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Evaluation of Carbon Sequestration and Global Warming Potential of Wheat in Khorasan-Razavi Province

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ABSTRACT

In order to determine soil characteristics and above-ground and below-ground carbon sequestration potential of wheat, a systematic random sampling method was employed to select 5 samples from 50 fields situated in Khorasan-Razavi Province, Iran during 2015. The experimental design was a completely randomized design with three replications. The ash method was used to determine the carbon sequestration conversion coefficients in spikes, stems, leaves and roots. Then, greenhouse gases (such as CO_2, N_2O and CH_4) emission were calculated using emission coefficients. The average organic carbon, total nitrogen, available phosphorus, available potassium, soil bulk density, pH and electrical conductivity were found to be 0.98%, 0.02%, 27.07 ppm, 341.32 ppm, 1.37 g.cm-3, 7.81 and 1.42 $dS.m^{-1}$, respectively. The maximum (52.0%) and minimum (31.99%) conversion coefficients were related to spikes (seeds included) and roots, respectively. In addition, the total carbon sequestration was 8.25 $t.ha^{-1}$ so that the maximum (4.28 $t.ha^{-1}$) and minimum (0.35 $t.ha^{-1}$) values were found in stems and roots, respectively. The total global warming potential (GWP) of wheat was recorded as 2377.86 kg CO_2 –equiv. per ton of seed. The first contributing factor was nitrogen fertilizers, accounting for 1331.30 kg CO_2 –equiv. per ton of seed.

Keywords: Ash method; conversion coefficient; nitrogen fertilizer; spike

Introduction

Atmospheric carbon dioxide concentration has increased by 25% since late 18th century. The conventional management of agroecosystems, intensive tillage and fossil fuels as well as converting pastures to drylands, deforestation and burning crop residue are among the most effective factors in increasing atmospheric carbon dioxide concentration (Hutchinson *et al.*, 2007). It has been reported that agricultural land contributes about 20 - 25% of total carbon dioxide released into the atmosphere (Duxbury *et al.*, 1993). There are several ecological solutions helping agroecosystems to reduce carbon dioxide emission into atmosphere, for example zero tillage systems (Follett et al., 2005), organic fertilizers (Falloon *et al.*, 1998), crop rotation (Follett *et al.*, 2005) and intercropping (Follett *et al.*, 2005) are the most important approaches.

Carbon sequestration is the most efficient and environmentally safe approach for entering carbon dioxide into the soil in the form of organic matter. Soil is the largest terrestrial carbon source so soil carbon sequestration management can positively impact soil carbon stocks (Ingram and Fernandez, 2001). It has been reported that carbon stock in unploughed soils is 67-512 $kg.ha^{-1}$ higher than ploughed soils (Unploughed soils). No tillage and crop residue retention increase carbone sequestration potential in agricultural land (Yan *et al.*, 2007). In a study, (Khorramdel *et al.*, 2013) have stated that intensive tillage and nitrogenous chemical fertilizers increased decomposition rate organic carbon of and decreased carbon sequestration potential. Accordingly, considering the low organic matter content of soil in arid and semi-arid regions of the world (Bationo and Buerkert, 2001), increase in soil organic matter

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Table 1. Consumed inputs in wheat agrosystems per ton of seed in Khorasan-Razavi during 2014˜2015

Manure (ton)	Insecticide (l)	Fungicide (l)	Herbicide (l)	Chemical fertilizers (kg)			Fuel (l)
				K	P	N	
0.78	0.31	0.42	2.13	36.98	158.14	253.45	8862.56

could be a multi-purpose solution to reduce atmospheric carbon dioxide and to improve carbon sequestration potential to achieve sustainability in agroecosystems. Native plants and dominant crops play a key role in carbon sequestration (Hill *et al.*, 2003). Species, adapted to arid and semi-arid regions, involve in carbon sequestration in different ways. It has been found that there is a significant relationship between vegetation carbon stock and carbon sequestration rate (Najm-Eldini, 2013). Carbon sequestration potential depends on species, climate conditions and land management techniques (Mortenson and Schuman, 2002). In a study on perennial millet (Ma, 1999) have found that the role of roots in carbon sequestration is much more than other tissues.

With special climate conditions, Iran has provided a suitable platform for the production of agricultural products. In the meantime, cereal production is the major determinant of agricultural goods. Nonetheless, there are major water restrictions in crop production in semi-arid areas such as Khorasan-Razavi, where farming depends on irrigation. Drought-tolerant cereals, especially wheat which is considered as a strategic species, have great importance in these areas. Although there are various approaches to improve carbon sequestration potential, a significant part of the land in Khorasan-Razavi production area is located in arid and semi-arid regions where organic matter content is considerably low (< 0.1%) for lack of vegetation and high oxidation rates (Hajabbasi and Hemmat, 2000; Mosaddeghi *et al.*, 2000; Shirani *et al.*, 2002). Accordingly, evaluating carbon sequestration potential in different tissues of wheat, as one of the most important crops in the region, is not only necessary, it is essential for its sustainable production. Moreover, determining the soil characteristics of this valuable product and assessing its global warming potential (GWP) would help to better management of natural resources. Therefore, the current study was aimed to evaluate soil characteristics, determine carbon sequestration potential in above-ground and below-ground tissues of wheat and assess GWP in Khorasan-Razavi Province.

Material and methods

Carbon sequestration potential

A systematic random sampling method (Chambers and Brown, 1983) was employed to select 5 samples from 50 fields situated in Khorasan-Razavi Province, Iran during 2015. Roots were collected from 0 – 30 cm depth (Mahdavi *et al.*, 2009). The sampling was done using transects (three 100 m), each measuring 50 × 50 cm plots. All above-ground and below-ground tissues were collected from each plot. The vegetative (including stems, leaves and roots) and reproductive (spikes including seeds) tissues were collected in spring. Soil samples were randomly taken from five plots in each transect. Sampling was performed just under the plants at the depth of 0 – 30 cm. The ash method was used to determine the carbon sequestration conversion coefficients in spikes, stems, leaves and roots (Abdi *et al.*, 2008; Bordbar *et al.*, 2008; Forouzeh *et al.*, 2008). For this purpose, the weighted samples were oven dried for 24 h at 60 °C and then burned for 3 hr at 500 °C. The ash samples were cooled down in a desiccator before weighting (Polidori *et al.*, 2008). Soil carbon sequestration was calculated after determining soil organic carbon (Walkley and Black, 1934) and soil bulk density (Black, 1965) using Nosetto *et al.*, 2006) equation.

Greenhouse gas emission and GWP

In order to assess greenhouse gas emissions and GWP a questionnaire method (50 questionnaires) was used to collect detailed information on fuel consumption, organic (cattle manure) and mineral fertilizers (N, P and K), herbicides and pesticides. The number of questionnaires was determined according to Snedecor and Cochran (1980). The average input consumption amount in Khorasan-Razavi is shown in Table 1. Greenhouse gases (such as CO_2, N_2O and CH_4) emission was calculated using emission coefficients (IPCC, 2007; Snyder *et al.*, 2009; Tzilivakis *et al.*, 2005; Lal, 2004). It should be noted that due to lack of CO2 emission coefficient for pesticides and low application in most of the fields, this parameter was not assessed. In this regard, it has been reported that pesticides have a negligible effect on GWP (Khoshnevisan *et al.*, 2013).

Since greenhouse gases affect GWP in different ways (IPCC, 2007), so the index was calculated based on CO2 using the following equation (Tzilivakis *et al.*, 2005).

$$GWP=CO_2\ flux+(N_2O\ flux\times310)+(CH_4\ flux\times21) \qquad (1)$$

Where GWP is global warming potential (kg CO_2 –equiv. per ton of seed), CO_2 flux is carbon dioxide emission, N_2O flux is nitrogen oxide emission and CH_4 flux is methane emission.

Questionnaire's reliability was evaluated using the Cronbach's Alpha method (Cronbach, 1951). The data on carbon sequestration potential were analysed in a completely randomized design using SAS 9.1. Collected samples were considered as replications. The means were compared by LSD test and graph was plotted in Excel.

Results

Questionnaire's reliability (α=84%) was found to be satisfactory using the Cronbach's Alpha method.

Soil physical and chemical properties

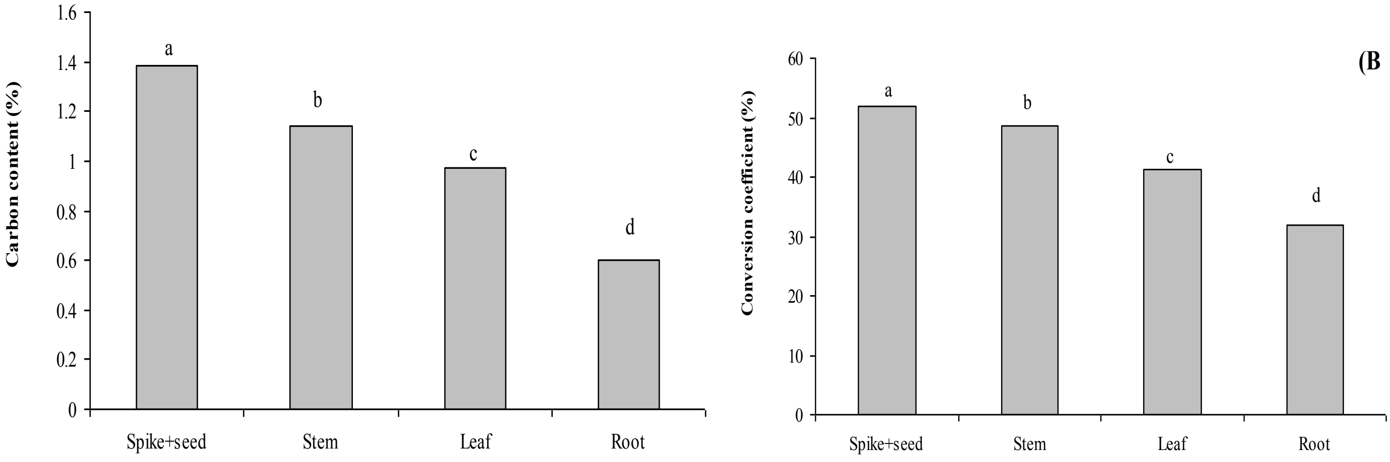
The soil texture was found to be clay loam. The average organic carbon, total nitrogen, available phosphorus, available potassium, bulk density, pH and EC of soil were found to be 0.98%, 0.02%, 27.07 ppm, 341.32 ppm, 1.37 g.cm^{-3}, 7.81 and 1.42 dS.m^{-1}, respectively.

Above-ground and below-ground tissues yield

The average yields for spikes+ seeds, stem, leaves and roots of wheat were recorded as 509.16, 880.64, 236.97 and 109.73 g.m^{-2}, respectively.

Carbon sequestration potential conversion coefficients

There was significant difference between above-ground and below-ground tissues in terms of carbon content and conversion coefficients (Table 2). The maximum (1.39%) and minimum (0.60%) carbon content were related to spikes (seed included) and roots, respectively. Carbon content increased by 91 and 62% in stems and leaves, respectively compared with the roots. Increase in above-ground carbon content was 95% higher than that in the roots (Figure 1A). The maximum conversion coefficient (52.0%) was observed in spikes, whereas the minimum value (31.99%) was related to the roots. Conversion coefficient increased by



(A) (B)

Means with different letter(s) in each have significant difference based on Duncan's test (p ≤ 0.05).

Figure 1. Mean comparison for (A) carbon content and (B) conversion coefficients of wheat above-ground and below-ground tissues

Table 2. Analysis of variance (mean of squares) on carbon content, conversion coefficients and carbon sequestration potential as affcted by wheat above-ground and below-ground tissues

Carbon sequestration potential	Conversion coefficient	Carbon content	df	S.O.V.
155654**	391.05**	0.548**	3	Above-ground and below-ground tissues
112	4.63	0.00282	16	Error
-		-	19	Total

**: Significant at 1% probability level

52 and 29% in stems and leaves, respectively compared with the roots. Furthermore, above-ground tissues average conversion coefficient was 48% higher than the roots (Figure 1B).

Carbon sequestration potential significantly affected by plants tissues (Table 2). The total carbon sequestration was 8.25 t.ha^{-1} so that the maximum (4.28 t.ha^{-1}) and minimum (0.35 t.ha^{-1}) values were found in stems and roots, respectively. Stems, spikes, leaves and roots accounted for 52, 32, 12 and 4% of the total carbon sequestration, respectively (Table 2).

Global warming potential (GWP)

The total GWP of wheat was recorded as 2377.86 kg CO2 –equiv. per ton of seed. The first contributing factor was nitrogenous fertilizers, accounting for 1331.30 kg CO_2 –equiv. per ton of seed. Among applied mineral fertilizers, the minimum greenhouse gas emission (194.24 kg CO_2 –equiv. per ton of seed) was related to K fertilizers. As to P fertilizers, there was 38% less emission compared with nitrogenous fertilizer. The maximum and minimum greenhouse gas emission were related to herbicides (13.86 kg CO2 –equiv. per ton of seed) and fungicides (7.80 kg CO2 –equiv. per ton of seed), respectively (Figure 3).

Discussion

The soil carbon sequestration was found to be 4027.80 g.m^{-2}. Low organic matter content in soil may be the reason why the soil carbon sequestration is low. The soil carbon sequestration potential in canola fields in Khorasan-Razavi has been reported as 3.46 t.ha^{-1} (Khorramdel *et al*., 2015). Planting legumes in crop rotation not only improves soil nitrogen content, but increases soil carbone stocks (Melero *et al*., 2011). It has been confirmed that in any system where carbon input is greater than carbon output, carbon sequestration will occur (Jastrow *et al*., 2007). In addition, increase in carbon sequestration (57 ± 14 g.m^{-2} per year) through shifting from conventional tillage to zero tillage was reported by (West and Post, 2002) who stated that crop rotation increases carbon sequestration by 0.15 ± 0.11 Mg.ha^{-1} per year. Returning crop residue into the soil increase carbon sequestration rate (Havlin *et al*., 1990) and improve soil structure (Lal, 1997) through increasing soil organic carbon content. It has been well documented that carbon sequestration is affected by cropping systems (monoculture or intercropping) and soil organic matter management (Schulp *et al*., 2008). Perennial plants produce more woody tissues (Nobakht *et al*., 2011; Tamartash et al., 2012) and need less soil tillage (Jastrow *et al*., 2007; West and Post, 2002) and can be in rotation with legumes (López-Bellido *et al*., 2010) have great impact on soil organic matter content and carbon sequestration (Campbell *et al*., 1996a; Campbell *et al*., 1996b; López-Bellido *et al.,* 2010). Accordingly, taking advantages of new tillage practices such as minimum tillage or zero tillage, returning crop residue into the soil and planting legumes in rotation are highly recommended to increase soil carbon sequestration potential and to get closer towards sustainable wheat production, especially in arid and semi-arid regions.

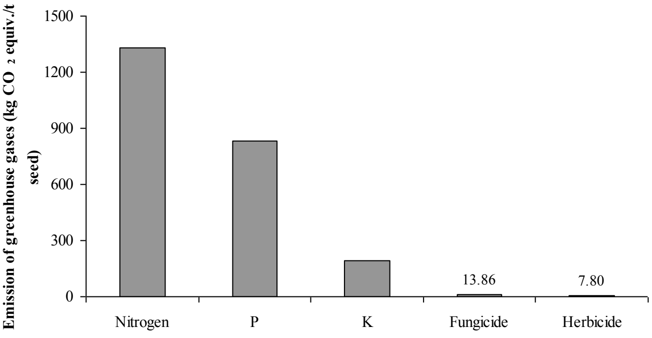


Fig. 3- Total green house gases emissions for wheat agroecosystems in Khorasan-Razavi based on consumed inputs

Reduction in leaves and roots conversion coefficients might be due to higher concentration of minerals in these tissues. On the other hand, higher conversion coefficient in spikes is mainly caused by lower water content in these tissues. The higher conversion coefficient in above-ground tissues compared with underground tissues has been previously reported by (Jafarian and Tayefeh Seyyed Alikhani, 2013).

In a study comparing above-ground and below-ground tissues of canola the maximum conversion coefficient (51.65%) was related to siliques. The conversion coefficients for stems, leaves and roots were found to be 5, 16 and 34% less than siliques (Khorramdel *et al*., 2015). Significant differences between *Cistus* species, dendrostellera (*Dendrostellera lessertii*) and camel grass *(Artemisia deserti*) in terms of conversion coefficients were found by Forouzeh *et al.* (2008).

Although, roots contain more lignin than stems, root exudates (Daudu *et al*., 2009) and lower C to N ratio (Russell *et al*., 2005) may be considered as the main reason for reduced carbon sequestration potential in roots compared with stems. On the other hand, lignin accumulation in stems and also higher dry weight in comparison with other tissues increases carbon sequestration potential. Therefore, it seems that lignified tissues are more able to sequestrate carbon. Accordingly, considering the significance of agriculture in increasing greenhouse gas emission, it is highly recommended to plant perennial species such as forage crops and medicinal plants, as well as to reduce the conventional tillage practices and optimum use of organic fertilizers to mitigate global warming potential (Braschkat *et al.*, 2003). Taking advantages of these environmentally safe techniques not only reduces soil erosion but also improve carbon sequestration potential and promotes agroecosystems stability. In addition, in order to make the results more applicable, returning wheat residues as a by-product into the soil, especially in arid and semi-arid regions of Khorasan-Razavi Province, is recommended to improve soil organic matter and carbon sequestration potential. As mentioned before, the total carbon sequestration potential for canola was 5.12 $t.ha^{-1}$ (Khorramdel *et al.*, 2015), and stems and leaves accounted for 1.81 and 0.76 $t.ha^{-1}$, respectively. Carbon sequestration potential for silique and root were found to be 4 and 56% less than stem. In a study the maximum (10.02 $t.ha^{-1}$) and minimum (0.18 $t.ha^{-1}$) carbon sequestration potential were found in spikes and roots, respectively (Jafarian and Tayefeh Seyyed Alikhani, 2013). Singh *et al.* (2003) have reported that carbon sequestration potential varies in above-ground and below-ground tissues. In addition, it has been reported that above-ground carbon sequestration potential is higher than that in below-ground tissues (Gao *et al.*, 2007; Yong, 2007).

Taking together, considering the low organic matter content in soil (Hajabbasi, and Hemmat, 2000; Mc Conkey *et al.*, 2003; Mosaddeghi *et al.*, 2000) and positive effect of crop residues on soil physical, chemical and biological properties (Kirchmann *et al.*, 2016; Busari *et al.*, 2015), it is recommend to return wheat residues into the soil to increase soil organic matter especially in arid and semi-arid regions of Khorasan-Razavi fields. Improving soil carbon sequestration potential results in increased crops biomass, enhanced soil fertility and greater soil water retention capacity, which in turn reduce soil degradation and erosion (Jafarian and Tayefeh Seyyed Alikhani, 2013). Therefore, any measure that increases vegetation growth rate would be predicted to improve carbon sequestration potential.

In agroecosystems, fossil fuels and nitrogenous fertilizers are the main sources for greenhouse gases (mainly CO_2 and N_2O) emission. It has been reported that 59% of CO2 emission is caused by nitrogenous fertilizers manufactures (Brentrup *et al.*, 2004). In addition, 14% of CO_2 emission in agroecosystems has been attributed to soil tillage (Cooper *et al.*, 2011). Therefore, in order to mitigate CO_2 emission from agroecosystems minimum tillage techniques should be taken into account. Carbon dioxide emission due to herbicides application has been estimated as 1996-2000 kg CO_2 –equiv. per each active component (Nagy, 2000). In addition to increasing the concentration of carbon dioxide during the past centuries due to industrial development, increase in N_2O from 275 to 319 ppm is going to be a great concern. Although the N_2O concentration in the atmosphere is quite low, its GWP is 310 times more than CO_2, in addition, it is harmful to the ozone layer (Crutzen, 1981). According to IPCC, nitrogen emission into atmosphere is equal to 1.25 kg N_2O-eqiuv. per 100 kg (ISO, 2006). Brentrup *et al.* (2004) believed that N_2O emission directly depends on chemical fertilizers production and application. Similarly, Bouwman (1990) has introduced extensive use of chemical fertilizers and tillage as the main reason for N_2O emission from agroecosystems. The maximum GWP for irrigated wheat (889.61 kg CO_2–equiv. per ton of seed) was related to 220 $kg.ha^{-1}$ nitrogen application. The value was recorded as 937.73 kg CO_2–equiv. per ton of seed for rain-fed wheat when 60 kg ha^{-1} nitrogen was applied (Khorramdel *et al.*, 2014). It has been stated that the annual N_2O emission for wheat field in Germany as affected by tillage and chemical fertilizers application is 0.2-0.27 kg of N_2O per ha^{-1} (Barker-Reid *et al.*, 2005). Meisterling *et al.* (2009) indicated that organic cropping systems produced 30 kg less CO_2 than conventional cropping systems to produce 1 kg of bread. Similar results have been found by Moudrý *et al.* (2013). Thus, although nitrogenous fertilizers increase seed yield, it should be kept in mid that excessive use of chemical fertilizers not only increases production cost and energy consumption, but also increases greenhouse gases emission during production process. As mentioned earlier greenhouse gases emission amount depends on management and climate conditions (Khan *et al.*, 2009; Khan *et al.*, 2010), therefore, it can be suggested that taking account of sustainable approaches such as conservation tillage, organic fertilizer application and having legumes in crop rotation systems would appreciably improve agroecosystems sustainability (Braschkat *et al.*, 2003). New methods including conservation tillage (minimum tillage or zero tillage) not only save more energy, but also prevent soil erosion through increasing soil organic matter content and enhance carbon sequestration potential. The development of agricultural technologies has led to an increase in energy consumption, which in turn has led to an increase in environmental pollution principally due to release various pollutants into different ecosystems in the form of leaching, evaporation, sublimation, etc., resulting in different health issues (Skowroñska and Filipek, 2014). Generally, during 2011 and 2012 over 15 million ton chemical fertilizer (in the form of urea, P_2O_5 and K_2O) were used in Europe. These amount of fertilizers produced 1.6 ton CO_2 per each ton of NH_3 and released 2-2.5 ton of N_2O per each ton of HNO_3 (Skowroñska and Filipek, 2014). During chemical fertilizer production 3-10% N_2 and 0.3-3%

NH_4 are release into the atmosphere. Difference in soil moisture content in different agroecosystems increases N_2O and nitrate leaching (Brentrup and Palliere, 2008; Lammel, 2000). Therefore, it is suggested that the environmental status of these production systems should be investigated using various ecological approaches such as life cycle assessment. In this regard, Brentrup *et al*. (2004) have stated that evaluating stability of production systems is essential. They have emphasized that LCA could solve agroecosystems problems such as input consumption and land use change. Similarly, Eckert *et al*. (1999) have pointed out to the same approach. Furthermore, as these approaches compare the environmental performance in different production systems, thus, following these approaches would help to introduce the most appropriate systems to reduce pollution and to optimize input use by applying more precise amounts of fertilizer and other chemicals at the optimal time.

Conclusion

The obtained results demonstrated that carbon sequestration in wheat fields located in Khorasan-Razavi Province is very low, which can be attributed to low soil organic matter content. There was a significant difference between above-ground and below-ground tissues in terms of carbon sequestration potential and conversion coefficient. Accordingly, it is highly recommended that sustainable measures such as returning the crop residues into the soil should be put in place to improve soil physical, chemical and biological properties and also carbon sequestration potential, especially in arid and semi-arid regions, where organic matter oxidation rate is high. Furthermore, as nitrogenous fertilizer application plays a crucial role in increasing GWP, thus it is suggested that organic fertilizers and legumes might be a suitable alternative for chemical fertilizers. Last but not least, it is suggested that the status of agroecosystems is examined using various ecological approaches such as life cycle assessment.

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