Chapter 5
Effect of Hill Placement of Nutrients on Millet Productivity and Characteristics of Sahelian Soils of Niger: Analysis of Yield Trend After Three Years of Cropping

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Abstract Reports from implementation of the low-input mineral fertilizer microdosing technology have shown up to 120% yield increase. However on the acidic Sahelian soils (pH 4–5 (H_2O)) with low carbon content (0.2%), the question is whether applying such small dose would not lead to nutrient mining over years, which ICRISAT set three studies of 3 years each to address. Experiments 1 (2003) and 2 (2008) involved three planting densities, two pearl millet varieties and four fertility management options with removal of crop residue in experiment 1. Experiment 3 (2010) involved the combinations of 4 rates of organic and mineral fertilizers and 10 millet varieties. Both organic and mineral inputs were hill-applied.

In all experiments nutrient hill placement resulted in total biomass increase in the second and third years compared to the control. After 3 years of cropping, yield decrease of -2307 kg.ha^{-1} was observed with the control in experiment 1 between years 1 and 3, while -1238 kg.ha^{-1} was observed with 6 g NPK per hill which was statistically significant. In experiment 3 yield decrease was -1516 kg.ha^{-1} with the control and -648 kg.ha^{-1} with 300 g per hill of organic manure. Soil pH decreased by 0.17 in NPK amended plots whereas it decreased by 0.29 in the others as observed in experiment 1. In all case, biomass decreased but in lower amplitude with organic manure addition.

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Keywords Microdosing technology • Dryland • Nutrient dynamic • Yield decrease • Organic manure • Sahelian soils

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5.1 Introduction

In contrast with the Asian countries that experienced the green revolution, agricultural production in the dryland zones of Africa, has remained stagnant (IFDC 2005–2006). There are many reasons for this. Agriculture is practiced in a fragile and harsh environment characterized by low soil fertility due to inadequate management over years. Most of the soils have lost their physical and chemical properties with crust formation in most cases as well as low nutrient content. According to Bationo et al. (1997) average total N, available P and organic C content of Sahelian soils are 150 mg kg^{-1}, 2.8 mg kg^{-1}, 0.2%, respectively. Harsh climatic conditions are the second cause of low production. Average annual temperature is 35 °C with highly variable and erratic rainfall in time and space. Socio-economic conditions of small scale farmers, such as low asset-base, poor access to inputs and markets, are also a major constraints. As a consequence, while some countries in other parts of the world are using 80 kg/ha of fertilizer, in the dryland of Africa it is limited to less than 8 kg/ha annually. These production environment constraints adversely affect crop and land productivity and make farming inherently risky.

The development of the microdosing technology by ICRISAT and partners aims at helping dryland farmers in managing this risk. Reports from the implementation of this technology have shown up to 120% yield increase (Tabo et al. 2007). Such a high yield increase implies consequent nutrient uptake. Earlier studies have also found insufficient crop residues on-farm after harvest to meet all the multiple purposes of residue use (Baidu-Forson 1995). This affects negatively agricultural productivity and land resource integrity. Because Sahelian soils are acidic (pH 4–5 (H_2O)) and low in nutrients and carbon content (0.2%) the main question remains as whether soil nutrient unbalance would not occur in the long term following the application of the technology. Hence there is a need for additional studies to understand the processes involved in the nutrient dynamics under these conditions and enable the use of such a successful technology for millet production in a sustainable manner.

To address the question of nutrient dynamics and sustainable millet production we conducted three experiments of 3 years each in 2003–2005, 2008–2010 and 2010–2012 which we refer to as experiment 1, experiment 2 and experiment 3. The objectives of experiments 1 and 2 were: to study the sustainability of hill placed mineral fertilizer with regards to crop productivity, soil nutrient dynamic and crop water use. The objectives of experiment 3 were: (i) to study the effect of the combination of hill applied mineral fertilizer and pearl millet genotype on yield; (ii) to determine the optimal combination of varieties, hill placed mineral, and organic amendment options that would lead to better yield and improved water use, and (iii) to test the long term effect of the combination of hill placed mineral and organic amendment and genotypes on pearl millet production and soil nutrients dynamic. In the present paper we will focus on the effect of hill placed nutrients in each experiment on total biomass yield and discuss the trends observed after 3 years of cropping in the three experiments.

5.2 Material and Methods

5.2.1 Site Description

The experiments were conducted at ICRISAT research station at Sadore 13.15°N, 2.17°E, approximately 40 km southwest of Niamey. The long-term averaged rainfall at the station is 550 mm. Mean monthly temperature at Sadore varies between 25 and 41 °C (Sivakumar et al. 1993). The soils are Arenosols (World Reference Base for Soil Resources, FAO 1998), classified as psammentic Paleustalf according to the US soil taxonomy (West et al. 1984). The soil is acidic with relatively high Al saturation. The fields had a gentle 2.5% slope.

5.2.2 Experimental Soil Properties

The soil of the experimental fields is acidic with pH (H_2O) of 4.3, 4.7 and 4.8 for experiments 1, 2 and 3 respectively (Table 5.1). The exchangeable bases (0–20 cm soil depth) is 0.5 cmol kg^{-1}, available P, organic matter content and Cation Exchange Capacity are all low, often at the lowest limits as per Bunasol (1990) indicating low capacity of the soil to prevent leaching of nutrients applied with fertilizers. However the lower level of total N of 174 mg-N/kg (Experiment 1 – Table 5.1) is high according to the same classification, which may be due to the fact that before the experiment set up the fields were left as fallow for more than 10 years, leading to N accumulation.

Table 5.1 Initial chemical characteristics of soils (0–20 cm) in the experimental fields

Soil characteristics	Exp 1	Exp 2	Exp 3
pH-H2O (1:2.5)	4.35	4.77	4.84
Exchangeable base	0.49	0.52	1.89
Total N (mg-N/kg)	174	200	242
Bray P1 (mg-P/kg)	6.69	2.79	4.73
C. Org (%CO)	0.19	0.24	0.27
CEC-Ag (cmol+/kg)	0.11	0.70	

5.2.3 *Experimental Design*

Experiments 1 and 2 involved three factors, which are: two millet varieties (ICMV IS 99001 and the local landrace), three planting densities (15,000, 10,000 and 5000 hills per ha) and four options of soil fertility management (0 input (control), 2 g DAP per hill at planting and 1 g Urea at stem elongation, 3 g NPK per hill at planting, and 6 g NPK per hill at planting). In experiment 1 all, crop residues were removed after grain harvest. In experiment 2, residues were left in each plot after harvest. Experiment 3 involved three factors including four levels of organic manure management (0 g input, 100 g farm yard manure per hill, 200 g farm yard manure per hill, and 300 g farm yard manure per hill), four levels of mineral fertilizer application (0 input (Control), 2 g DAP per hill at planting and 1 g Urea at stem elongation, 3 g NPK per hill at planting, and 6 g NPK per hill at planting) and ten millet varieties with varying growth habits, growing period length and head shape among which one is the farmer's variety (Local landrace, ICMV IS 99001, ICMV IS 89305, SOSAT-C88, ICRI-TABI, Mil De Siaka (PE05578-C2), (Kado Nio de Mali (PE05572), Sounamau (PE08030), ICMV IS 94206, TCHIOUMA-SOUNA (F8XM1-C2)) (Table 5.2).

Experiments 1 and 2 were conducted in Randomized Complete Block Design with 3 replications. Experiment 3 was conducted in a split plot design in 3 replications. Organic manure management was the main plot and the combinations of mineral fertilizer levels and varieties were applied in the sub-plots. Every year planting was done with the first important rain (rainfall equal or higher than 20 mm), which occurred in June except for 2012 when re-planting of experiment 3 was done on 22nd July due to total seedling destruction of the first planting by grasshoppers. In all three experiments, 6 m × 6 m plot size was used. In experiment 3 within row and between row spacing was 1 m, Whereas in experiments 1 and 2 row spacing depends on planting density treatment. In all three experiments, every year the same plot was used for each treatment.

5.2.4 *Data Collection*

Before the installation of each experiment, initial soil samples (0–20 cm, 20–40 cm) were collected and analyzed for pH (H_2O), total N, Bray P1, K^+, Ca^{2+}, Mg^{2+}, Na^+,

Table 5.2 Treatments under study in the three experiments, starting dates and planting dates

	Organic fertilizer	Mineral fertilizer	Variety	Planting density	Date started	Planting dates
Experiment 1	NA	No minerals	Sadore local	0.8 m × 0.8 m	2003	27-Jun-03
		2 g DAP + 1 g Urea	ICMV IS 99001	1 m × 1 m		9-Jun-04
		6 g NPK		1.5 m × 1.5 m		1-Jun-05
		3 g NPK				
Experiment 2	NA	No minerals	Sadore local	0.8 m × 0.8 m	2008	18-Jun-08
		2 g DAP + 1 g Urea	ICMV IS 99001	1 m × 1 m		13-Jun-09
		6 g NPK		1.5 m × 1.5 m		4-Jun-10
		3 g NPK				
Experiment 3	No organic	No minerals	Sadore local	NA	2010	26-Jun-10
	100 g per hill	2 g DAP + 1 g Urea	ICMV IS 99001			18-Jun-11
	200 g per hill	6 g NPK	ICMV IS 89305			22-Jul-12
	300 g per hill	3 g NPK	SOSAT-C88			
			ICRI-TABI			
			Mil de Siaka (PE05578-C2)			
			Kado Nio de Mali (PE05572)			
			Sounamau (PE08030)			
			ICMV IS 94206			
			Tchiouma-Souna (F8XM1-C2)			

Organic C and CEC. Additional soil samples were collected in all experiments to evaluate potential changes in these parameters after 3 years of cropping. Only results of experiment 1 are reported in the present paper due to none availability of the results of analysis of the samples of the two other experiments at the time the paper was finalized. For soil sample collection 3 years after cropping the following procedure was adopted: each plot was divided into four equal parts. For each sampling core, soil samples were collected in the middle of each quarter and from the junction of the 4 quadrants giving a total of 5 sampling points. These samples were bulked and a sub-sample was taken.

The crop was harvested at maturity as border rows were eliminated from each side of the plot to avoid border effect. To study crop performance in terms of total biomass production, stover weight, head weight and grain weight per plot were recorded and converted to kg/ha based on the area harvested. Total biomass was calculated as the sum of stover and head yields. Data analysis was done every year for each experiment with ANOVA module in Genstat v13. As the same plots were used every year in all experiments, the data of each experiments were pooled together and analyzed as repeated measurement using Residual Maximum Likelihood (REML) in Genstat V13. To study the effect of nutrient management and the other treatments on total biomass production after 3 years of cropping we calculate the difference between total biomass per plot of year 1 and that of year 3. The resulted data was analyzed with ANOVA module of Genstat V13. In experiment 1 soil sampling to evaluate nutrient dynamic after 3 years of cropping was done in selected plots. As a result, we obtained unbalanced treatment structure which was analyzed with AUNBALANCE module in Genstat v13.

This paper addresses the effects of the treatments tested on total biomass production, which not only involves grain production, but covers farmer preoccupation at household level as it includes the vegetative production, a source of feed for animals, source of energy as well as a construction material. Therefore data interpretation focused on interaction between years and the treatments when they exist. But when there is no interaction the main effect was presented. After this we discussed treatments effect on the difference between total biomass in the first and third year of cropping analyzing the trends observed. As for the treatments, we will address the effect of organic and mineral fertilizer application. The other treatments will a subjects of another paper.

5.3 Results

5.3.1 Rainfall Distribution During the Experimental Years

Cumulative rainfall across the experimental years was similar to the long term average of 550 mm except for 2010 with total rainfall of 387 mm and 2012 when total rainfall was 641 mm (Fig. 5.1). However occurrence of dry spell of variable duration was recorded in all years. Such dry spells were observed in July 2003, in June 2004 and 2005 and in early July 2009 and between late July and early August 2011 (Fig. 5.2a–c, e). Most of these dry spells did not coincide with the reproductive period of the crop when pearl millet is most sensitive to the negative effect of dry spells, however the dry spell between late July and early August 2011 may impact final yield as it occurred at head appearance and flowering stage. In 2011 and 2012, the rainy season started by mid-June but only few rainfall events were recorded at the end of September creating conditions for end of season drought that affects grain filling.

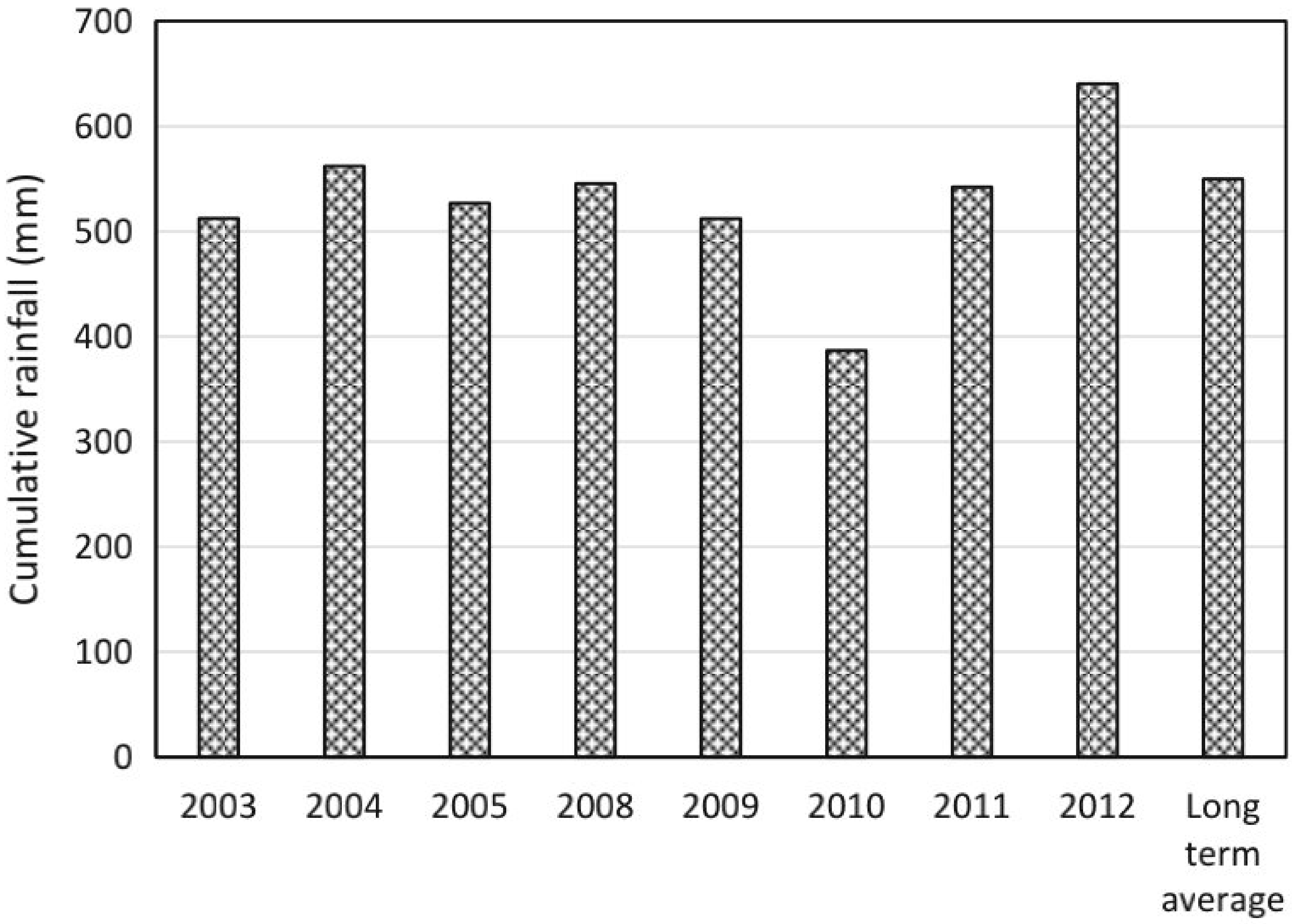

Fig. 5.1 Cumulative rainfall in the experimental years at ICRISAT research station at Sadore and long term average

5.3.2 *Effect of Mineral Fertilizer on Total Biomass Yield Across Years and Experiments*

Treatment main effect was observed in all experiments. Interaction between cropping years and mineral fertilizer application was observed only in experiment 3 which was highly significant at probability level of <0.001 (Table 5.3), however in all years mineral input resulted in increased total biomass production but in varying amplitude. For instance, in year 1 of experiment 1, average biomass increase due to mineral input application was 12% whereas in years 2 and 3 it reached 35% and 45%. The higher average yield increase in years 2 and 3 was due to application of 6 g NPK per hill which contributed significantly as yield increase due to this treatment was 43% and 53% in year 2 and year 3 respectively (Fig. 5.3a).

The same trend was observed in experiment 2 (Fig. 5.3b); however when compared with experiment 1, the effect of mineral input on total biomass yield was more important in year 1 as it reached 28% on average. This trend was similar for experiment 3 but in minor proportions (Fig. 5.3c). Total biomass yield was similar for all levels of mineral fertilizer in year 1 and 2 whereas in year 3, DAP +Urea produced higher biomass than the other treatments. In all experiments, the graphs show increasing effect of mineral input on biomass yield increase compared to the control particularly in year 3. Considering that the field was left uncropped for more than 10 years before the installation of the experiment, this indicates that the benefit from the technology increases with the number of years after a field is returned to production after a fallow period.

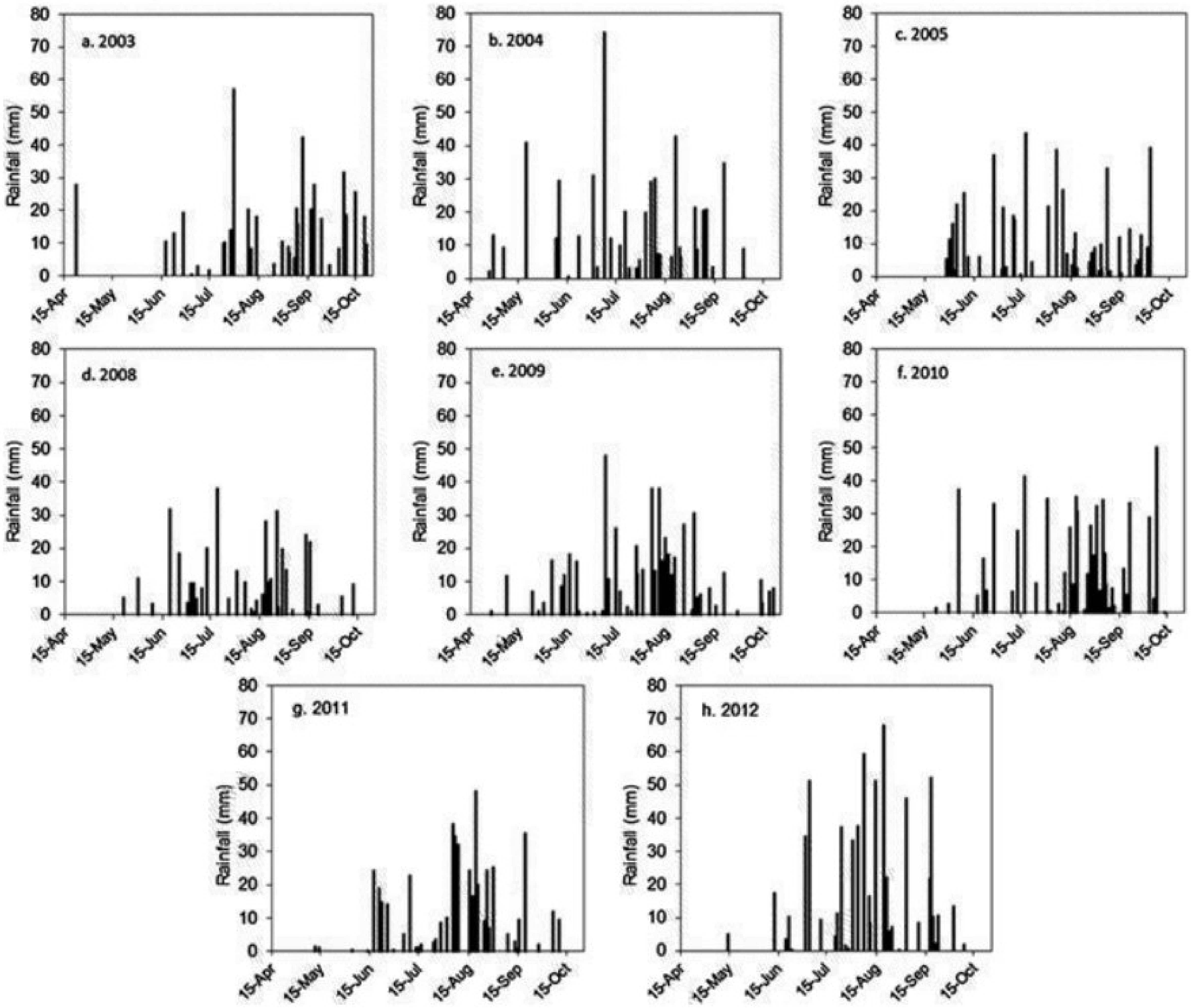

Fig. 5.2 Rainfall in the experimental fields across years (2003–2005; 2008–2010 and 2010–2012)

5.3.3 Effect of Organic Manure on Total Biomass Yield Across Years and Experiments

This amendment was applied only in experiment 3. There is high interaction between years and organic manure application (F. Probability < 0.001) (Table 5.3). In year 1 the graph shows similar biomass production for all levels of manure application ranging from 3320 to 3816 kg.ha^{-1} (Fig. 5.4), which could be due to the fertility level accumulated on the field following more than 10 year of fallow prior to the installation of the experiment. However in year 2 and 3, total biomass yield increased with the rate of organic manure application, which could be due a short term residual effect of the fallow in the Sahel as reported in Samaké et al. (2005), from a work in Mali, where 880 kg.ha^{-1} pearl millet grain yield was recorded in a plot after 7 years of fallow but in the following year, pearl millet yield from the same plot was 420 kg.ha^{-1}. Total biomass yield increased in plots with 300 g manure per hill compared to the control was 48% in year 2 and 62% in year 3.

Table 5.3 Table of Residual Maximum Likelihood analysis 3 years data of the three experiments

	Experiment 1: 2003–2005					Experiment 2: 2008–2010					Experiment 3: 2010–2012			
Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr	Wald statistic	d.f.	Wald/d.f.	chi pr
Year	766.71	2	383.35	77.5	<0.001	335.44	2	167.72	96	<0.001	557.07	2	278.54	<0.001
Fert_name	89.66	3	29.88	123.8	<0.001	45.93	3	15.31	46	<0.001	98.4	3	32.8	<0.001
Dens_name	103.67	2	51.83	129.7	<0.001	38.05	2	19.02	46	<0.001	20.96	3	6.99	<0.001
Var_name	38.22	1	38.22	120.4	<0.001	47.17	1	47.17	46	<0.001	138.13	9	15.35	<0.001
Year.Fert_name	5.08	6	0.85	105.4	0.538	5.94	6	0.99	96	0.437	88.13	6	14.69	<0.001
Year.Dens_name	26.32	4	6.57	101.6	<0.001	7.13	4	1.78	96	0.139	19.16	6	3.19	0.004
Fert_name.Dens_name	7.79	6	1.3	134.1	0.263	4.04	6	0.67	46	0.671	9.08	9	1.01	0.43
Year.Var_name	18.49	2	9.23	107.3	<0.001	7.14	2	3.57	96	0.032	295.22	18	16.4	<0.001
Fert_name.Var_name	4.41	3	1.47	138.2	0.226	10.13	3	3.38	46	0.026	22.46	27	0.83	0.714
Dens_name.Var_name	2.56	2	1.28	138.9	0.282	4.04	2	2.02	46	0.144	16.39	27	0.61	0.945
Year.Fert_name.Dens_name	8.05	12	0.67	106.7	0.777	6.72	12	0.56	96	0.869	10.08	18	0.56	0.929
Year.Fert_name.Var_name	5.03	6	0.84	105.1	0.544	5.27	6	0.88	96	0.514	57.05	54	1.06	0.362
Year.Dens_name.Var_name	3.71	4	0.93	109.5	0.451	1.1	4	0.27	96	0.894	39	54	0.72	0.938
Fert_name.Dens_name.Var_name	8.68	6	1.45	139.8	0.201	3.56	6	0.59	46	0.734	80.17	81	0.99	0.505
Year.Fert_name.Dens_name.Var_name	15.43	12	1.28	106.5	0.239	8.23	12	0.69	96	0.761	137.33	162	0.85	0.921

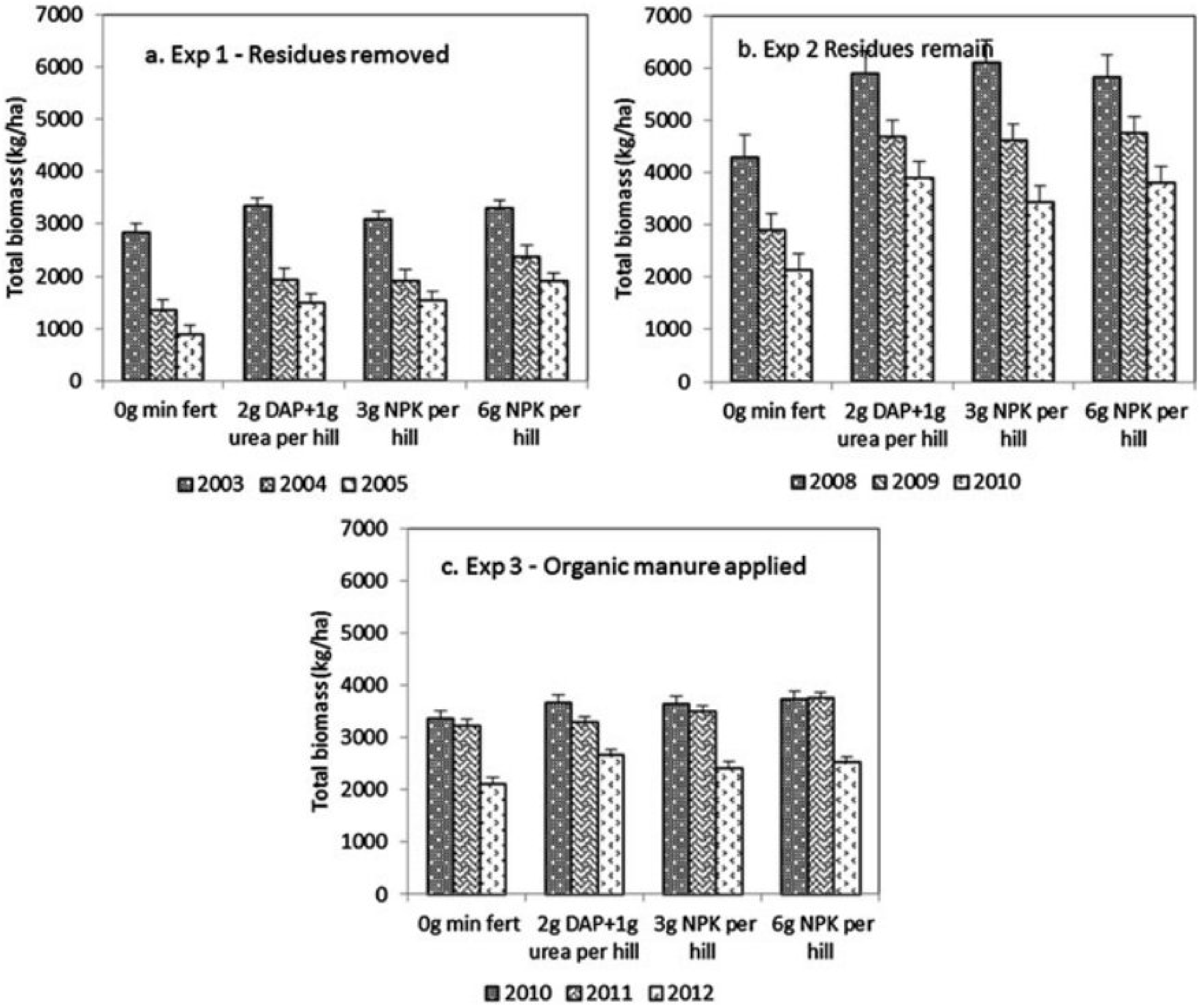

Fig. 5.3 Effect of spot applied mineral fertilizer on millet total biomass yield over 3 years (Means are average over other treatments. Error bars are standard error of difference between mean)

5.4 Pearl Millet Total Biomass Yield Trend After Three Years of Cropping

5.4.1 Effect of Mineral Fertilizer

Yield differences were observed between years 1 and 3 in all experiments following mineral fertilizer hill application which were all negative. This means that total biomass yield dropped over years as mineral fertilizer application is concerned. However the results were statistically significant only in experiment 1 (Fig. 5.5). Here we observed that the highest negative difference of -2307 kg.ha^{-1} was observed in the control plot, while the least difference of -1238 kg.ha^{-1} was observed with NPK 6 g per hill. With DAP + Urea biomass yield difference was similar to that of 6 g NPK per hill. The application of nutrient reduced the amplitude of yield drop between year 1 and year 3 in this experiment. But application of 6 g NPK appeared as the most sustainable in this case after 3 years of cropping. There were no interaction between the treatments.

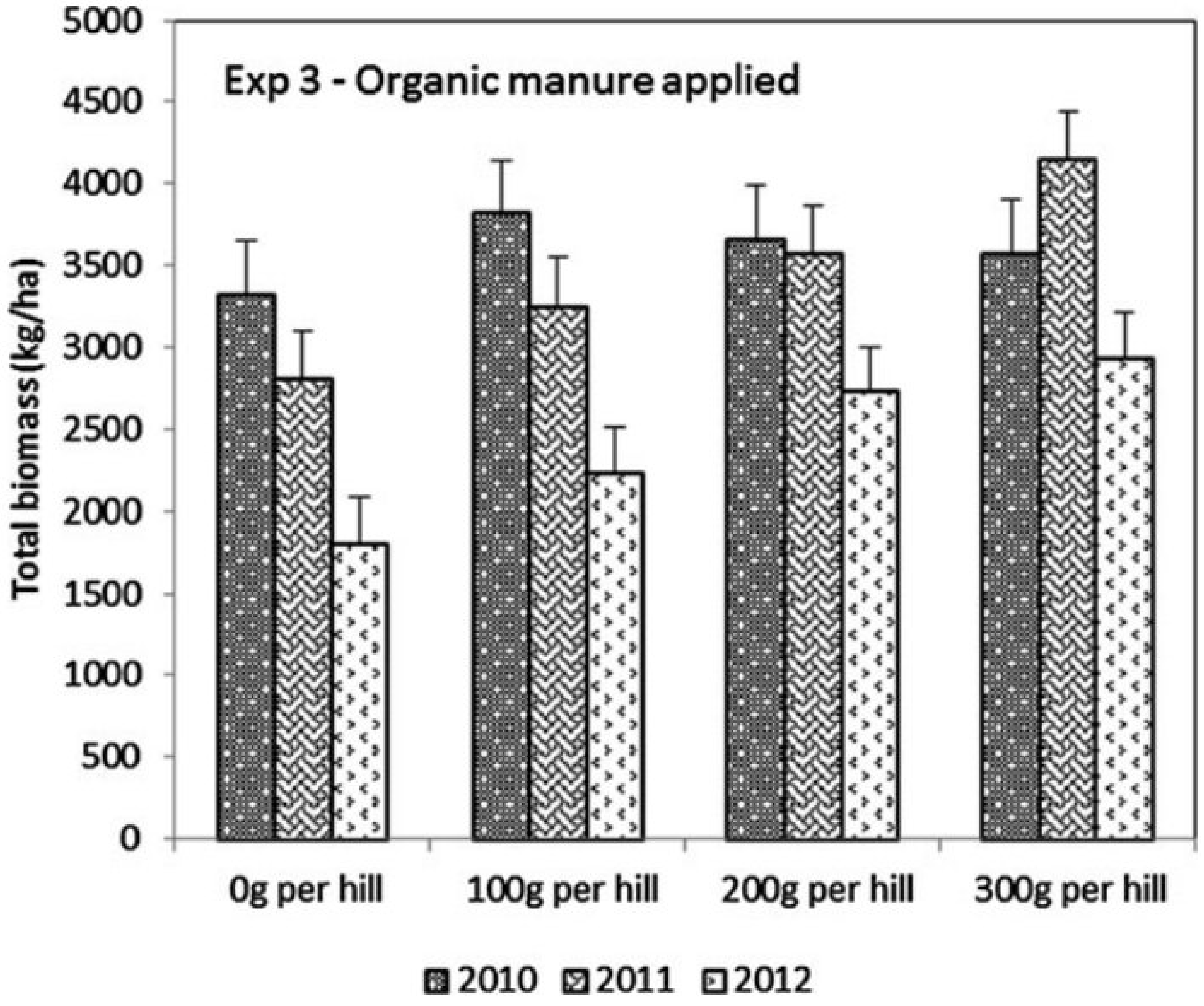

Fig. 5.4 Effect of spot applied organic manure on pearl millet total biomass yield in 3 years (Error bars are standard error of difference between mean)

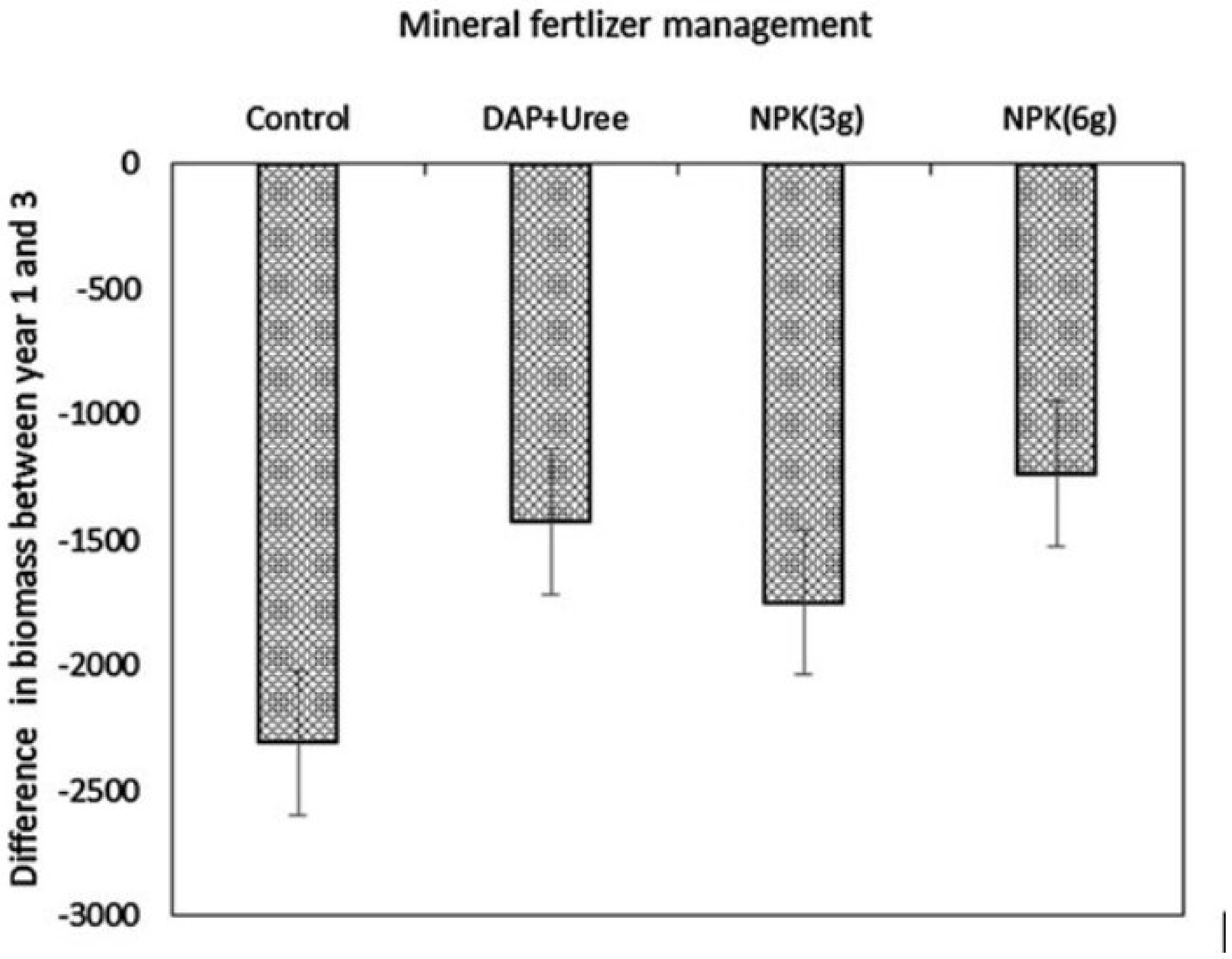

Fig. 5.5 Difference in biomass production between year 1 and year 3. Experiment 1 – Crop residues remove. (Error bars are standard error if difference between means)

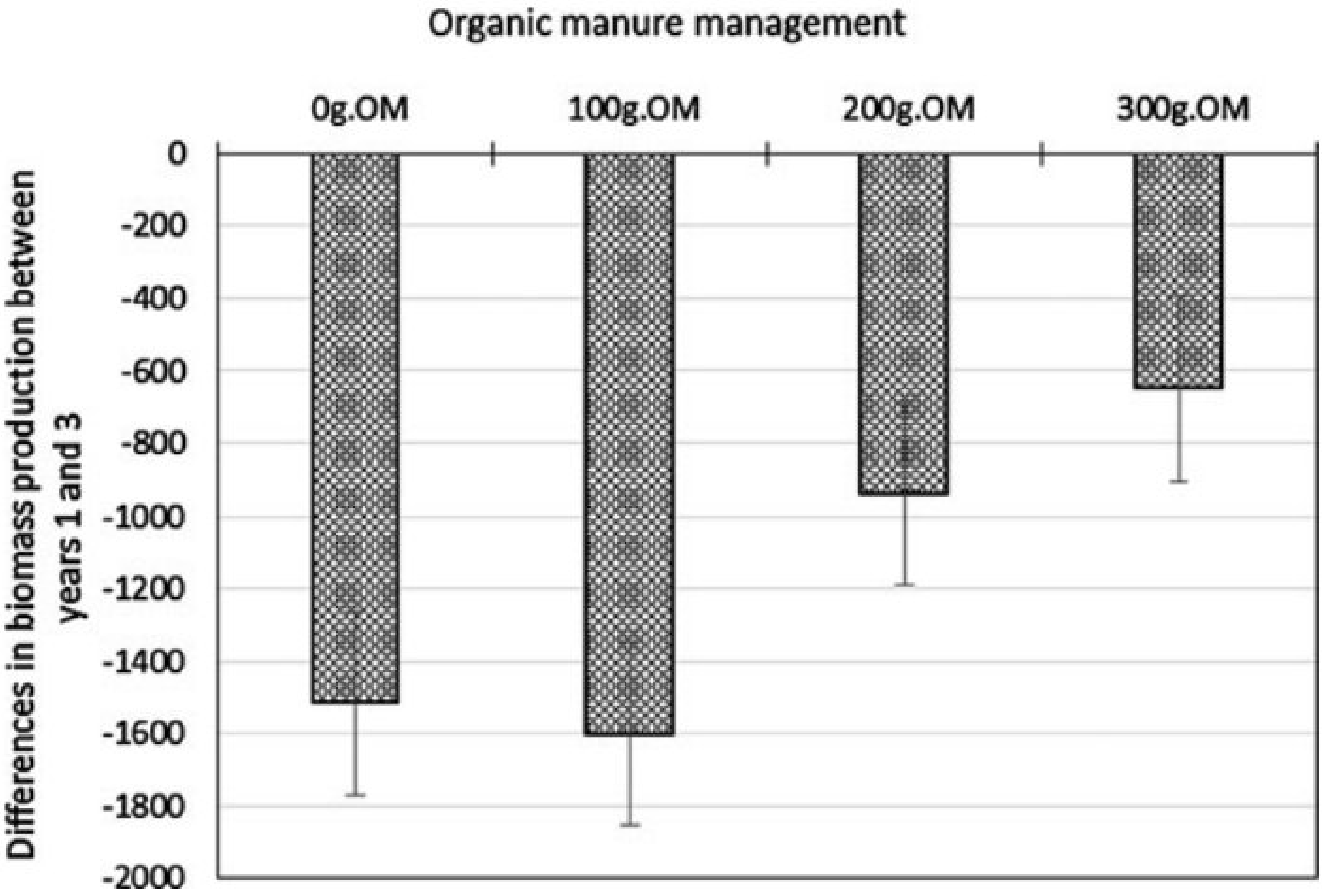

Fig. 5.6 Effect of organic manure on difference in biomass production between year 1 and year 3. Experiment 3. (Error bars are standard error if difference between means)

5.4.2 *Effect of Organic Manure*

There were no interaction between the treatments in terms of yield difference between Year 1 and 3.

Negative differences were observed in total biomass production between years 1 and 3 following organic manure application indicating tendency in yield drop over year. Yield drop of −1516 was observed without organic manure and −1601 kg.ha^{-1} in plots receiving 100 g Manure per hill (Fig. 5.6), whereas it was −648 kg.ha^{-1} with 300 g manure per hill which appeared as the most sustainable option in this case.

5.4.3 *Plant Nutrient Uptake*

5.4.3.1 Plant Nutrients Absorption

In the attempt to understand the reason that explain the trends observed we studied plant nutrient export as well as changes in soil chemical properties after 3 years of cropping. For this we calculated nutrient export through straw and grain for the different options of nutrient management in experiment 1, which was done in 2004 and 2005. We realized that in 2004 as well as in 2005, highest level of nutrient uptake (N, P and K) was recorded in the plots amended with 6 g NPK per hill, which was almost two times the uptake under the other treatments (Table 5.4). Nutrient uptake in plots amended with 6 g NPK per hill was higher than the other treatments but was statistically significant only for potassium absorption. In 2005 statistically significant differences were observed between 6 g NPK per hill and the other treatments. Crop

Table 5.4 Effect soil fertility management on nutrient uptake in 2004 (kg/ha)

2004			
Soil fertility management	Nitrogen	Phosphorus	Potassium
Control	12.6	0.74	14.3
2 g DAP + 1 g Urea	13.5	0.86	14.6
NPK(3 g)	13.5	0.83	14.1
NPK(6 g)	21.1	1.22	23.7
Sed (±)	3.90	0.191	3.211
Fprob	0.129	0.085	0.022

Table 5.5 Effect soil fertility management on nutrient uptake in 2005 (kg/ha)

2005			
Soil fertility management	Nitrogen	Phosphorus	Potassium
Control	9.49	0.6341	10.09
2 g DAP + 1 g Urea	11.02	0.807	12.08
NPK (3 g)	10.03	0.7369	13.65
NPK (6 g)	18.5	1.2899	24.58
Sed (±)	2.793	0.1906	3.061
Fprob	0.017	0.016	0.001

nutrients (N, P, K) uptake was similar for the control, 2 g DAP + 1 g Urea and 3 g NPK per hill (Table 5.5). The above observed trend shows that nutrient application and particularly NPK at 6 g per hill induce high amount of nutrient removal.

5.5 Soil Nutrients Characteristics Following Three Seasons of Cropping

So far this investigation was done only in experiment 1. Results of analysis of soil samples from experiments 2 and experiment 3 will be reported in future papers.

In experiment 1, Soil pH decreased in all treatments, indicating possible acidification of the experimental soil (Fig. 5.7a). The rate of pH decrease was more pronounced in the control and the plots in which 2 g DAP + 1 g Urea were applied. Total N level after three years was variable as it was negative only for 2 g DAP + 1 g Urea and NPK at 3 g per hill (Fig. 5.7b). The balance of available P after three years was negative only in the control plot, which could be due to low pH favoring P trapping in the soil complex. As we could observe from the graphs, the higher the pH, the higher was the positive P balance. Plant export from soil with already low P content could have contributed to lowering it further.

Compared to the initial level, Cation Exchange Capacity decreased less in amended plots compared to the control, which is lined with trend observed with regards to pH (Fig. 5.7d).

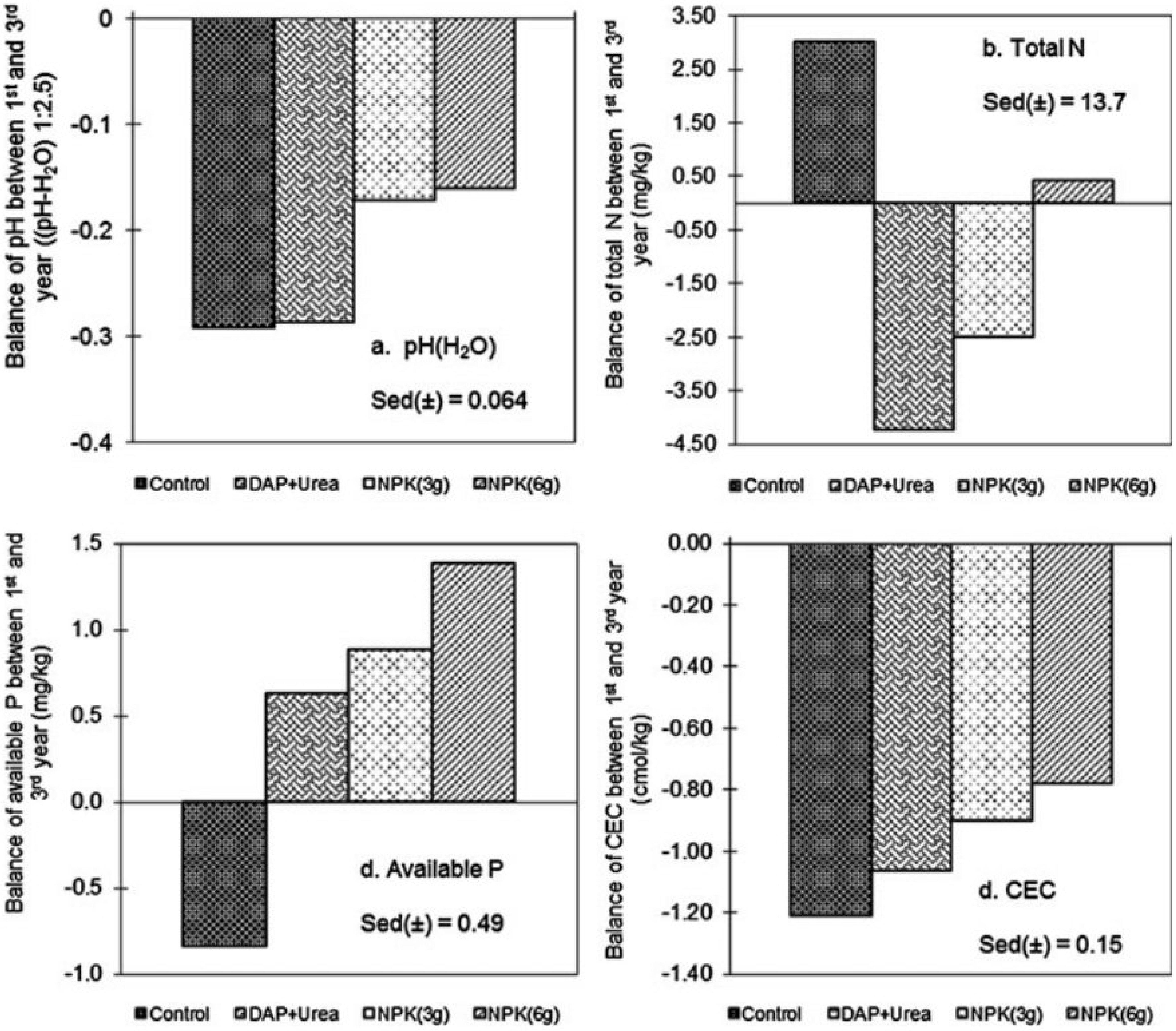

Fig. 5.7 Effect of mineral fertilizer applied as microdose on soil chemical characteristics after 3 years of cropping (2003–2005). ICRISAT research station, Sadore, Niger

5.6 General Analysis

As a photoperiod sensitive crop, the period of planting is crucial for millet crop. Therefore as risk management strategy, famers even practice dry sowing, especially in case there is a delay in the onset of the rainy season. Millet planting normally occurs with the first important rain event in the season (defined climatologically when at least 20 mm rain is received in one event or in three consecutive days and with no dry spell exceeding 7 days within the next 30 days (Sivakumar 1988, 1991). This is important as due to high evapotranspiration, the soil upper layer dries up quickly after rainfall events.

In our study, across experiments and years, planting was done in the window between 1st and 27th June (4 weeks) (Table 5.2), when air temperature was high and photoperiods at their maximum. In the present study, crop was planted in appropriate time except for experiment 3 in 2012 planted on 22nd July when photoperiod was shortening because the whole experiment was replanted due to total destruction of the seedlings following grasshoppers attack. Dry spells were observed but in most cases in period that did not coincide with the reproductive stage except for 2011 when reproduction may be affected. In 2012 when replanting was done, the last rains were received in October and the crops could avoid end of season drought.

After three seasons of cropping we observed that the technology produces a very good results in all three experiments in terms of total biomass yield increase compared to the control. Hill application of organic manure was positive in terms of biomass yield increase and this effect increase from year 1 to year 3. However after 3 years of cropping, total biomass yield decreased with varying amplitude in all treatments even though not statistically significant in all. Reasons for this may be multiple among which for experiment 1, soil acidification inducing the effect of aluminum toxicity that affect particularly root growth (Kretzschmar et al. 1991) can be considered. As we could observe, applying 6 g NPK per hill resulted in the least pH decrease and yield drop but also in positive P balance. The same reason holds for organic manure application in experiment 3. Also plant nutrient removal following input application was high for 6 g NPK per hill. Therefore considering the small amount of nutrient added, we can speculate that nutrient mining may occur. Three years may be quite a short time to observe significant changes in soil nutrient balance; however the trend observed in experiment 1 presumes that soil characteristics especially pH, and CEC may be affected negatively even though with lower amplitude. From this study it appeared that without external input soil characteristics and crop yield are affected negatively after 3 years of cropping. With addition of minerals total biomass decreased but with less amplitude. When crop residues were left in the field biomass yield decrease was also observed but not statistically significant. Therefore for the technology to be sustainable, adequate measures must be taken to sustain the soil fertility level. P being a critical element for plant root growth and subsequent nutrient uptake, the buffering capacity of the soil must be improved to improve available P content. Soil organic matter content must also be improved, which can be achieved with manure application but also with application of crop residues. In the three experiments covered in this paper all these options are tested, each of them for 3 years. Crop residues are used for other purposes such as source of energy but also as construction material in addition to feeding to animals. If at the end of the season they are left in the field, they would be removed due to the roaming character of pastoralism in the region as reported by Baidu-Forson 1995. Our study has shown that total biomass yield drop could be reduced by applying crop residues which according to (Kretzschmar et al. 1991) contribute to reducing aluminum toxicity effect and increasing P availability that results from increased pH but also contribute to enriching the soil by trapping basic cations from dust (Hermann 1996). However in the present study leaving millet stover in the plots did not stop yield decrease over time. Therefore the risk of nutrient mining may still exit.

Results obtained from experiment 3 have shown that total biomass yield increased with the rate of the manure which is in line with the work of Schlecht and Buerkert (2004) who reported linear increase in millet grain with manure rate increase, a result of a work conducted in Niger. In terms of the effect over years, further decrease of the amplitude of yield drop when manure alone is applied or combined with mineral is observed. The beneficial effects of manure on soil characteristics may explain this trend. Many studies have reported increased soil porosity and aggregate stability, increased water infiltration and water holding capacity, decreased eolian soil losses, increased soil organic matter (SOM), pH, CEC and nutrient availability which can lead to sustainable yield and sustained soil fertility over time following manure application (Bationo and Mokwunye1991; Buerkert and Hiernaux 1998; Schlecht et al. 2004).

Until further investigations on the soil chemical characteristics and plant nutrient uptake from the experiments 2 and 3, it appears that in this study inter-annual rainfall variability cannot be considered as the causes for yield drop over years. Nevertheless, the results of soil analysis of experiment 1 show that among others, soil pH may be the main factor leading to the trend observed.

5.7 Conclusion

The present study confirmed the positive effect of hill applied mineral or organic fertilizer and their combination on millet total biomass yield. As observed in experiment 1, this positive effect is associated with high export of plant nutrients. It also revealed that, the effect is more important few years after the field is returned to production after a fallow period. Whether crop residues are maintained on the field or not or in case of combination of the mineral with organic manure, after 3 years of cropping total biomass yield decreased in all treatments even though with varying amplitude. The trend observed in terms of total biomass yield drop show that leaving the residues in the field even though it has minor positive effect is an option to attenuate the negative long term effect on yield. However due to the roaming nature of pastoralism in the Sahelian zone, the risk of all the residues left in the field being removed by grazing animals is high. Therefore measures should be taken so that farmers can benefit from this grazing either by practicing well-structured corralling scheme by signing contract with herd owners, or in case the residues are taken home to be fed to animals, they should make sure equal quantity even if combined with home waste is taken back to the field. This appears as the only mean to sustain soil fertility and drastically reduce the amplitude of yield decrease following hill application of mineral fertilizer.

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