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CARBON SEQUESTRATION POTENTIAL OF SOILS UNDER MAIZE PRODUCTION IN IRRIGATED AGRICULTURE OF THE PUNJAB PROVINCE OF PAKISTAN

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ABSTRACT

Carbon sequestration (CS) potential of maize cultivation in Irrigated Agriculture of Punjab - Pakistan (IAP) is unknown. Carbon sequestration potential of maize crop in a representative IAP region of Faisalabad division was determined. Base values of soil carbon were achieved through field experiments by growing a local variety of maize (Monsanto-919 Hybrid) in NIAB-I, NIAB-II and Gojra sites during autumn of 2012. The above- and below-ground biomass of maize was quantified from shoot and root sampling. Soil samples from 0-15, 15-30, 30-45, 45-60, and 60-75 cm depths were collected before and after cultivation for soil major properties and net CS estimation. The above-ground biomass C values at NIAB-I, NIAB-II and Gojra were 9.60, 8.21 and 9.61 mg ha^{-1}, respectively. The below-ground biomass C values for above respective sites were 1.5, 1.3 and 1.4 mg ha^{-1}. Change in Soil Organic Carbon (SOC), i.e., values of SC in soil after a growing season were 6.78, 7.76, 6.88 mg ha^{-1} at the three sites, respectively. Using mean of these CS values and assuming similar conditions in the rest of IAP of Punjab province of Pakistan, a total of 10,497 mg of C was calculated to be sequestered during the autumn 2012 growing season in 593.7 ha of IAP. Here we can demonstrate that the results of carbon sequestration encourage sustainable agriculture and environment.

Key words: Above- and below-ground biomass, soil carbon pools and inventory, sustainable agriculture.

INTRODUCTION

Potential of natural system to store atmospheric carbon in soil is affected by global climate change. Literature reveals historical climate change on the planet earth in general (Smith *et al.* 1997; IPCC 2007) and Punjab province of Pakistan in particular (Abbas 2013; Abbas *et al*. 2014). Agricultural and forest management practices enhance soil organic carbon (SOC) through the phenomenon termed as carbon sequestration. Soil and litter contain more than double amount of carbon than vegetation (Dixon *et al*. 1994; Jobbagy and Jackson 2000). Soil being the largest carbon sinks stores almost 53% of the terrestrial carbon. Out of this amount, 10% is cycled through the soil in each year (Raich and Potter 1995). Exceeding 50% of SOC is stored in soil organic matter (SOM), which typically contains around 58% carbon. Therefore, the soil that contains 1% SOC has about 1.72% SOM. Soil carbon pools are enriched through addition of organic matter and best management practices. Due to recent concerns about climate change the importance of increased SOC and the role of climate change in carbon sequestration through plant biomass are widely accepted (Lal 2004).

The term biomass refers to mass of live or dead organic matter. Total carbon pools of terrestrial ecosystem are conceptually divided into above and below-ground biomass, dead mass and litter (Caracalla *et al*. 2009). In addition to SOM, carbon is also stored in plant's above and below-ground biomass. Above ground portion of plant including stem, leaves, branches, bark, seeds, and foliage form above-ground biomass. Live biomass below the earth surface like live roots forms the belowground biomass. Root biomass has three portions including fine root that have less than 2 mm diameter, small roots that have 2-10 mm diameter and large root that have greater than 10 mm diameter. Dead biomass comprises non-living woody material other than litter, either standing, lying on the ground surface or below the ground surface.

Maize, sugar beets, potatoes and winter wheat are potential source of carbon sequestration (Freibauer *et al*. 2004; Smith 2004; Suyker *et al*. 2004; and Moureaux *et al*. 2006). Pakistan being an agricultural country has huge acreage of maize, which is one of the most important cereal crops grown in Pakistan under irrigated as well as rainfed conditions. It has increasingly gained importance because of short growing season and higher yield contributing over 4.6% of total food grain production in the country. It is also used in industries to manufacture corn sugar, corn oil, corn protein, corn flours and corn syrup (Minfal 2009). Two crops of maize are usually harvested each year in Pakistan. The crop sown in February is known as spring maize, whereas that sown in August is known as autumn maize.

Data regarding carbon sequestration potential of maize acreage in Pakistan is scarce. These data are important for quantification of carbon pools in the country to confirm outcomes of modeling studies. Most of the aspects of maize cultivation in Pakistan have been studied over the past few decades but extensive literature review did not reveal any in-depth study to estimate carbon sequestration potential of this crop in Pakistani soils. Therefore, the present study was designed to estimate carbon sequestration potential of maize production in Irrigated Agriculture of Punjab – Pakistan (IAP).

MATERIALS AND METHODS

Experimental sites: Field experiments were conducted on three sites; two fields at the Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad (Latitude 31º 4167' N; Longitude 73º 0833' E; 183 meter above mean sea level at Karachi) and one field in Gojra region of District Toba Tek Singh (Latitude 31º 1487' N; Longitude 72º 6866' E; 172 meter above mean sea level at Karachi) in the division of Faisalabad. The Nuclear institute for Agriculture and Biology is located on Jhang road, Faisalabad at a distance of 7 km from the city center. Faisalabad and Gojra are 30 km apart. Texture NIAB soils is predominately clay loam, which varies spatially from clay loam to loam horizontally and is silt clay loam at lower depths.

Climatic conditions: The climate of the study region is semi-arid with summer maximum temperature of 46 ºC, winter minimum temperature reaching freezing point and average annual precipitation of 300 mm (Abbas 2013). The historic climatic data were collected from Pakistan Metrological Department to calculate reference crop evapotranspiration (ET_o) for the study sites. A complete analysis of historical data was conducted through a modeling approach. The objective of this modeling approach was to evaluate climate change patterns by analyzing time series data of climate extremes (minimum & maximum temperatures and precipitation) data. Historical data of climate extremes data were collected for Faisalabad. A total of 13 temperature and 11 precipitation indices, established by the Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI), were calculated using above data and RClimDex, a program written in the statistical software package R. A nonparametric Mann–Kendall test and Sen’s slope estimates were used to determine the statistical significance and magnitude of a trend, respectively.

Measurement of soil properties: Soil samples from all study sites were collected from 0-15, 15-30, 30-45, 45-60 and 60-75 cm depths to measure soil major physical (soil texture, bulk density), hydrological (soil moisture content, moisture content at field capacity and at permanent wilting point) and chemical (electrical conductivity, pH and soil organic carbon) attributes.

Physical attributes: Soil texture was determined using the hydrometer method. Forty gram (40 g) of air-dried soil was mixed with 60 mL of 2% sodium hexametaphosaphate solution as a dispersing agent. Distilled water (150 mL) was also added to the beaker to facilitate the reaction and dispersion. After 24 hours of incubation at room temperature (20 ºC), the suspension was stirred with a mechanical shaker for 10 minutes and transferred to 1000 mL graduated cylinder. After vigorous shaking with metal plunger, initial reading was taken after 40 second of the shaking and final reading was noted after 4 hours with a Bouyoucos Hydrometer (Modi *et al*. 1957). Soil texture analysis was determined by using textural class triangle of the International soil classification system (ISCS). Soil bulk density (ρ_b) was determined by using core method Grossman and Reinsch (2002). Non-destructive intact soil core samples were taken from 0-15, 15-30, 30-45, 45-60, and 60-75 cm depths using a core sampler known volume (V_t). Samples were oven-dried at 105 °C for 48 hours and weighed (M_s). The relationship $\rho_b = M_s/V_t$ was used to determine ρ_b (mg m^{-3}).

Hydrological attributes: Soil moisture content determinations were made for irrigation scheduling. Gravimetric method was used to determine θ by taking soil samples from 0-15, 15-35, 35-55 cm soil depths. The samples were weighed for their fresh weight after collection (M_w), oven-dried at 105 °C and weighed (M_d) for mass based θ determination as: θ (g) = $(M_w - M_d)/M_d$. Soil water content on volumetric basis (denoted by mass unit cm^3/cm^3) were determined by multiplying ρ_b with θ. Values of θ_{FC} were determined after free drainage was negligible i.e., soil water content at soil water potential less than -10 to -33 kPa. Similarly, θ_{FC}, portion of water retained in soil reservoir at which plants to sustain their lives, was determined at soil water potential equivalent to -1500 kPa.

Chemical attributes: Soil and water suspension was made at 1:1 (soil to water ratio) by shaking the mixture in a mechanical shaker for 20 minutes of each sample. Suspension was filtered using a high retention (40 micron) filter paper. Filtrate was then used to determine soil pH and EC with a multi-meter connected with the calibrated pH and EC electrodes. All measurements were made at room temperature (20 ± 2 ºC).

Soil Organic Carbon: Soil organic carbon was determined by loss on ignition (LOI) method. Since the top soil layers are the carbon reservoirs (Lal 2001) the samples collected from the top 15 cm soil layer were used to determine LOI (Konen *et al.* 2002). Triplicate soil samples 10 g were weighted with the use of electrical balance model HF-400/12627144. Air-dry soil samples sieved as < 2 mm diameter was placed in aluminum cans for oven-drying at 105 ºC for 24 hours. The samples were then cooled in a desiccator for a couple of hours then weighed (M_{105}). The loss on ignition test was carried out by using a muffle furnace (Model L-47T, West Germany, and following the standard procedure was adopted (Schulte and Hopkins 1996).

The samples were combusted at 550ºC for 5 hours (APHA 1995). The combusted samples were transferred to an oven at a temperature of 105 ºC for a couple of hours then taken out and cooled down in a desiccator. The samples were then weighed again (M_{550}). The LOI and percent SOM were calculated by using following equation (Navarro *et al*. 1993).

$$\mathrm{LOI}(\%) = \mathrm{SOM}(\%) = \left(\frac{M_{105} - M_{550}}{M_{105}}\right) \times 100$$

It was assumed that the SOM = [0.58]×SOC (Howard 1965). The values of SOC (%) were converted to mg of C ha^{-1} (mg C ha^{-1}), as the amount of SOC found in a soil layer of the depth *d* (cm) and bulk density ρ_b (g cm^{-3}), using the following relationship SOC (mg C ha^{-1}) = $d \times \rho_b \times$ SOC% (Baldock 2008).

Field activities: The selected fields were leveled and divided into three blocks at each site. Disc plough was used for primary tillage, cultivator for secondary tillage and finally planker was used for seed bed preparation. The commonly used local variety Monsanto-919 Hybrid was sown at all locations during the month of August with row to row distance of 75 cm and plant to plant distance of 25 cm in the experimental plots arranged under factorial experimental design. Sowing was done manually using three seeds per spot, which were thinned to one plant per spot after germination. Phosphorus in the form of total soluble phosphorous (TSP) was used at the rate of 100 kg ha^{-1} in all plots. Nitrogen (N) as urea was applied in splits with 1/3rd N at sowing and remaining 2/3rd in equal proportions at 15 days after sowing and at tasseling stage. All other cultural practices such as thinning, hoeing, irrigation and plant protection measures were kept similar at all sites. Table 1 summarizes crop husbandry operations at the three locations.

Biomass carbon content: Whole plant samples were collected from 1 m^2 area of all the three replicates after 15 days of interval leaving appropriate borders. For above-ground biomass determination the maize plants were separated into leafs, stems and cobs. Fresh weight of each plant component was measured separately by using an electrical balance. The samples were then allowed to air dry for two days. In the meanwhile, root part of the plants was separated from stems, carefully washed, wiped with a towel, and air dried for below-ground biomass determination. The fresh weight of roots was determined with an electrical balance.

Sub-samples of each above- and below-ground biomass fractions were oven-dried at 70 °C for three days to a constant weight. Weights of the oven-dried leaves, stem, cob and roots were individually recorded by using an electrical balance. Total dry matter (TDM) was obtained by summing weights of all the components. Carbon contents of above- and below-ground biomass were determined as:

Biomass carbon content =0.50 × organic biomass

Net carbon sequestration: Net carbon sequestration during the experimental growing season of autumn 2012 was determined by subtracting SOC values of pre-harvest soil samples from those of the post-harvest soil samples. Maize acreage of IAP was collected from the Statistics of Pakistan and Agricultural Departments. Per hectare values of CS were multiplied with IAP acreage to extrapolate the SOC values to IAP scale. Values for above- and below-ground CS potential were determined.

Statistical analysis: Mann-Kendall Test and Sen's Slope Estimates were used to detect significance level and extremes values of climate extremes. The above- and below-ground biomass data collected from three different locations were statistically analyzed by Analysis of Variance (ANOVA). The means were compared by least significance difference LSD.

RESULTS AND DISCUSSION

Climatic conditions of the study site: Mean monthly values of maximum and minimum temperatures of the 2012 growing season (August – November) were comparatively lesser than those observed during the historical period of 1973-2011. Precipitation distribution during the both periods (1973-2011) and 2012 growing season was different reflecting a seasonal shift. Precipitation in August 2012 was 38.5 mm as compared to the historical (1973-2011) average precipitation of August, i.e., 40 mm. Similarly, the observed precipitation during September 2012 (163.5 mm) was significantly higher than average precipitation (37.5 mm) of the period 1973-2011. November 2012 did not receive recordable precipitations. This concludes a comparatively drier 2012 growing season as compared to the historical data as observed by (Abbas *et al*. 2014).

Slope values of linear trends and their significance indicators derived from Mann-Kendall test and Sen's Slope estimates for the trend in temperature indices (i.e., TN10p, TN90p, TX10p, TX90p, TNn, TNx, TXn, TXx, DTR, CSDI, WSDI, SU25, and TR20) are given in Table 2. Indices calculations from the daily time series data of temperature extremes revealed statistically significant warming trends during the historical period.

Minimum number of heavy precipitation days when annual count of days of total precipitation ≥ 10 mm (R10) were 5 days during 1999. The maximum value of

R10 was 20 days that occurred during 1997. Mean R10 were 11.8 days that if converted to percent days per year during the base period of 1981-2010 become 3.24%. Minimum number of very heavy precipitation days when annual count of days of total precipitation ≥ 20 mm (R20) were 3 days during 1982, 1985, 1994, 1998, 1999, 2002, 2007, and 2009. The maximum value of R20 was 11 days that occurred during 1981. Mean R20 were 5.83 days that if converted to percent days per year during the base period of 1981-2010 become 1.49%.

The minimum values of very wet days (defined by index R95p, i.e., total precipitation when precipitation > 95th percentile) were 0 mm during the years 1982, 1985, 1986, 1993, 1995, 1996, 1999, 2000, and 2004. The maximum very wet days were 417 mm during 1997. Mean values for very wet days for the base period were calculated to be 98.3 mm. Similarly, the minimum values of extreme wet days (defined by index R99p, i.e., total precipitation when precipitation > 99th percentile) were 0 mm during the years 1981, 1992, 1997, 1998, 2005, and 2010. The maximum very wet days were 244 mm during 1997. Mean values for very wet days for the base period were calculated to be 28.7 mm. Simple daily intensity index (SDII), which is the annual total precipitation (mm day^{-1}) divided by the number of wet days when total precipitation of the day was ≥ 1.0 mm) in the year. Maximum value of SDII was 7 mm day^{-1} during the year 1999 and the minimum value was 19.7 mm day^{-1} during 1981 with the yearly mean of 11.8 mm day^{-1}.

July 1981 had the highest one-day precipitation. The precipitation was 180 mm per day. One-day lowest precipitation for the base period occurred during June 1982. The precipitation was only 25 mm. The highest and the lowest one-day precipitation in Faisalabad were respectively lower and greater than the province averages. July 1997 had the highest 5-day precipitation. The precipitation was 208 mm per day for the base period. Five-day lowest precipitation for the base period also occurred during June 1982. The precipitation was only 40 mm. The highest and the lowest 5-day precipitation in Faisalabad were respectively lower and greater than the province averages.

The minimum total wet days for Faisalabad during the base period were 806 during 1997. Maximum total wet days for Faisalabad during the base period were 155 during 1999. Mean total wet days per year for Faisalabad during the base period were 370.2. Therefore 1997 was the wettest year of the base period. The year 1999 was the driest year of the base period.

Soils of the study sites: Texture of NIAB soils is predominately clay loam, which is varies spatially from clay loam to loam horizontally and is silt clay loam at lower depths. Texture of Gojra site soil is predominantly silt loam and varies from loam to silt loam throughout the soil profile of 0-75 cm.

Soil of NIAB-I site is predominantly clay loam; loam followed by silt clay and sandy loam at increasing depths, i.e., 0-15, 15-30, 30-45, 45-60 and 60-75 cm (Table 3). The top two layers (0-15 and 15-30 cm) had the maximum ρ_b values (1.54 and 1.52 mg cm^{-3}, respectively) as compared to lower depths. Results showed that field capacity θ_{FC} contained same values of moisture content (32 cm^3/cm^3) at the depths 0-15, 15-30 and 30-45cm, while other two depths 30-45 and 60-75 cm had θ_{FC} equivalent to 30 and 22 cm^3/cm^3. The maximum values of θ_{WP} were observed at first and second and forth depths which were 18.6, 19.2 and 17.8 cm^3 cm^{-3} and the minimum θ_{WP} were at the lower depth 60-75 cm (Table 3). The θ_{WP} had maximum and minimum values at upper depth 18.2 and 8.4 at depths 0-15 and 45-60 cm accordingly. The maximum and minimum values of EC of the soil ranged from 0.48 to 0.35 dS m^{-1} at depths 1 and 2, respectively. Whereas, the soil pH varied from 7.96 to 8.25 at different depths have higher value (8.25) at shallow depth.

Soil of the NIAB-II site is mainly clay loam; loam followed by silt loam and sandy at depths 0-15, 15-30, 30-45, 45-60 and 60-75 cm respectively (Table 3). The maximum and minimum was ρ_b 1.56 and 1.38 at depths 0-15 and 60-75 cm was observed correspondingly. There was tendency of higher moisture content at FC at shallow soil layers than at deeper soil layers. The highest θ_{FC} (30 cm^3/cm^3) was at 0-15 cm and the lowest θ_{FC} (24 cm^3/cm^3) was 60-75 cm soil depth. Similar trend was observed for θ_{WP} as the highest θ_{wp} (18.2 cm^3/cm^3) was at 0-15 cm and the lowest θ_{wp} (12.8 cm^3/cm^3) was 60-75 cm soil depth. The values for EC and pH of NIAB-II soil ranged from 0.70 (at 45-60 cm depth) to 0.94 dSm^{-1} (at 0-15 cm depth) and from7.85 (at 45-60 cm depth) to 8.23 (0-15 cm depth), respectively.

The soil of Gojra are predominantly loam followed by silt loam, silt clay loam, and slid at depths 0-15, 15-30, 30-45, 45-60 and 60-75 cm respectively (Table 3). Its ρ_b decreased with increase in soil depth with the highest value (1.46 g cm^{-3}) at the top layer (0-15 cm) and the lowest value (1.40 g cm^{-3}) at the deepest soil layer (60-75 cm). The top soil layers were drier than the lower layers as at FC the values of θ were 22, 24, 28, 34 and 28 cm^3/cm^3 at the depths 0-15, 15-30, 30-45, 45-60 and 60-75 cm, respectively. The opposite was true in case of θ_{WP} as the maximum θ_{WP} was observed at 45-60 cm depth while the minimum θ_{WP} were at shallower soil layers (Table 3). The maximum EC of Gojra soil was 0.42 dS m^{-1} at 0-15 cm depth and the minimum value was 0.33 dS m^{-1}at 45-60 cm depth. The values of pH were found to be 7.65, 7.58, 7.66, 7.59 and 7.69 at 0-15, 15-30, 30-45, 45-60 and 60-75 cm soil depths, respectively. Average soil pH was more than 7 at the three study sites reflecting lower level of alkaline nature of soil which is good for crop growth. The soil EC values at the three sites were also in the normal range showing that the concentration of soil available nutrients was ideal for crop growth.

Soil organic carbon: The SOC values prior to cultivation at all soil depths of the three experimental sites were lower than those observed after harvest (Fig. 1). Both the pre-cultivation and post-harvest values of SOC significantly decreased, as indicated by different LSD letters and error bars with increase in soil depth at all the sites. Resultantly, the highest SOC value prior to cultivation (9.39, 6.80, 7.63 mg ha^{-1} and 2.03, 1.60, 3.25 mg ha^{-1}) as well as after harvest (16.17, 14.56, 14.51 mg ha^{-1} and 5.31, 4.45, 5.72 mg ha^{-1}) respectively at NIAB-I, NIAB-II, and Gojra were recorded at the shallow soil layers (i.e., top 0-15 cm) and the lowest values of SOC were observed at the deeper soil layers (i.e., 60-75 cm). Soil carbon has a direct correlation with soil quality. The NIAB-I side had higher SOC because it had predominantly clay loam to loam texture since the C pools are strongly associated with clay particles and non-crystalline minerals that stabilize and protect organic matter (Paul 1984; Torn *et al*. 1997).

The pre-cultivation SOC is sourced from previous agricultural activities. Variation in SOC with soil depth may be due to variation in ρ_b values at varying depths (Table 3) as observed by (Abbas and Fares 2009) who reported an increase in carbon pools with increase in ρ_b.(Abbas and Fares 2009) argued that a decrease in CO_2 emission with an increase in ρ_b is due to temporarily stable soil aggregates that hold SOC tightly within the aggregates and protect it against microbial processes unless the aggregates are disturbed with tillage and other agricultural practices.

Soil bulk density decreases as the soil depth increases. As previous studies revealed top 20 and 30 cm soils layers typically have the highest concentration of SOC (Spain *et al*. 1983; Burke *et al*. 1989). The post-harvest values of SOC showed a reasonable amount of carbon sequestered. Upper layers relatively sequestered more SOC as compared to lower depths as shown in the figure for site NIAB-I, NIAB-I1 and Gojra.

Aboveground Biomass and biomass carbon: The result of above-ground biomass, grain yield and carbon content at three site presented (Fig. 2a). The higher biomass was 19.3 and 19.2 mg ha^{-1} observed with respects to NIAB -1 and Gojra, a non-significance difference was found between two sites NIAB -1 and Gojra. The biomass was lower 16.4 mg ha^{-1} at NIAB-II which indicated that a significance difference of biomass was found with respect to NIAB-I and Gojra.The above-ground carbon content was calculated 9.6, 8.21 and 9.61 mg ha^{-1} at NIAB-I, NIAB-II and Gojra respectively as literature (Freibauer *et al*. 2004; Smith 2004) reported that crops maize, sugar beets, potatoes and winter wheat are the potential source of carbon sequestration.

The measured values of carbon content at sites NIAB-I, NIAB-II and Gojra were 9.6, 8.21 and 9.61 mg ha^{-1} respectively (Fig. 2a). The higher values of carbon content were 9.6 and 9.61 mg ha^{-1} at NIAB-I and Gojra respectively while site NIAB-II reflecting lower carbon content as compared to other sites. The results of statistical analysis of measured carbon content were also shows significance difference $p<0.05$ in values of carbon content of the three locations. The biomass carbon content was relatively higher at NIAB-I site as compared to NIAB-II and Gojra. The carbon content depends on the biomass. If biomass will be higher than carbon content must be higher. The grain yield observed at different soil type 7.50, 6.13 and 7.73 mg ha^{-1}at locations NIAB-I, NIAB-II, Gojra. Grain yield was found significantly higher 7.50 mg ha^{-1}at NIAB 1 and Gojra 7.73 mg ha^{-1} as compared to NIAB-II with minimum grain yield was 6.13 mg ha^{-1} (Fig. 2a). The non-significance difference was found between NIAB-I and Gojra because both sites had closed value of grain yield 7.50 and 7.73 mg ha^{-1} respectively. A significance difference was noted at NIAB-II Site with respect to NIAB-I and Gojra.

Below-ground Biomass and biomass carbon: The analysis of root biomass indicated the closet values of root-biomass at three sites. The root biomass was 3.0, 2.5 and 2.9 mg ha^{-1} at NIAB-I, NIAB-II and Gojra respectively. A non-significance difference was found at NIAB-I, NIAB-II and Gojra regarding to root biomass (Fig. 2b).

The analysis of belowground carbon indicated the closet values of carbon content at three sites. A non-significance difference was found at NIAB-I, NIAB-II and Gojra regarding to belowground carbon content. The belowground carbon content give average carbon content values were 1.5, 1.3, and 1.4 regarding to site NIAB-I, NIAB-II and Gojra, respectively, as it was found similar to (Amos and Walters 2006) corn root biomass carbon which is varying from 1.5 and 4.4 mg C $ha^{-1}year^{-1}$. Statistical analysis also indicated that there was non-significance difference (p=0.3) at NIAB-I, NAIB-II, and Gojra location. Three locations have closet values of below-ground biomass carbon. The Fig. 2b also gives the comparison of above and belowground carbon content. All three sites aboveground carbon content having higher values as compared to below ground carbon content. The reason is that above ground biomass is higher because it is included all leaves, stem and cob biomass, while below ground biomass have only just one root biomass. Carbon content directly depends on organic biomass, that's why a significance difference in quantity of above and below-ground carbon was observed (Fig. 2b).

Estimation of carbon stocks of maize acreage in Punjab: The maize acreage data were collected from Bureau of Statistics, Punjab, Lahore (http://www.bos.gop.pk/). Using mean of sequestered carbon values, it was calculated that a total of 10,497 mg of C is sequestered during every growing season of maize in irrigated agriculture of the Punjab province of Pakistan.

Table 1. Dates (dd.mm.yy) of crop husbandry operations at the Nuclear Institute of Agricultural Biology Faisalabad (NIAB-I and NIAB-II) and Gojra locations.

Operations	NIAB-I	NIAB-II	Gojra
Sowing date	10.08.12	09.08.12	14.08.12
Crop establishment	16.08.12	15.08.12	22.08.12
Phosphorous (P) and potassium (K) applications			
P (SSP) @ 100 kg ha^{-1}	10.08.12	08.08.12	14.08.12
K (SOP) @100 $kgha^{-1}$	10.08.12	08.08.12	14.08.12
N (Urea) application (Nitrogen was applied in three doses in all treatments)			
1st dose	10.08.12	08.08.12	14.08.12
2nd dose	25.08.12	22.08.12	28.08.12
3rd dose	28.09.12	27.09.12	04.10.12
Hand weeding	30.08.12	24.08.12	30.08.12
Plant protection measures (Application of Furadan @ 25 kg ha^{-1})			
1	01.09.12	27.08.12	04.09.12
2	12.10.12	09.10.12	15.10.12
Irrigations			
1	10.08.12	09.08.12	14.08.12
2	16.08.12	15.08.12	22.08.12
3	28.08.12	22.08.12	28.08.12
4	02.09.12	31.08.12	06.09.12
5	16.09.12	14.09.12	20.09.12
6	30.09.12	28.09.12	04.10.12
7	14.10.12	12.10.12	18.10.12
8	29.10.12	25.10.12	30.10.12
Final harvest	27.11.12	15.11.12	06.11.12

Table 2. Slope values and significance levels of linear trends developed on averaged annual anomalies of temperature indices for the selected cities and analysis period 1981-2010.

Indices	Indicator name, unit	Definitions	Slopes, significance
TN10p	Cool night frequency, %	Percentage of days with TN < 10th percentile	– 0.53***
TN90p	Hot night frequency, %	Percentage of days with TN > 90th percentile	0.64***
TX10p	Cool day frequency, %	Percentage of days when TX < 10th percentile	– 0.13
TX90p	Hot day frequency, %	Percentage of days when TX > 90th percentile	0.48**
TXn	Minimum Tmin (Coldest night), ºC	Monthly minimum value of daily temperature	– 0.07*
TXx	Maximum Tmin (Hottest night), ºC	Monthly maximum value of daily maximum temperature	0.03
TNn	Minimum Tmax (Coldest day), ºC	Monthly minimum value of daily minimum temperature	0.058*
TNx	Maximum Tmax (Hottest day), ºC	Monthly maximum value of daily minimum temperature	0.059*
DTR	Diurnal temperature range, ºC	Mean of the difference between TX and TN	– 0.03**
CSDI	Cold days (cold spell duration indicator), days	Annual count of days with at least 6 consecutive days when TN < 10th percentile	– 0.55***
WSDI	Warm days (warm spell duration indicator) , days	Annual count of days with at least 6 consecutive days when TX > 90th percentile	0.45*
SU25	Summer days, days	Annual count when TX(daily maximum) > 25 ºC	0.49+
TR20	Tropical night, , days	Annual count when TN(daily minimum) > 20 ºC	0.90***

+Significance level <= 90%. *Significance level <= 95%. **Significance level <= 99%. ***Significance level <= 99.9%.

Table 3. Depth-wise values of soil physical properties and hydrological attributes of NIAB-II site

Depth(cm)	Sand %	Clay %	Soil Texture	ρ_b g cm^{-3}	θ_{FC} cm^3/cm^3	θ_{WP} cm^3/cm^3	EC dS m^{-1}	pH
NIAB-I								
0-15	26	10	Clay loam	1.54	32	18.6	0.48	8.25
15-30	22	10	Clay loam	1.52	32	19.2	0.35	7.96
30-45	29	12	Loam	1.40	30	15.6	0.41	8.08
45-60	46	30	Silt clay loam	1.44	32	17.8	0.46	8.19
60-75	56	12	Sandy loam	1.40	22	9.4	0.44	8.18
NIAB-II								
0-15	38	28	Clay loam	1.56	30	18.2	0.94	8.23
15-30	30	24	Loam	1.39	30	15.6	0.83	8.11
30-45	48	22	Loam	1.40	26	14.8	0.72	8.04
45-60	38	10	Silt loam	1.42	24	8.40	0.70	7.85
60-75	54	18	Sandy loam	1.38	24	12.8	0.75	8.02
Gojra								
0-15	50	10	Loam	1.46	22	8.4	0.37	7.65
15-30	40	10	Silt Loam	1.42	24	8.6	0.42	7.58
30-45	22	12	Silt Loam	1.42	28	9.6	0.39	7.66
45-60	18	32	Silt clay Loam	1.40	34	20.0	0.33	7.59
60-75	14	4	Silt	1.40	28	5.4	0.35	7.69

ρ_b = bulk density; θ_{FC} & θ_{WP} = moisture contents at field capacity & wilting point, respectively; EC = electrical conductivity.

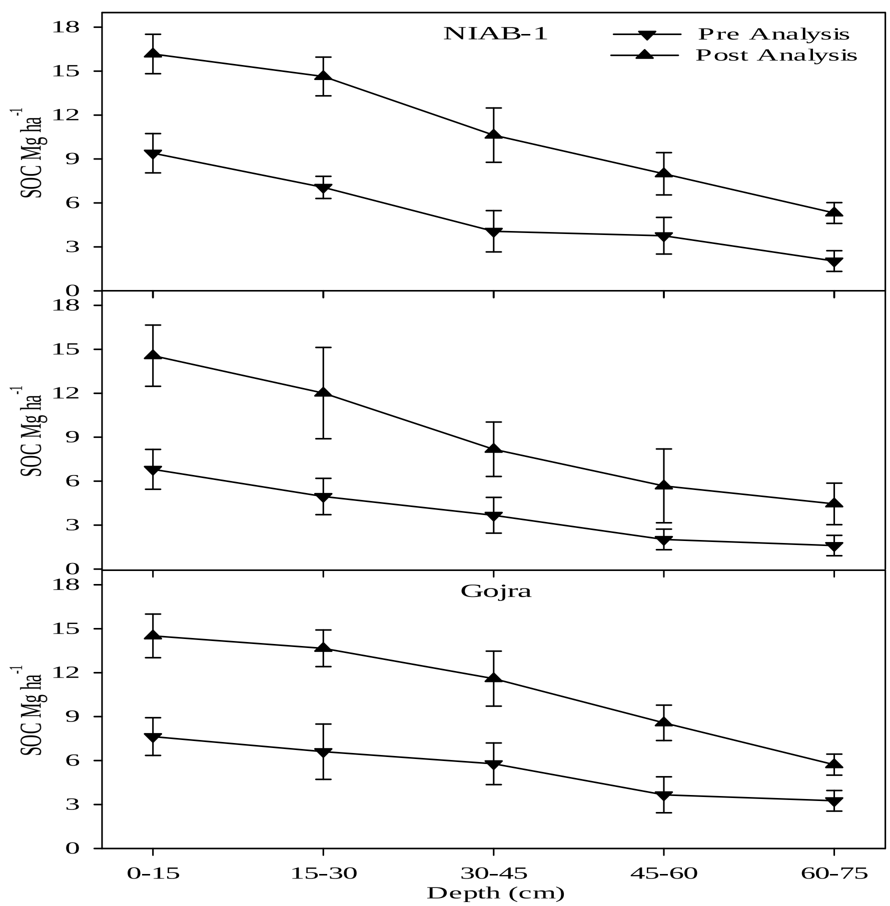

Figure 1. Pre-cultivation and post-harvest soil organic carbon (SOC) values of the samples collected from NIAB-I (top) , NIAB-II (middle), and Gojra (bottom) sites. The samples were collected from 0-15, 15-30, 30-45, 45-60, and 60-75 cm soil depths.

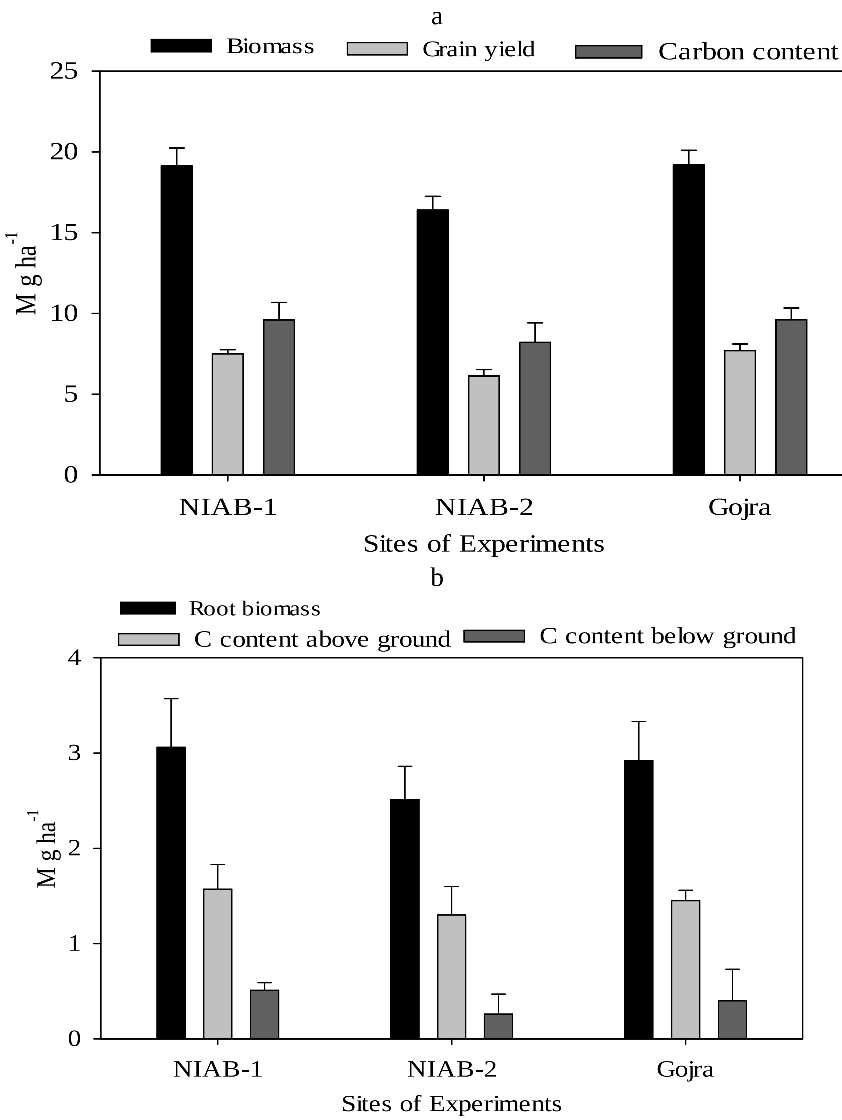

Figure 2. a) Above-ground maize biomass, grain yield and carbon content at NIAB-I, NIAB-II and Gojra sites; b) Below-ground maize biomass, above and below ground carbon content at NIAB-I, NIAB-II and Gojra.

Conclusion: A key conclusion from this research has been that agricultural soils in irrigated areas of Punjab have a potential to sequester carbon that can be derived from maize crop. Three sites of Faisalabad NIAB-I, NIAB-II and Gojra were analyzed for carbon sequestration and quantification of above and belowground biomass carbon. These three locations have considerable amount of biomass carbon 9.6, 8.21, and 9.61 mg ha^{-1}at NIAB-I, NIAB-II and Gojra, respectively. It shows that above ground biomass of maize can store average 9.14 mg ha^{-1} carbon. The average below-ground biomass carbon at three locations was 1.4 mg ha^{-1}. The above-ground biomass can store large amount of carbon as compared to below-ground biomass. Using mean of sequestered carbon values and assuming similar conditions in the rest of irrigated agriculture of Punjab - Pakistan, a total of 10,497 mg of C can be sequestered during every growing season of maize. Based on literature (Abbas *et al.* 2014) in semi-arid region of irrigated Punjab, where maize is commonly grown and there is no significant change in historical (1981-2010) trends of precipitation. Changes in temperature extremes alone do not affect carbon sequestration phenomenon. Soils and agricultural practices in this region are similar. With these prevailing conditions above estimates of carbon sequestration in irrigated the Punjab province of Pakistan are valid.

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