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Combined organic/inorganic fertilization enhance soil quality and increased yield, photosynthesis and sustainability of sweet maize crop

Aspasia Efthimiadou[1], Dimitrios Bilalis[2*], Anestis Karkanis[2], Bob Froud-Williams[1]

[1]University of Reading, School of Biological Sciences, Reading, Berksire, RG6 6AH, United Kingdom
[2]Agricultural University of Athens, Department of Crop Science, Iera Odos 75, 11855 Athens, Greece

[*]Corresponding Author: bilalisdimitrios@yahoo.gr

Abstract

A field experiment was conducted to determine the effects of inorganic and combined organic/inorganic fertilization on growth, photosynthesis and yield of a sweet maize crop (*Zea mays* L. F_1 hybrid Midas), under Mediterranean climatic conditions. A randomized complete block design was employed with four replicates per treatment (inorganic fertilizer (21-0-0), control and 12 combined organic (poultry, cow manure and barley) and inorganic fertilization (synthetic fertilizer: 21-0-0) treatments. The amount of N contributed to the soil *via* the different fertilization treatments was the same (240 kg N ha^{-1}). Organic soil amendments increased the level of soil organic matter and total nitrogen. The highest height, dry weight, leaf area index and yield were recorded with the cow manure treatments (with or without chemical fertilizer). Moreover, combined organic and inorganic fertilizers resulted in higher increase in photosynthetic rate and stomatal conductance compared with those found under inorganic fertilization. A high correlation coefficient (r=0.926, p<0.001) between yield and photosynthetic rate was found. Sustainability yield indices (sustainable yield index and agronomic efficiency) showed that the maize crop is more stable under combined organic and inorganic fertilization compared with mineral fertilization. Our results indicate that combined organic and inorganic fertilization enhances organic matter in soils and increases yield of sweet maize.

Keywords: Fertilization, Maize, Manure, Mulch, Organic, Sustainability.
Abbreviations: AE-Agronomic efficiency, BM-barley mulch, CM-cow manure, DAS-days after sowing, F-fertilizer, LAI-leaf area index, PM-poultry manure, SYI-sustainable yield index.

Introduction

Maintaining and improving soil quality is crucial if agricultural productivity and environment quality are to be sustained for future generations (Reeves, 1997). Intensive agriculture has had negative effects on the soil environment over the past decades (*e.g.* loss of soil organic matter, soil erosion, water pollution) (Zhao *et al.*, 2009). Management methods that decrease requirements for agricultural chemicals are needed in order to avoid adverse environment impacts (Bilalis *et al.*, 2009). The use of manure and mulching are two of the basic cultivation techniques of Organic Agriculture (Efthimiadou *et al.*, 2009). Moreover, emerging evidence indicates that integrated soil fertility management involving the judicious use of combinations of organic and inorganic resources is a feasible approach to overcome soil fertility constraints (Abedi *et al.*, 2010; Kazemeini *et al.*, 2010; Mugwe *et al.*, 2009). Combined organic/inorganic fertilization both enhanced C storage in soils, and reduced emissions from N fertilizer use, while contributing to high crop productivity in agriculture (Pan *et al.*, 2009). Tiwari *et al.*, (2002) have also reported that the inclusion of manure in the fertilization schedule improved the organic carbon status and available N, P, K and S in soil, sustaining soil health. Addition of organic materials of various origins to soil has been one of the most common practices to improve soil physical properties (Celik *et al.*, 2004). Combined use of NPK and farmyard manure increased soil organic matter, total N, Olsen P and ammonium acetate exchangeable K by 47%, 31%, 13% and 73%, respectively compared to application of NPK through inorganic fertilizers (Bhattacharyya *et al.*, 2008). Mando *et al.* (2005) also found that soil organic matter and crop performance was better maintained using organic material with a low C/N ratio (manure) than with a high C/N ratio (straw). In addition, Zhao *et al.* (2009) reported that farmyard manure combined with chemical fertilizer management resulted in a higher increase in maize yield, soil organic matter, available N and available P compared with those found under straw manure combined with chemical fertilizer management. Moreover, Mucheru-Muna *et al.* (2007) reported that tree marigold [*Tithonia diversifolia* (Hemsl.) A. Gray] with half recommended rate of mineral fertilizer gave the highest grain yield. The main objective of this study was to evaluate the effect of inorganic and combined organic and inorganic fertilization on soil properties, growth, photosynthesis and yield components of sweet maize. We also intended to evaluate the sustainability of maize crop under different organic-inorganic fertilization treatments.

Material and methods

Experimental design

Field experiments were carried out in southern Greece (Oropos, 60 km from Athens, Lat: 34^o, Long: 23^o) in 2005 and 2006. Sweet maize (*Zea mays* L.) F_1 hybrid (Midas) was planted. The experimental site had previously been cropped with vegetables. The soil was a clay loam. The experiments were carried out under semi-arid Mediterranean climatic conditions, where soils typically have low organic matter content and weak structure, resulting in low infiltration rates

Table 1. The effect of combined organic-inorganic fertilization on maize height (cm), plant dry weight (kg ha^{-1}) and leaf area index (LAI), 81 days after sowing

Treatment	Height		Plant dry weight		LAI	
	2005	2006	2005	2006	2005	2006
PM X/2+ F	150.75	133.5	10031	8106	1.64	0.67
PM X + F	146.75	139.75	8438	8281	1.17	0.60
PM 2X + F	141.75	141	7188	8750	1.01	0.94
CM X/2 + F	156.25	139.75	8906	8516	2.03	0.82
CM X + F	163.75	145.5	10625	9316	2.27	1.09
CM 2X	167.75	150.5	12266	11082	2.58	1.79
BM X/2 + F	154.75	136.75	10938	8555	1.57	0.70
BM X + F	141.75	139.5	11094	8570	1.18	0.86
BM 2X + F	138.25	145.75	15102	10176	0.94	1.41
PM X+ BM X+F	147.75	145.5	11406	9980	1.41	1.17
CM X+BM X+F	152.75	147.75	10938	10391	1.80	1.54
Fertlizer (21-0-0)	155.75	130	10491	7559	1.96	0.63
Control	134.75	126.25	5453	5859	0.35	0.31
$LSD_{5\%}$	7.51	2.34	298	311	0.02	0.09

PM: Poultry manure, CM: cow manure, BM: barley mulch, X=10 t ha^{-1}, F: fertilizer (21-0-0).

and low moisture retention. Some meteorological data of the experimental site are presented in Fig. 1. The precipitation during the growing season (April-August) in 2005 (151 mm) was higher than that in 2006 (76 mm). A randomized complete block design was employed with four replicates per treatment. The experiment was set up over an area of 2700 m^2. The plot size was 4.0 × 6.0 m. The three kinds of amendments used were: Cow manure (CM), poultry manure (PM), barley residues (B) and fertilizer (F). All were subjected to chemical analysis. The cow manure (1.21% nitrogen) that was used had undergone natural outdoor fermentation (composting) for 6-8 months. The poultry manure (0.74% nitrogen) was industrially processed, standardised and the dry product was used. Fresh barley mulch (0.69% nitrogen) was used which was harvested immature prior to flowering, just before the establishment of the experiments. Chemical fertilizer 21-0-0 (ammonium sulphate, $(NH_4)_2SO_4$) was also used. The incorporation after the establishment of the treatments (cow/poultry manure and barley mulch) was carried out twice with a rotary hoe in each plot separately. According to a literature search and local practice, the optimum level of nitrogen for the cultivation of sweet maize is 240 kg N ha^{-1}. The treatments used were: fertilization with 240 kg N ha^{-1} (fertilizer 21-0-0), poultry manure 5 t ha^{-1}(35 kg N ha^{-1}) + fertilizer (205 kg N ha^{-1}), poultry manure 10 t ha^{-1} (70 kg N ha^{-1}) + fertilizer (170 kg N ha^{-1}), poultry manure 20 t ha^{-1} (140 kg N ha^{-1}) + fertilizer (100 kg N ha^{-1}), cow manure 5 t ha^{-1} (60 kg N ha^{-1}) + fertilizer (180 kg N ha^{-1}), cow manure 10 t ha^{-1} (120 kg N ha^{-1}) + fertilizer (120 kg N ha^{-1}), cow manure 20 t ha^{-1} (240 kg N ha^{-1}), barley mulch 5 t ha^{-1} (35 kg N ha^{-1}) + fertilizer (205 kg N ha^{-1}), barley mulch 10 t ha^{-1} (70 kg N ha^{-1}) + fertilizer (170 kg N ha^{-1}), barley mulch 20 t ha^{-1} (140 kg N ha^{-1}) + fertilizer (100 kg N ha^{-1}), barley mulch (10 t ha^{-1}) + poultry manure (10 t ha^{-1}) + fertilizer (100 kg Nha^{-1}), barley mulch (10 t ha^{-1}) + cow manure (10 t ha^{-1}) + fertilizer (50 kg N ha^{-1}) and control (no treatment).

Planting, irrigation and weed control

The maize was sown manually. In 2005 and 2006, the maize was sown on the same dates (25/4/2005 and 25/4/2006). Maize was planted at an 80-cm row spacing and 16 cm plant spacing, at an approximate density of 78125 plants ha^{-1}. A sprinkler irrigation system (overhead irrigation) was used. Each irrigation dose was 50 mm (500 m^3 ha^{-1}) with an irrigation frequency of 3-7 days, depending on rainfall. Each irrigation lasted for 150 min. The weeds were destroyed and weed seed return was prevented by two inter-row cultivations with a rotary hoe during the experimental period. The weeds on the row were destroyed manually.

Samplings, measurements and methods

Organic matter was an important measurement because manure and mulches were incorporated into the soil. The organic matter was measured by the Walkey-Black method, for 0-15 cm depth for every plot (Walkey and Black, 1934). The total N was determined using the Kjeldahl method (Bremner, 1960). Three soil samples were taken of 100 cm^3 per plot. The Kjeldahl method was applied and a Buchi 316 device was used in order to combust and extract the soil samples. For the computation of leaf area, dry weight and height, 5 plants were randomly selected in each plot. The dry weights of all plant parts were determined after drying for 72 h at 65ºC. Leaf area was measured using an automatic leaf area meter (Delta-T Devices Ltd). Thus, the measurements on a per plant basis (cm^2 plant^{-1}) were converted into a leaf area index (LAI) by multiplying this value by the average crop density of each plot.For the computation of yield and yield components, 10 plants were harvested per plot and all yield measurements were made at 14% seed moisture content. 1000-Grain weight was estimated by randomly taking 4×100 grains from each plot which were then weighed and the average value multiplied by ten.

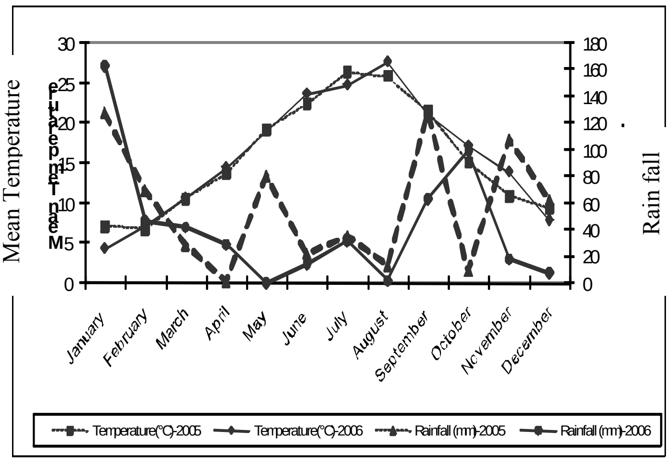

Fig 1. Meteorological data for the experimental site (temperature: °C and rainfall: mm).

Table 2. The effect of combined organic-inorganic fertilization on maize (kg ha^{-1}) yield, 1000-grain weight (kg), grain per rank, 81days after sowing.

Treatment	Yield		1000 grain weight		Grain per rank	
	2005	2006	2005	2006	2005	2006
PM X/2+ F	5475	2387	0.161	0.138	34	17.6
PM X + F	5291	2558	0.14	0.137	36.7	18.7
PM 2X + F	4670	3017	0.139	0.141	33.1	21.5
CM X/2 + F	4902	2890	0.150	0.140	31	21
CM X + F	5770	3196	0.161	0.141	35	22.7
CM 2X	6122	3602	0.164	0.145	36.2	24.5
BM X/2 + F	5582	2670	0.160	0.136	34	20.1
BM X + F	5203	2962	0.144	0.138	36.3	21.5
BM 2X + F	5070	3407	0.138	0.141	36.4	24
PM X + BM X + F	5236	3197	0.140	0.142	34.5	22.2
CM X + BM X + F	5627	3499	0.149	0.144	35.9	23.6
Fertlizer (21-0-0)	5801	2496	0.138	0.134	35.7	18.4
Control	2103	1703	0.126	0.124	18.1	15.2
$LSD_{5\%}$	187.42	74.25	0.001	0.009	1.5	1.1

PM: Poultry manure, CM: cow manure, BM: barley mulch, X=10 t ha^{-1}, F: fertilizer (21-0-0).

For the computation of grains per rank, ten ears per plot were measured.Measurements of photosynthetic rate (molCO_2 m^{-2} s^{-1}) and stomatal conductance (mol m^{-2} s^{-1}) were undertaken between the hours of 10.30 and14.30, with five measurements per plot, at 36, 51 and 66 days after sowing (DAS). Measurements were made using an LCi Leaf Chamber Analysis System (ADC, Biosientific, Hoddedson, UK). Sustainability indices (sustainable yield index, SYI, and agronomic efficiency, AE) were also calculated. The quantitative assessment of the sustainability of agricultural practices was developed by Singh *et al.* (1990). Agronomic efficiency was also developed by Novoa and Loomis (1981). The SYI and AE indices were calculated as follows:

$$SYI = \frac{Ym - Sd}{Ymax} \quad \text{and} \quad AE = \frac{Y - Yo}{Fn}$$

Where, *Ym i*s the mean yield, *Sd* the standard deviation, *Ymax* is the maximum yield obtained under a set of management practices, *Y* is the yield of a fertilized plot, *Yo* the grain yield in control plots and *Fn* is the amount of nitrogen applied, all expressed in the same units. Low values of Sd suggest the sustainability of the system (Bhattacharyya *et al.*, 2008).

Statistical analysis

The data were subjected to statistical analysis according to the randomized complete block design. Differences between treatment means were compared at *P*=5% with ANOVA in order to find the statistically significant differences and then LSDs were used to compare the plots. The statistical analysis of the data was realized using the STATGRAPHICS Plus 5.1 logistic package.

Results

Organic matter

In both years, 41 DAS, the lowest concentration (2.48% and 1.96%, in 2005 and 2006, respectively) of organic matter (*P*<0.05) was found in the control plot, while the highest was in the double rate cow manure treatment (Fig. 2). Organic matter content was proportionate to the amount of manure applied.

Total nitrogen

In both years, 41 DAS, the lowest concentration of total N (*P*<0.05) was found for the control plot (0.11% and 0.09%, in 2005 and 2006, respectively) and fertilizer treatment (0.16% and 0.13%, in 2005 and 2006, respectively), which was significantly different from the other treatments (Fig. 2). Total N was proportionate to the amount of manure applied.

Height and LAI

The height measurements (81 DAS) of 2005 demonstrated that the plants in the control plots remained shorter (134.75 cm) in comparison to those under other treatments (*P*<0.05). Plant height in the barley mulch+fertilizer plots was similar to that in the control plots (Table 1). In 2006, all treatments produced taller plants than the control. The double rate cow manure plot gave the tallest plants (150.5 cm) and the control the shortest (126.25 cm). In 2005, the LAI was least for the untreated control (0.35) and greatest for double cow manure treatment (2.58 cm). In the 2006 experiment, the lowest LAI (*P*< 0.05) was again obtained for the control and the highest for the double rate cow manure treatment. LAI increased as the amount of poultry manure, cow manure and barley mulch increased (Table 1).

Dry weight

In 2005, the lowest dry weight was measured in the control plots (5453 kg ha^{-1}) and the highest with double cow manure (12266 kg ha^{-1}) and double barley mulch+fertilizer (15102 kg ha^{-1}) treatments (*P*<0.05). The fertilizer treatment was better than all poultry manure+fertilizer treatments (Table 1). In 2006, the control treatment had the lowest dry weight (5859 kg ha^{-1}), and the double rate cow manure procuded the highest biomass (11082 kg ha^{-1}). The dry weight under fertilizer treatment was lower than that with all organic fertilizer+fertilizer (21-0-0) treatments.

1000-Grain weight

In 2005, the lowest values of 1000-grain weight (0.126 kg) were obtained with the untreated control (*P*<0.05). The greatest value (0.164 kg) was associated with the double rate cow manure treatment (Table 2). The double rate poultry manure+fertilizer and double rate barley mulch+fertilizer gave lower values in comparison to the half rate treatments (*P*<0.05). Double rate cow manure gave higher values in comparison to half and full rate treatments. In 2006, the maximum values of 1000-grain weight were lower than the maximum values recorded in 2005. The control plot had the lowest value (*P*<0.05). Double rate cow manure treatment

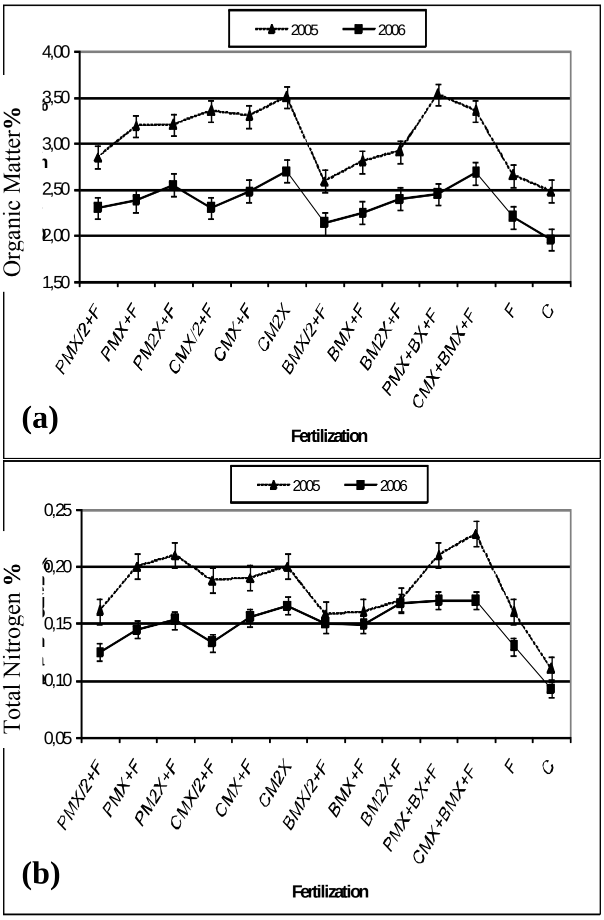

Fig 2. The effect of combined organic-inorganic fertilization on a) soil organic matter % and b) total nitrogen %, 41 days after sowing (PM: poultry manure, CM: cow manure, BM: barley mulch, X=10 t ha^{-1}, F: fertilizer (21-0-0)). Bars indicate $LSD_{5\%}$.

had the greatest effect, while 1000-grain weight increased as the rates of amendment in the poultry manure, cow manure and barley mulch treatments increased (Table 2).

Grains per rank

In 2005, the lowest value was obtained with the control (18.1). The greatest value was observed for poultry manure+fertilizer treatment (P<0.05). In 2006, in comparison to the previous year, the maximum number of grains per rank was fewer (Table 2). The control had the least grains per ear (15.2), while the greatest number was recorded in the double rate cow manure plot (24.5). The number of grains per rank was directly related to the amounts of soil amendments applied.

Yield

In 2005, the control plot had the lowest (2103 kg ha^{-1}) yield and the double rate cow manure plot the greatest (6122 kg ha^{-1}), followed by the fertilizer treatment. The second lowest yield after the control was for that with double rate poultry manure+fertilizer treatment (Table 2). In 2006, yields were reduced in comparison to the previous year, when organic and inorganic fertilizers were used. The control had the lowest yield (1703 kg ha^{-1}) and the double rate cow manure plot the greatest (3602 kg ha^{-1}). As the amount of poultry manure, cow manure and barley mulch increased, yield also increased, which was not the case in 2005.

Sustainability indices

The SYI was greater in all the plots under all treatments which included cow manure. The lowest values of SYI were recorded in the control plots (Fig. 3). Also, lower values of SYI were recorded in 2006 than in 2005. Among various treatments analyzed, applications of double rate cow manure without mineral fertilizer sustained AE in both years. In 2005, AE was greater in the plots treated with fertilizer, with and without single rate cow manure, and in those treated with double rate cow manure. Similarly to SYI, lower values of AE were also recorded in 2006 than in 2005.

Photosynthesis

In 2005, at the first assessment (35 DAS) the highest rates of photosynthesis were obtained in the half rate poultry manure, double rate cow manure and cow manure+barley mulch plots (P<0.05). At the second assessment (51 DAS), it was observed that the photosynthetic rate increased as the amount of cow manure increased and decreased as the amount of barley mulch and poultry manure increased (Table 3). The greatest photosynthetic rate was obtained in the double rate cow manure treatment (45.25 μmolCO_2 m^{-2} s^{-1}). Moreover, the photosynthetic rate was least for the untreated control (22.75-31.50 μmolCO_2 m^{-2} s^{-1}). In 2006, the highest photosynthetic rate was obtained in plots treated with the double rate cow manure (42.05 μmolCO_2 m^{-2} s^{-1}, at 51 DAS) and least in the control plot (20.88 μmolCO_2m^{-2}s^{-1}, at 35 DAS).

Stomatal conductance

In 2005,at the first assessment (35 DAS), the fertilizer treatment resulted in the highest stomatal conductance values (2.32 mol m^{-2} s^{-1}) and double rate barley mulch the lowest (0.70 mol m^{-2} s^{-1}). The treatments with poultry manure and cow manure produced higher values than did the control. The half rate barley mulch plot also produced higher values than did the control, whereas those obtained with the full and double rates were lower than the control. The plots treated with poultry manure+barley mulch+fertilizer gave lower values than the did the control, whereas treatment with cow manure+barley mulch+fertilizer resulted in values a little higher than those of the control (Table 4). In the second assessment of 2005 (51 DAS), the control plot had the lowest value, while greater values were obtained for full rate poultry manure, double rate cow manure and half rate barley mulch treatments (P<0.05). All treatments resulted in values higher than those of the control (0.83 mol m^{-2} s^{-1}). Stomatal conductance was reduced as the amount of barley mulch increased and increased as the amount of cow manure increased. In the third assessment (66 DAS) ,the untreated control had the lowest value (0.61 mol m^{-2} s^{-1}) and the results were similar to those of the previous assessment. In 2006, the values of stomatal conductance were lower in comparison to those of 2005. At 35 DAS, the greatest values were observed in plots treated with double rate barley residue, double rate cow manure and double rate poultry manure (P<0.05). The lowest stomatal conductance at 35 DAS was obtained with half rate barely mulch treatment (0.73 mol m^{-2} s^{-1}). At 51 DAS, the lowest value was found in the control plots (0.79 mol m^{-2} s^{-1}) and the greatest in those treated with double rate barley mulch+fertilizer (1.87 mol m^{-2} s^{-1}) and double rate cow manure (1.73 mol m^{-2} s^{-1}). At 66 DAS, the lowest values were

Table 3. The effect of combined organic-inorganic fertilization on maize photosynthetic rate (μmolCO_2 m^{-2} s^{-1}), 35, 51 and 66 days after sowing (DAS).

Treatment	Photosynthetic rate					
	35 DAS		51 DAS		66 DAS	
	2005	2006	2005	2006	2005	2006
PM X/2 + F	44.02	37.03	45.11	32.11	41.12	28.76
PM X + F	42.18	38.09	42.89	36.92	38.19	33.20
PM 2X + F	41.11	39.21	36.23	39.21	27.00	36.35
CM X/2 + F	33.33	37.98	35.00	34.15	34.00	34.10
CM X + F	42.15	39.23	41.63	38.21	39.21	37.83
CM 2X	43.43	41.31	45.25	42.05	43.75	39.22
BM X/2 + F	38.23	37.09	40.00	29.61	43.00	31.23
BM X + F	43.05	38.83	35.00	35.33	39.00	36.03
BM 2X + F	42.21	41.15	33.63	40.04	34.00	38.95
PM X + BM X + F	39.01	38.78	35.75	36.23	42.22	34.03
CM X + BM X + F	43.27	39.38	37.00	37.03	43.00	37.31
Fertlizer (21-0-0)	40.93	31.13	39.63	28.22	36.50	29.81
Control	22.75	20.88	31.50	26.98	26.37	22.63
$LSD_{5\%}$	1.21	1.23	1.92	1.06	1.17	1.16

PM: Poultry manure, CM: cow manure, BM: barley mulch, X=10 t ha^{-1}, F: fertilizer (21-0-0).

Table 4. The effect of combined organic-inorganic fertilization on maize stomatal conductance (mol m^{-2} s^{-1}), 35, 51 and 66 days after sowing (DAS).

Treatment	Stomatal conductance					
	35 DAS		51 DAS		66 DAS	
	2005	2006	2005	2006	2005	2006
PM X/2 + F	2.22	1.21	1.77	0.91	1.99	0.82
PM X + F	2.10	1.61	1.87	1.21	1.87	1.11
PM 2X + F	1.30	1.72	0.90	1.33	0.63	1.20
CM X/2 + F	1.40	1.33	1.27	1.11	0.69	0.61
CM X + F	1.55	1.54	1.44	1.32	0.79	0.66
CM 2X	1.90	1.71	1.90	1.73	1.38	1.32
BM X/2 + F	1.69	0.73	1.88	1.31	1.68	1.2
BM X + F	0.88	0.90	1.50	1.40	1.41	1.32
BM 2X + F	0.76	1.69	1.26	1.87	1.28	1.61
PM X + BM X + F	0.77	0.88	1.71	1.33	1.63	1.46
CM X + BM X + F	1.18	1.05	1.46	1.30	1.10	1.04
Fertlizer (21-0-0)	2.32	1.36	1.27	1.26	1.02	1.05
Control	1.05	0.91	0.83	0.79	0.61	0.51
$LSD_{5\%}$	0.14	0.16	0.21	0.14	0.17	0.11

PM: Poultry manure, CM: cow manure, BM: barley mulch, X=10 t ha^{-1}, F: fertilizer (21-0-0).

Table 5. Correlation coefficients[a] between yield, plant characteristics, physiological traits and soil properties.

	Experiment 2005	*Experiment 2006*
Yield × 1000 Grain weight	0.691**	0.927***
Yield × Grain per rank	0.929***	0.990***
Yield × Dry weight	0.662*	0.967***
Yield × Photosynthetic rate	0.912***	0.926***
Dry weight × Photosynthetic rate	0.583*	0.898***
LAI × Photosynthetic rate	0.678*	0.812***
Organic matter × Yield	0.434^{ns}	0.861***
Organic matter × Dry weight	0.204^{ns}	0.865***
Total Nitrogen × Yield	0.593*	0.935***
Total Nitrogen × Dry weight	0.248^{ns}	0.936***
Photosynthetic rate × Stomatal conductance	0.792**	0.778**

*[a]r was calculated using the linear equation. Significant at *P=0.05, **P=0.01 and ***P=0.001. ns: Not significant.*

measured in the control and greatest in the double barley mulch plot (1.61 mol $m^{-2} s^{-1}$).

Discussion

Soil organic matter is an important source of nutrients for plant growth that needs to be maintained for agricultural sustainability (Herencia *et al.*, 2007). The addition of organic material of various origins (*e.g.* manure, green manures) to soil has been one of the most common practices to improve soil properties (Bulluck *et al.*, 2002; Celik *et al.*, 2004; Edmeades, 2003; Li *et al.*, 2008; Sankakkara *et al.*, 2004). Organic amendments also improve soil structure and aggregate stability, as well as moisture retention capacity (by increasing the total number of storage pores) (Bhatacharyya *et al.*, 2008). Organic matter content was proportionate to the amount of manure applied. In both years, the lowest concentration of organic matter was found in the control and mineral fertilized plots. Melero Sanchez *et al.* (2008) reported that organically fertilized soils show significant increases in total organic carbon, Kjeldahl N, available P, ammonium acetate-extractable K, microbial biomass carbon and enzymatic activities compared with those found under inorganically fertilized plots. Other investigators have also reported that combined organic/inorganic fertilization both enhanced C storage in soils and reduced emissions from N fertilizer use (Pan *et al.*, 2009). Compared with applying only chemical fertilizers, the method of combined application of organic manure and inorganic fertilizers as a total basal dressing is beneficial to the balanced release of nutrients and reduction of N loss, thus increasing the N use efficiency (Liu *et al.*, 2008). Moreover, poultry/cow manure and barley mulch combined with chemical fertilizer resulted in higher increases in total soil N compared with those found in control or mineral fertilized plots. In a similar study, Zhao *et al.* (2009) also found farmyard manure combined with chemical fertilizer management resulted in higher increase in maize yield, soil organic matter, available N and available P compared with those found under mineral fertilizer treatment. These investigators also reported that straw manure, as a replacement for farmyard manure, could be a promising strategy for improving some physical and biological properties as compared to farmyard manure. Moreover, Herencia *et al.* (2009) reported that the use of organic fertilizer resulted in higher soil organic matter, soil N content and available P and K. Combined organic and inorganic fertilization promoted plant growth (height, dry weight and leaf area index) in comparison to the mineral fertilized and control plots (Table 1). Moreover, the photosynthetic rate (Table 3) and stomatal conductance of the untreated control and mineral fertilization treatments was significantly lower than that of combined organic and inorganic fertilization treatments. Selvaraju and Iruthayaraj (1995) reported that stomatal conductance and transpiration rate of maize plants increased with N application. High correlation between photosynthetic rate and both LAI and dry weight was observed. The toxicity of barley mulch only influenced the stomatal conductance at 35 DAS. High correlation between photosynthetic rate and stomatal conductance was measured (Table 5). The double rate cow manure (240 kg ha^{-1}) was one of the best treatments. The reduced photosynthetic rate in control plots resulted in a significant reduction in yield of sweet maize. The lowest values of 1000 grain-weigh, grain for rank and yield of maize were obtained in control plots (Table 2). Combined organic and inorganic fertilization promoted crop yield (Table 2) and AE (Figure 3). Kimeto *et al.* (2004) also found that a combination of both organic and inorganic nutrient source gave higher maize yield than when

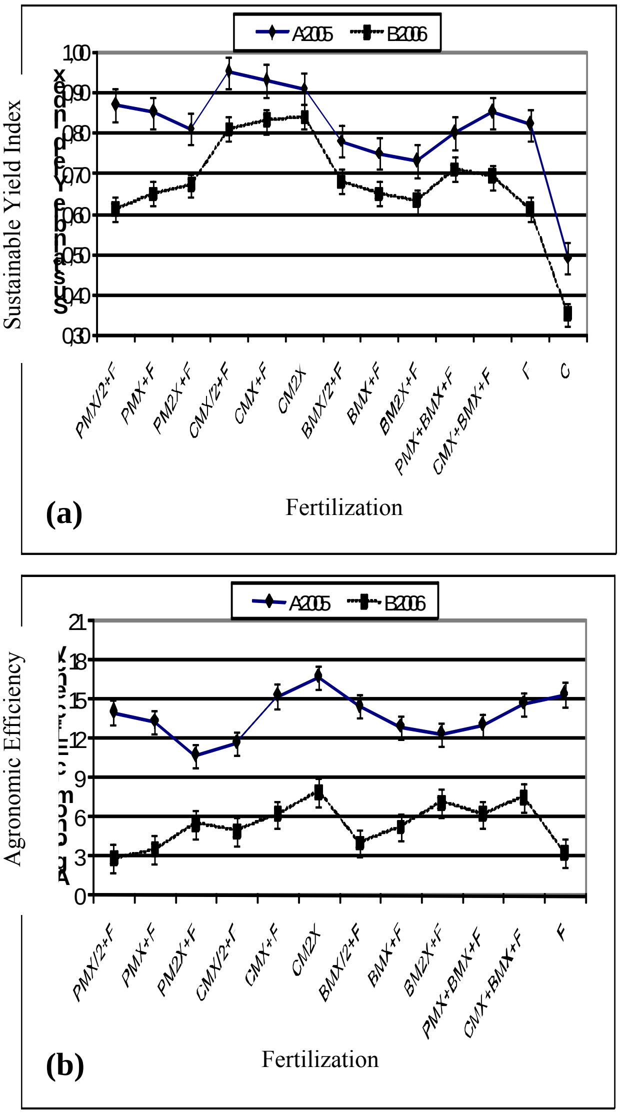

Fig 3. The effect of combined organic-inorganic fertilization on a) sustainable yield index and b) agronomic efficiency (PM: poultry manure, CM: Cow manure, BM: Barley mulch, X=10 t ha^{-1}, F: fertilizer (21-0-0)). Bars indicate $LSD_{5\%}$.

each was applied separately. Improvement in the efficiency of fertilizers when used in conjunction with manure is well documented (Bhattacharyya *et al.*, 2008). Also, Pan *et al.* (2009) found that N use efficiency was higher under combined fertilization (by 12.6% and 39.0% for combined application of chemical fertilizers with pig manure and combined application of chemical fertilizers with straw return, respectively) compared to inorganic fertilization alone. Shah *et al.* (2009) also observed that AE and N use efficiency were higher in treatment where 25% N was supplied from poultry manure and 75% from mineral fertilizer. Yield was influenced by the type and the quantity of organic fertilizers. That addition of organic material to soil improves maize yield is well known (Bahrani *et al.*, 2007; Rasool *et al.*, 2008). Sadeghi and Bahrani (2009) showed that the optimum crop growth and the highest wheat grain yield was achieved with the highest crop residues and N rates, indicating that the most reliable system for dryland wheat production is complete residue incorporation into the soil and application of 70 kg N ha^{-1}. In the present study, the highest yield of maize was measured in plots treated with double cow manure. However, in 2006, yields were reduced in comparison to the previous year. This result shows that continuous maize cropping cannot achieve yield sustainability. The SYI (Figure 3) was highest in 2005. Also, it may be inferred from the SYI data that maize crop is more stable under double rate cow manure and combined organic and inorganic fertilization treatment compared with inorganic fertilization. Bhattacharyya *et al.* (2008) have also reported that a soybean-wheat system was more stable under farmyard manure-treated treatments compared with other fertilizer practices.

Conclusion

Our results indicate that combined organic/inorganic fertilization greatly affected the growth, yield and photosynthesis of sweet maize. The most significant impact was observed when cow manure was applied to soil. The lowest dry weight, height and LAI were measured in the control and inorganically fertilized plots. Moreover, the photosynthetic rate and stomatal conductance of the untreated control and plots treated with mineral fertilizers were significantly lower than those under combined organic and inorganic fertilizer treatments. High correlation between maize yield and organic matter was registered. Moreover, combined organic and inorganic fertilization promoted the sustainability (high sustainable index) and agronomic efficiency of maize crop. In sustainable agriculture, combined organic and inorganic fertilization can affect the growth, yield and sustainability of maize crop.

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