0	6.6 \pm 0.1	8.9 \pm 0.1
Cahul	Ahp1	0–12	7.1 \pm 0.6	65.9 \pm 0.5	27.1 \pm 0.2	7.0 \pm 0.1	9.6 \pm 0.7
	Ahp2	12–20	7.1 \pm 0.6	65.8 \pm 0.5	27.1 \pm 0.2	7.0 \pm 0.2	9.8 \pm 0.6
	Ahp3	20–35	7.3 \pm 0.4	65.2 \pm 0.3	27.5 \pm 0.1	7.0 \pm 0.2	9.8 \pm 0.4
	Ah	35–47	7.3 \pm 0.6	64.7 \pm 0.2	28.3 \pm 0.2	7.3 \pm 0.0	9.7 \pm 0.6

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Table 3. Soil masses and SOC stocks corrected for equivalent soil masses (ESM) of topsoil horizons of control and experimental sites in Orhei and Cahul after incorporation of vetch and harvest of the main crop (mean values \pm SD, $n = 10$).

study site	depth (cm)	soil mass (kg m^{-2})		ESM depth correction (cm)	SOC stock (kg m^{-2})	
		control	vetch		control	vetch
Orhei	0–12	155 \pm 6	133 \pm 2	2.0 \pm 0.2	2.6 \pm 0.1	2.8 \pm 0.1
	12–20	113 \pm 2	108 \pm 1	0.4 \pm 0.1	2.0 \pm 0.1	2.1 \pm 0.0
	20–35	222 \pm 9	221 \pm 3	–	3.9 \pm 0.1	3.9 \pm 0.1
	35–47	172 \pm 7	169 \pm 1	–	2.8 \pm 0.1	2.8 \pm 0.1
	total	661 \pm 24	631 \pm 7	2.3 \pm 0.3	11.3 \pm 0.2	11.6 \pm 0.1
Cahul	0–12	153 \pm 1	129 \pm 2	1.9 \pm 0.1	2.2 \pm 0.1	2.4 \pm 0.1
	12–20	117 \pm 2	106 \pm 1	0.8 \pm 0.2	1.8 \pm 0.0	1.9 \pm 0.0
	20–35	226 \pm 4	213 \pm 3	1.0 \pm 0.4	3.5 \pm 0.1	3.5 \pm 0.1
	35–47	169 \pm 1	169 \pm 1	–	2.7 \pm 0.1	2.7 \pm 0.0
	total	665 \pm 8	618 \pm 7	3.6 \pm 0.7	10.2 \pm 0.3	10.5 \pm 0.0

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Table 4. Above- and belowground dry mass and total C and N input of hairy vetch (HV) and mixtures of hairy vetch with cereals used in green manure experiments worldwide (mean values \pm SD).

country	cover crop	dry mass (tha ⁻¹)			C input (tha ⁻¹)			N input (kg ha ⁻¹)			reference
		above	below	total	above	below	total	above	below	total	
USA	HV	4.8 ± 0.4	–	4.8 ± 0.4	–	–	–	184 ± 15	–	184 ± 15	Abdul-Baki et al. (1996)
	HV+ rye	5.9	–	5.9	–	–	–	151	–	151	
	HV	2.5 ± 1.1	–	2.5 ± 1.1	–	–	–	85 ± 29	–	85 ± 29	Guldan et al. (1996)
	HV	3.0 ± 0.6	1.1 ± 0.8	4.1 ± 1.3	1.2 ± 0.1	0.4 ± 0.3	1.6 ± 0.5	–	–	–	Kuo et al. (1997)
	HV+ rye	3.5 ± 1.2	2.1 ± 0.6	5.6 ± 1.8	–	–	–	112 ± 62	26 ± 14	138 ± 76	Griffin et al. (2000)
	HV	1.8 ± 0.9	–	1.8 ± 0.9	–	–	–	69 ± 37	–	69 ± 37	Kuo and Jellum (2000)
	HV	2.5 ± 0.7	–	2.5 ± 0.7	–	–	–	86 ± 28	–	86 ± 28	Cline and Silvernail (2001)
	HV	3.5	0.9	4.4	1.5	0.3	1.8	–	–	–	Puget and Drinkwater (2001)
	HV	4.7 ± 1.5	–	4.7 ± 1.5	–	–	–	178 ± 68	–	178 ± 68	Sainju and Singh (2001)
	HV	–	–	–	2.1 ± 0.7	–	–	2.1 ± 0.7	–	168 ± 62	Sainju et al. (2002)
	HV	4.1 ± 1.6	–	4.1 ± 1.6	–	–	–	124 ± 57	–	124 ± 57	Teasdale et al. (2004)
	HV	4.3 ± 1.6	0.3 ± 0.3	4.6 ± 1.3	1.5 ± 0.6	0.1 ± 0.1	1.6 ± 0.5	136 ± 52	6 ± 4	142 ± 48	Sainju et al. (2005a, b)
	HV+ rye	6.6 ± 1.4	0.6 ± 0.3	7.2 ± 1.3	2.5 ± 0.6	0.2 ± 0.1	2.7 ± 0.6	193 ± 113	8 ± 3	201 ± 112	
HV	4.5 ± 1.9	–	4.5 ± 1.9	–	–	–	170 ± 92	–	170 ± 92	Cook et al. (2010)	
HV	4.9 ± 2.3	–	4.9 ± 2.3	–	–	–	–	–	–	Mischler et al. (2010)	
Japan	HV	3.9	–	3.9	–	–	–	145	–	145	Tarui et al. (2013)
	HV+ oat	5.5	–	5.5	–	–	–	159	–	159	
Norway	HV	4.1 ± 2.5	–	4.1 ± 2.5	–	–	–	–	–	–	Brandsaeter et al. (2008)
Korea	HV	4.7 ± 0.9	–	4.7 ± 0.9	–	–	–	152 ± 17	–	152 ± 17	Jeon et al. (2011)
China	HV	3.1 ± 0.6	–	3.1 ± 0.6	–	–	–	134 ± 27	–	134 ± 27	Zhu et al. (2011)
		4.1 ± 1.2	1.0 ± 0.7	4.3 ± 1.3	1.8 ± 0.5	0.3 ± 0.1	2.0 ± 0.5	140 ± 37	13 ± 11	143 ± 37	

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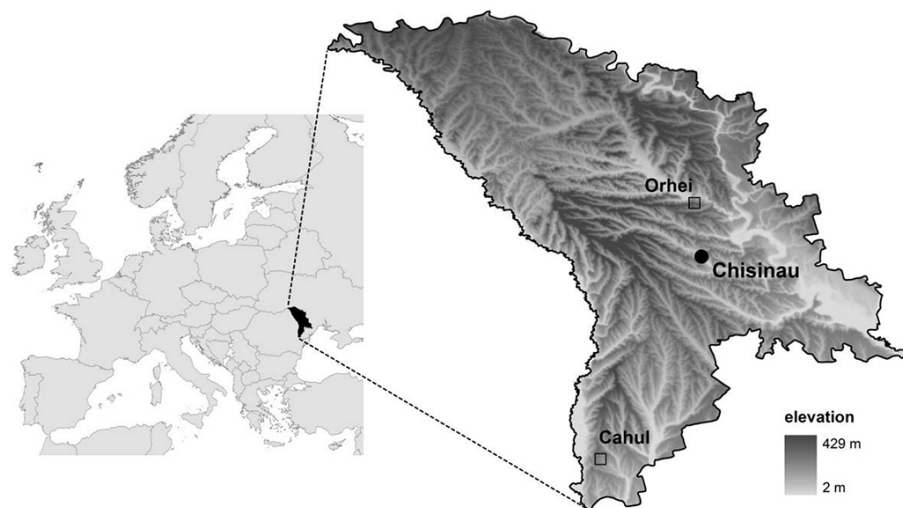


Figure 1. Topographic map of the Republic of Moldova showing the location of the study sites in the districts of Cahul and Orhei.

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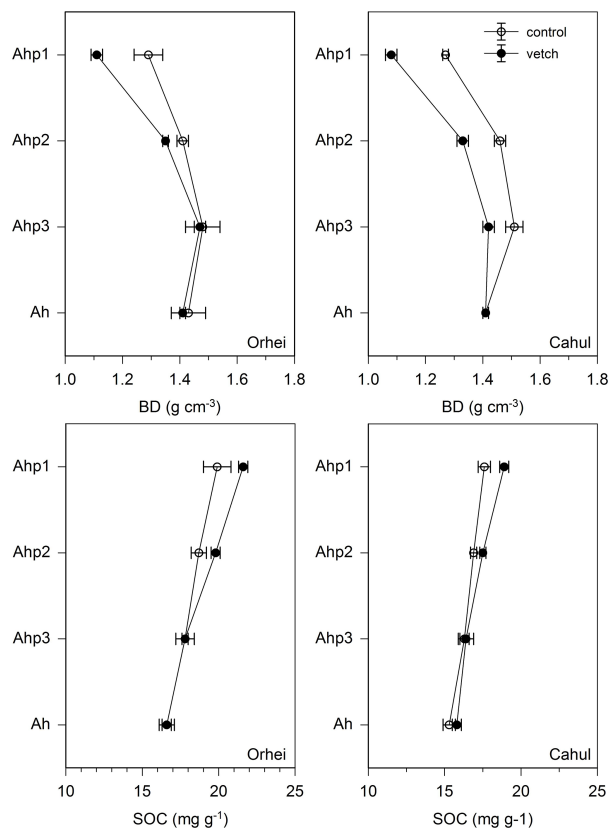


Figure 3. Bulk densities (BD) and soil organic carbon (SOC) contents of topsoil horizons of control and experimental sites in Orhei and Cahul after incorporation of vetch and harvest of the main crop. Error bars represent SD ($n = 10$).

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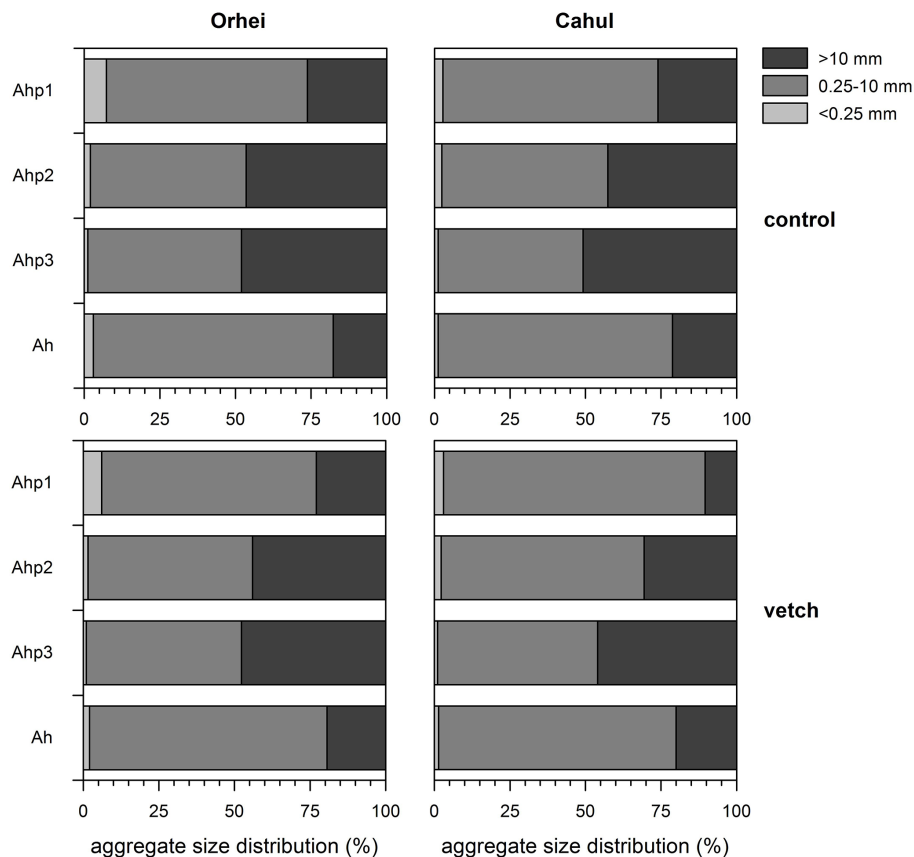


Figure 4. Distribution of microaggregates (< 0.25 mm), macroaggregates (0.25–10 mm) and clods (> 10 mm) in topsoil horizons of control and experimental sites in Orhei and Cahul after incorporation of vetch and harvest of the main crop.

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