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# Impact of nitrogen fertilization on soil respiration and net ecosystem production in maize

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**ABSTRACT**

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Agriculture in the semi-arid is often challenged by overuse of nitrogen (N), inadequate soil water and heavy carbon emissions thereby threatening sustainability. Field experiments were conducted to investigate the effect of nitrogen fertilization levels ($N_0$ – 0, $N_{100}$ – 100, $N_{200}$ – 200, $N_{300}$ – 300 kg N/ha) on soil water dynamics, soil respiration (Rs), net ecosystem production (NEP), and biomass yields. Zero nitrogen soils decreased Rs by 23% and 16% compared to $N_{300}$ and $N_{200}$ soils, respectively. However, biomass yield was greatest under $N_{300}$ compared with $N_0$, which therefore translated into increased net primary production by 89% and NEP by 101% compared to $N_0$. To a lesser extent, $N_{200}$ increased net primary production by 69% and net ecosystem production by 79% compared to $N_0$. Grain yields were greatest under $N_{300}$ compared with $N_{100}$ and $N_0$, which therefore translated into increased carbon emission efficiency (CEE) by 53, 39 and 3% under $N_{300}$ compared to $N_0$, $N_{100}$ and $N_{200}$ treatments, respectively. There appears potential for 200 kg N/ha to be used to improve yield and increase CEE.

**Keywords**: $CO_2$ emission; C sequestration; N rates; terrestrial ecosystem; management practice; greenhouse gases

Soil respiration is the largest pathway by which carbon (C) is lost from the soil to atmosphere in terrestrial ecosystems (Raich and Mora 2005). Slight changes in the amounts of soil C released potentially affect atmospheric $CO_2$ concentrations (Shi et al. 2012). Numerous studies have shown that nitrogen (N) fertilization can increase net ecosystem production (NEP), an indicator of ecosystem C sequestration (Janssens et al. 2010). Bowden et al. (2004) found that increased N fertilization depressed soil $CO_2$ emissions, Fernández-Luqueño et al. (2009) reported increased in soil respiration with increased N fertilization, whilst Lee et al. (2007) reported neutral or non-significant effects. There is the need to identify and implement N management practices that can sustainably improve crop yields while also reducing the impact of N on the environment. Strategies effective for reducing greenhouse gas emissions include reducing N application rates (Ayeni 2010). However, it needs to be in accordance with the increasing worldwide demand for food, which creates economic pressure towards more intensive agriculture (Canfield et al. 2010). The objective of this study was to determine the effects of different nitrogen application rates on grain and biomass yield and its influence on soil water content, soil respiration, carbon emission efficiency and net ecosystem production.

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## MATERIAL AND METHODS

**Study site**. The study was conducted in 2014, 2015 and 2016 cropping season under field condition at Experimental Station of Gansu Agricultural University located in Gansu province, North-West China. The area is characterized by a hilly landscape and is prone to erosion. The aeolian soil in that region is locally known as Huangmian (Chinese Soil Taxonomy Cooperative Research Group, 1995), which equates to a Calcaric Cambisol in the FAO (1990) soil classification, and is primarily used for cropping (Zhu et al. 1983). The soil is a sandy loam with ≥ 50% sand, and has moderately low fertility, slightly alkaline pH (≈ 8.3), soil organic carbon ≤ 7.65 g/kg, and Olsen-P ≤ 13 mg/kg. In crop season rainfall recorded at the site was 280 mm in 2014, 274 mm in 2015 and 227 mm in 2016 (Figure 1).

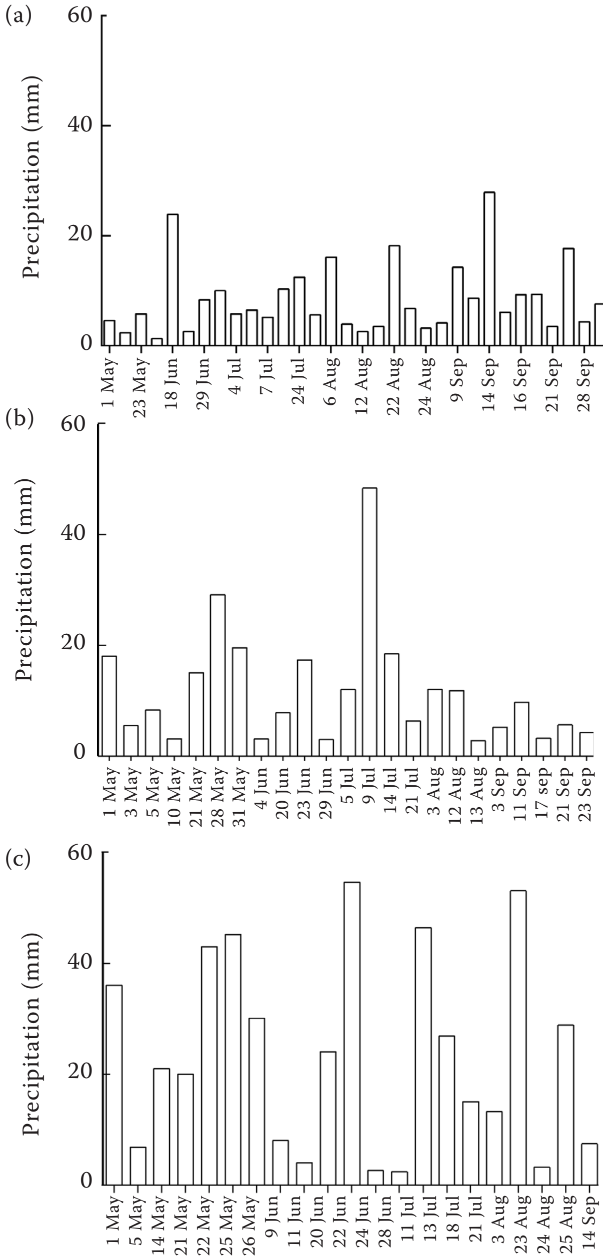


Figure 1. Daily precipitation for (a) 2014, (b) 2015 and (c) 2016 cropping season

**Experimental design**. The experiment used a randomized complete block design with four treatments and three replications. Treatments were: Zero-nitrogen ($N_0$); 100 kg/ha ($N_{100}$); 200 kg/ha ($N_{200}$) and 300 kg/ha ($N_{300}$) of nitrogen, respectively. Experiment was conducted on three consecutive years with the same treatments performed on the same plots all years under field conditions. Maize stover was removed for animal feed in all the years; it is the normal practice in the community. Pre-plant application of 300 kg N/ha is the standard farmers' practice in the region. Nitrogen fertilizer was applied in the form of urea (460 g N/kg) in two splits, as follows: ⅓ full rate corresponding to the treatment at sowing and the remaining ⅔ pre-anthesis. There were a total of 12 plots (plot's dimensions: 3.3 m × 8.5 m) with alternate wide and narrow ridges (0.7 m and 0.4 m wide, respectively) as described by Lamptey et al. (2017). All the ridges were covered with plastic film to increase soil temperature and speed-up germination, and also to reduce evaporative losses (Gan et al. 2013). The experiment was initiated in 2012; however, this article reports the experimental data for the 2014, 2015 and 2016 cropping seasons.

**Measurement and calculation**. Gravimetric water content (0–30 cm depth) was measured using the oven-drying method (Ferraro and Ghersa 2007). Gravimetric water content (0–30 cm) was multiplied by soil bulk density (1.25 ± 0.042 g/cm$^3$) to obtain the volumetric water content.

Soil surface respiration (Rs) was measured using an EGM-4 (British PP Systems, Norfolk, UK) portable $CO_2$ analyzer. The Rs was measured between 08:00–11:00 h as recommended by Alves et al. (2012) so as to capture diurnal patterns of high microbial activity. Three measurements were taken from each plot at each sampling time to reduce the effects of environmental variation (Hu et al. 2016) and the mean was used for statistical analysis.

Carbon emission (CE) was estimated based on Rs using the following equation described by Lamptey et al. (2017):

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$$CE = \sum\left[\left(\frac{Rs_{i+1} + Rs_i}{2}\right) \times (t_{i+1} - t_i) \times \times 0.1584 \times 24\right] \times 0.2727 \times 10 \quad (1)$$

Where: Rs – soil respiration (μmol $CO_2/m^2/s$) measured at biweekly intervals in growing season, i + 1 and i – previous and the current sampling date; t – days after sowing. 0.1584 converted μmol $CO_2/m^2/s$ to g $CO_2/m^2/h$, 0.2727 converted g $CO_2/m^2/h$ to g $C/m^2/h$, and 24 and 10 were to convert g $C/m^2/h$ to kg/ha for the growing season.

To quantify grain yield per unit of carbon emission, carbon emission efficiency (CEE) which was expressed as follows (Lamptey et al. 2017):

$$CEE = \text{grain yield (kg/ha)}/\text{carbon emission (kg/ha)} \quad (2)$$

**Carbon sequestration**. Net ecosystem production was estimated using the following equation described by Hu et al. (2016):

$$NEP = GPP - Ra - Rs \quad (3)$$

$$NPP = GPP - Ra - Rr \quad (4)$$

Merging Eqs. (3) and (4):

$$NEP = NPP + Rr - Rs \quad (5)$$

Where: Rs – soil respiration; GPP – gross primary production; NPP – net primary production; Ra – above ground respiration of the plants; Rr – root respiration of the plants.

By using Eq. (5), C flux from the atmosphere to the soil-plant system was calculated by measuring the NPP, Rr and Rs. The NPP for maize was estimated by the equation: C (kg) = 0.446 × DW (kg) – 67, as documented by Osaki et al. (1992). The Rr was calculated using the equation: RC = –0.66 + 0.16ln (Rs), $R^2 = 0.38$, $P < 0.001$, where RC means the annual relative contribution of Rr to Rs (Lamptey et al. 2017).

Carbon sequestration (carbon capture and storage) capacity was calculated using equation described by Iqbal et al. (2009) and Hu et al. (2016):

$$\text{Carbon sequestration} = NEP - \text{harvest crop} \quad (6)$$

At physiological maturity, grains were separated and weighed, and the grain yield per hectare for each treatment was deduced at 12% moisture content. The biomass yield per hectare for each treatment was also extrapolated.

**Statistical analysis**. Statistical analyses were undertaken with the Statistical package for the Social Sciences 22.0 (IBM Corporation 2013, Armonk, USA) with the treatment as the fixed effect and year as random effect. Differences between means were determined using Tukey's honestly significant difference test.

## RESULTS AND DISCUSSIONS

**Soil water content**. Soil water content (0–30 cm) differed at some sampling dates in 2014–2016 (Figure 2). The highest soil water content peaked

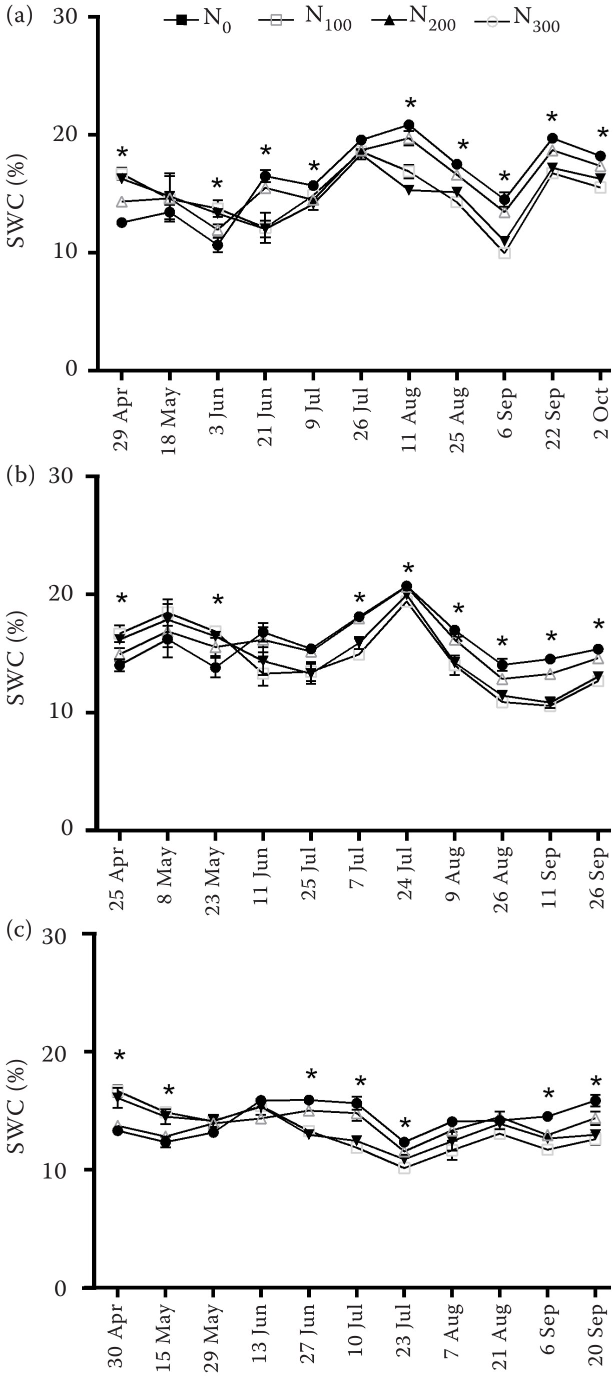


Figure 2. Seasonal variations of average soil water content (SWC) measured from late 29 April to late September and early October in (a) 2014, (b) 2015 and (c) 2016 from maize under different nitrogen rates. Asterisk denotes significance difference across treatment. $N_0$ – no nitrogen; $N_{100}$ – 100, $N_{200}$ – 200, $N_{300}$ – 300 kg N/ha

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in July and August, which corresponded with the highest precipitation (Figure 1). Air temperature for 2014–2016 is shown in Figure 3. There were significantly higher soil water contents in $N_{100}$ and $N_0$ at certain sampling stages (i.e., milking and maturity). According to Ritchie et al. (1997), milking stage in maize developmental stage is when the middle kernels are milky and yellowish. Maturity stage is when the black layer is visible, fully ripe, kernels hard and shiny). On average, SWC (0–30 cm) was ≈ 9% and ≈ 8% higher in $N_0$ than $N_{300}$ and $N_{200}$, respectively. Soil water content within that depth range decreased in the order: $N_0 > N_{100} > N_{200} > N_{300}$, respectively. Studies (e.g., Gao et al. 2010), showed that about 50–60% of the roots' biomass of maize is found in the upper part of the soil profile (≤ 40 cm deep). Therefore, increasing

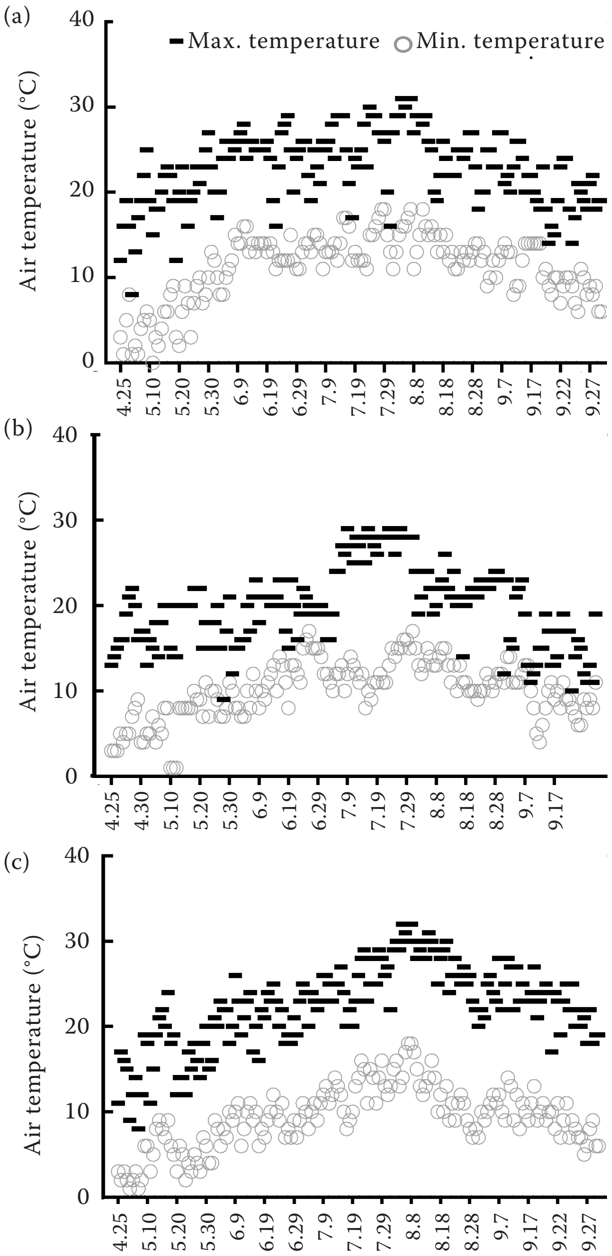


Figure 3. Minimum and maximum air temperature for (a) 2014, (b) 2015 and (c) 2016 cropping season

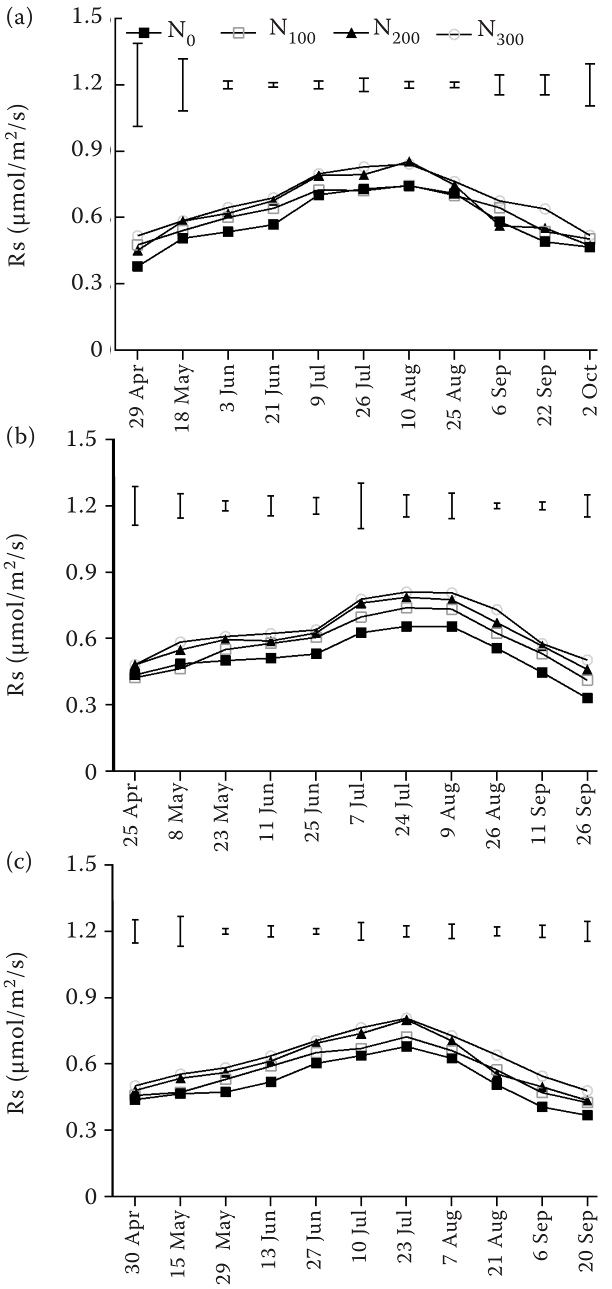


Figure 4. Seasonal variations of soil respiration (Rs) rates measured from late April to late September and early October in (a) 2014, (b) 2015 and (c) 2016 from maize under different nitrogen rates. Bars are the *LSD* (least significant difference) across treatments at each sampling time. $N_0$ – no nitrogen; $N_{100}$ – 100, $N_{200}$ – 200, $N_{300}$ – 300 kg N/ha

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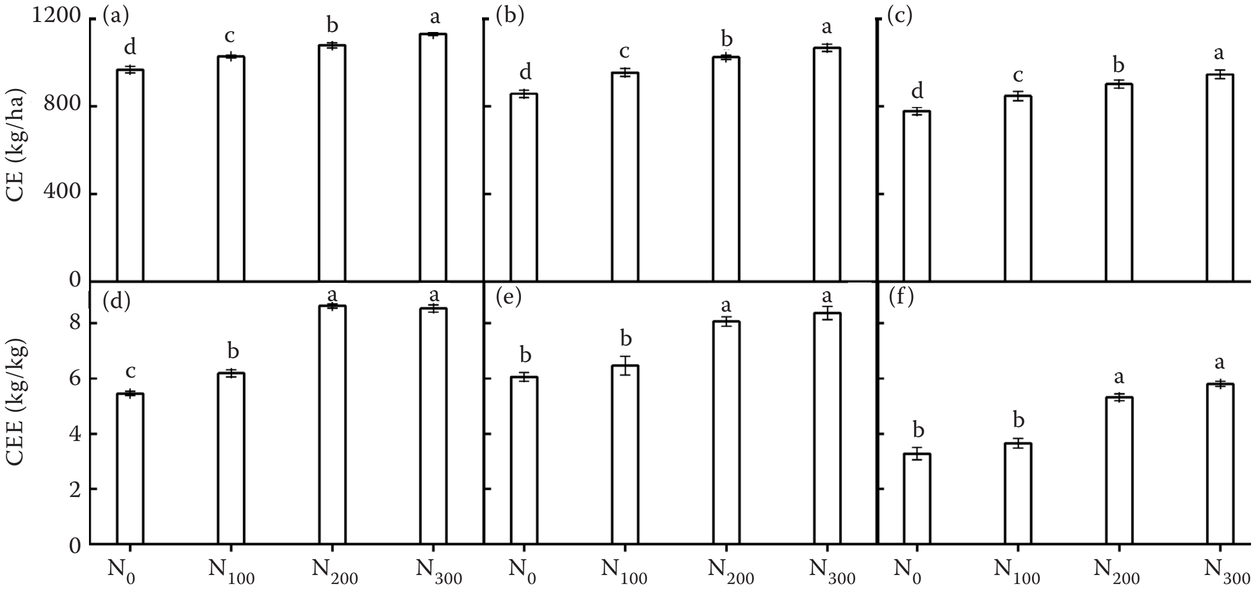


Figure 5. Carbon emission (CE) measured in (a) 2014, (b) 2015 and (c) 2016 and carbon emission efficiency (CEE) in (d) 2014, (e) 2015 and (f) 2016 from maize under different nitrogen rates. Bars with different letters in the figure are statistically different at $P < 0.05$. Error bars represent the standard error of means. Means comparison was done using Tukey *HSD* (honestly significant difference) ($P < 0.05$). $N_0$ – no nitrogen; $N_{100}$ – 100, $N_{200}$ – 200, $N_{300}$ – 300 kg N/ha

soil water content at this rooting depth should also increase uptake of water and nutrients by crops. Higher soil water contents in $N_0$ and $N_{100}$ plots recorded at certain sampling stages (i.e., milking to maturity) is as a result of lower aboveground biomass. The lower aboveground biomass reduced water loss through evapotranspiration compared with $N_{300}$ and $N_{200}$ treated crops (Nielsen and Halvorson 1991).

**Soil respiration and carbon emission**. Soil respiration fluxes were highest throughout July and into August, when soil water and temperatures were also high, and lowest in April when soil water and temperatures were lower (Figure 4). The emission values for the peaks ranged from 0.74–0.85 μmol/m$^2$/s in 2014 (Figure 2a), from 0.66–0.85 μmol/m$^2$/s in 2015 (Figure 2b) and from 0.67–0.82 μmol/m$^2$/s in 2016 (Figure 4c). Significant effects ($P < 0.05$) of N rates on soil respiration were observed on seven, eight and nine occasions in 2014, 2015 and 2016, respectively. The control plots ($N_0$) recorded the lowest carbon emission value of 968 kg/ha in 2014, 858 kg/ha in 2015 and 779 kg/ha in 2016, which were 17, 24 and 21% lower ($P < 0.05$), respectively compared to the $N_{300}$ (Figure 5a,b,c). Our results agree with the findings by Meng et al. (2006) who demonstrated that Rs of maize changed with crop growth, peaked in July and then declined gradually. Soil respiration positively correlated with biomass yield ($r$ = 0.972* and 0.990*) and grain yield (0.935; 0.980*) (Table 1), which was consistent with other studies (e.g., Yeboah et al. 2016). The increased soil respiration and carbon emission with increased N fertilization could be attributed

Table 1. Relationship between biomass yield, grain yield, soil respiration and soil water content

| Treatment | Biomass yield | | | Grain yield | | | Soil respiration | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 |
| Soil water content | –0.981* | –0.982* | –0.927* | –0.997** | –0.991** | –0.94 | –0.908 | –0.945 | –0.984* |
| Biomass yield | | | | 0.992** | 0.998** | 0.982* | 0.972* | 0.990* | 0.952* |
| Grain yield | | | | | | | 0.935 | 0.980* | 0.887 |

*$P < 0.05$; **$P < 0.01$

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Table 2. Net primary production (g C/m²/season) and net ecosystem production (g C/m²/season) in maize under different nitrogen (N) rates

| Treatment | Net primary production | | | Net ecosystem production | | |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 |
| $N_0$ | 655.44$^{b}$ | 514.80$^{c}$ | 194.61$^{c}$ | 573.56$^{b}$ | 443.45$^{c}$ | 129.84$^{c}$ |
| $N_{100}$ | 803.78$^{b}$ | 665.29$^{b}$ | 262.01$^{bc}$ | 716.82$^{b}$ | 585.84$^{b}$ | 191.49$^{bc}$ |
| $N_{200}$ | 1053.01$^{a}$ | 902.86$^{a}$ | 354.22$^{ab}$ | 961.78$^{a}$ | 817.46$^{a}$ | 279.17$^{ab}$ |
| $N_{300}$ | 1145.73$^{a}$ | 1000.97$^{a}$ | 431.45$^{a}$ | 1050.12$^{a}$ | 912.03$^{a}$ | 352.67$^{a}$ |
| Source of variation | | | | | | |
| N | | ** | | | ** | |
| Year (Y) | | *** | | | *** | |
| N × Y | | ** | | | ** | |

Different letters within columns in the same year denote significance at $P < 0.05$. **$P < 0.01$; ***$P < 0.001$. $N_0$ – no nitrogen; $N_{100}$ – 100, $N_{200}$ – 200, $N_{300}$ – 300 kg N/ha

to improved crop biomass resulting in increased microbial decomposition of organic matter and root respiration (Hanson et al. 2000).

**Yields and carbon sequestration**. Analysis of variance showed that N application rate, year and their interaction had significant effects on biomass yield, grain yield, NPP, NEP and harvest C (Tables 2 and 4). Application of $N_{300}$ increased grain yield by 83% in 2014, by 72% in 2015, and by 123% in 2016 compared with $N_0$. Application of $N_{200}$ also significantly increased grain yield compared with $N_0$, but to a lesser extent relative to $N_{300}$ (Table 3). This is supported by the fact that increased ET under $N_{300}$ and $N_{200}$ resulted to more efficient conversion of that water into crop biomass and improved partitioning (Calviño et al. 2003). The highest N fertilization rates had the highest ($P < 0.05$) NPP, NEP and harvest C while $N_0$ had the lowest (Tables 3 and 4). The $N_{300}$ increased average NPP by 48.93%; NEP by 54.93% and harvest C by 51.51% compared to $N_{100}$. Smaller effects were observed for $N_{200}$, which increased average net primary productivity by 33.45%; NEP by 37.76% and harvest C by 28.03% compared to $N_{100}$. Negative carbon sequestration was found in all the treatments (Table 4). Nitrogen at 200 ($N_{200}$) and 300 ($N_{300}$) increased NPP and NEP compared to other treatments because of increased biomass (Ayeni 2010). Although N fertilization increased biomass yield, net carbon sequestration values were negative for all treatments which indicate that carbon loss by soil respiration was not recompensed by the quantity of residue returned to the soil. Differences between treatments were mainly due to nitrogen × water uptake effects on yield (Yin et al. 2014). Soil water content was negatively correlated with

Table 3. Biomass yield and grain yield (kg/ha) in maize under different nitrogen (N) rates

| Treatment | Biomass yield | | | Grain yield | | |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 |
| $N_0$ | 14.711$^{b}$ | 13.045$^{c}$ | 5.866$^{c}$ | 5.282$^{c}$ | 5.195$^{b}$ | 2.560$^{b}$ |
| $N_{100}$ | 18.037$^{b}$ | 16.419$^{b}$ | 7.377$^{bc}$ | 6.367$^{b}$ | 6.176$^{b}$ | 3.188$^{b}$ |
| $N_{200}$ | 23.625$^{a}$ | 21.746$^{a}$ | 9.444$^{ab}$ | 9.312$^{a}$ | 8.268$^{a}$ | 5.145$^{a}$ |
| $N_{300}$ | 25.704$^{a}$ | 23.946$^{a}$ | 11.176$^{a}$ | 9.655$^{a}$ | 8.931$^{a}$ | 5.711$^{a}$ |
| Source of variation | | | | | | |
| N | *** | | | *** | | |
| Year (Y) | *** | | | *** | | |
| N × Y | ** | | | ** | | |

Different letters within columns in the same year denote significance at $P < 0.05$. **$P < 0.01$; ***$P < 0.001$. $N_0$ – no nitrogen; $N_{100}$ – 100, $N_{200}$ – 200, $N_{300}$ – 300 kg N/ha

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Table 4. Carbon in harvested crops (g $C/m^2$/season) and carbon sequestration (g $C/m^2$/season) in maize under different nitrogen (N) rates

| Treatment | Harvested crops | | | Carbon sequestration | | |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 |
| $N_0$ | 669.35$^b$ | 593.54$^c$ | 266.89$^c$ | –95.79$^a$ | –150.08$^a$ | –137.05$^a$ |
| $N_{100}$ | 820.68$^b$ | 747.06$^b$ | 335.64$^{bc}$ | –103.86$^b$ | –161.22$^b$ | –144.15$^b$ |
| $N_{200}$ | 1074.94$^a$ | 989.44$^a$ | 429.72$^{ab}$ | –113.16$^c$ | –171.97$^c$ | –150.56$^c$ |
| $N_{300}$ | 1169.53$^a$ | 1089.52$^a$ | 508.51$^a$ | –119.41$^c$ | –177.49$^d$ | –155.83$^d$ |
| Source of variation | | | | | | |
| N | | ** | | | *** | |
| Year (Y) | | *** | | | *** | |
| N × Y | | ** | | | ** | |

Different letters within columns in the same year denote significance at $P < 0.05$. **$P < 0.01$; ***$P < 0.001$. $N_0$ – no nitrogen; $N_{100}$ – 100, $N_{200}$ – 200, $N_{300}$ – 300 kg N/ha

biomass yield (–0.981; –0.982*) and grain yield (–0.997**; –0.991**) (Table 1).

**Carbon emission efficiency**. Nitrogen at 300 ($N_{300}$) increased CEE by 53% and 39% ($P < 0.05$) whereas $N_{200}$ treatment increased by 49% and 35% compared with $N_0$ and $N_{100}$, respectively by increasing grain yield (Figure 5d,e,f). The increase in CEE under $N_{200}$ and $N_{300}$ treatment was due to the higher crop yield. Qin et al. (2013) observed increased CEE due to improved grain yield resulting from higher soil moisture availability. It is clear that developing and adopting more effective and efficient cropping systems has a key role to play in increasing crop yields while mitigating a significant amount of greenhouse gases in agriculture (Gan et al. 2014).

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