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# Effects of long-term application of mineral and organic fertilizers on dynamics of nitrogen pools in the sandy soil of the Sahel region, Niger

Kanako Suzuki[a,*], Ryoichi Matsunaga[b], Keiichi Hayashi[c], Naruo Matsumoto[c], Satoshi Tobita[c], André Bationo[d], Kensuke Okada[a]

[a] Graduate School of Agricultural and Life Sciences, The University of Tokyo, Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan
[b] Kubota Corporation, Shikitsuhigashi, Naniwa-ku, Osaka 556-8601, Japan
[c] Japan International Research Center for Agricultural Sciences, Ohwashi, Tsukuba, Ibaraki 305-8686, Japan
[d] Action For Integrated Rural Development, KA98 46 G3121, Accra, Ghana

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ABSTRACT

Our study on soil N dynamics was conducted in the rainy season of 2005 and 2006. It focused on the effects of soil managements with sole and combined applications of mineral and organic fertilizers in the long-term experiment conducted since 1993 in the Niamey Center of the International Crop Research Institute for the Semi-Arid Tropics, Niger. Treatments were established with each three input levels of chemical fertilizer as urea and SSP, pearl millet residue, and cattle manure. The lowest and highest levels were focused in our study. Treatments with 2700 kg ha$^{-1}$ of applied crop residue showed high total N in the soil surface (< 30 cm), but did not show any change in the deeper layer (> 30 cm) or seasonal changes. Phosphate-buffer extractable organic nitrogen (PEON) as an indicator to estimate available N in the soil was not affected by the different treatments; however, similar seasonal changes were identified in all treatments. PEON in soil surface was high right before the rainy season began, then gradually decreased with increasing rainfall and remained at approx. 10 mg kg$^{-1}$ until the end of the season. In deeper layer, leaching was identified after heavy rainfall but at least 5 mg kg$^{-1}$ of PEON remained during the season. Inorganic N ($NO_3$—N plus $NH_4$—N) increased in the soil surface right after fertilizer application but its effect disappeared in a few weeks. The 'Birch effect' affected the fluctuations of PEON and inorganic N at the start of rains in the Sahel region of Niger.



## 1. Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the staple crop in the Sahel region of West Africa with the potential to survive under harsh conditions (Hoshikawa, 1980) but extremely low productivity. The means of pearl millet yields from 1961 to 2013 in five countries, Senegal, Mali, Burkina Faso, Niger, and Nigeria, was highest in Nigeria, but only 1030 kg ha$^{-1}$. For the others, the means of yields for 52 years were 584 kg ha$^{-1}$ in Senegal, 738 kg ha$^{-1}$ in Mali, 589 kg ha$^{-1}$ in Burkina Faso, and 424 kg ha$^{-1}$ in Niger (FAO, 2015). Thus, for 52 years they did not have a yield of more than 1 t ha$^{-1}$. According to the other study conducted at two villages in the Sahel region of Niger from 2008 to 2010, the storage of millet in the agricultural production unit (UPA, this presents the groups composed by two or three families who have the blood relationship.) was approx. 700–1300 kg as mean (Suzuki et al., 2015). Calculating the consumption per UPA (as 15 persons) using the daily consumption that is about 500–1000 g per person, the annual consumption should be about 2738–5475 kg (Suzuki et al., 2015). This explained that the current yield of pearl millet cannot cover for an UPA.

This low productivity is due to the small and erratic amount of rainfall and the low soil fertility (Abdoulaye and Sanders, 2006; Bagayoko et al., 2011; Suzuki et al., 2015). Breman and de Wit (1983) reported that plant growth is frequently limited more by low availability of N and P than by low rainfall. Suzuki (2008) attempted to elucidate the correlation between rainfall amounts and total dry matter (TDM) of pearl millet from 1998 to 2006. TDM did not show any correlation with the annual amount of rainfall but increased with the application of fertilizer and organic matters (Suzuki, 2008). This explained that the main factor for low productivity is low soil fertility in the Sahel region.

* Correspondence to: International Institute of Tropical Agriculture, PMB 5320, Oyo Road, Ibadan, Nigeria.
*E-mail addresses:* ksuzuki28@yahoo.co.jp, k.suzuki@cgiar.org (K. Suzuki).

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The Sahelian soil is extremely sandy; more than 90% is sand and less than 10% is silt and clay; the dominant clay mineral is kaolinite (West et al., 1984; Buerkert et al., 2000). Therefore, cation exchange capacity (CEC) is very low, about 1.0 $cmol_c\ kg^{-1}$ (West et al., 1984; Buerkert et al., 2000; Bationo et al., 2007). Owing especially to low CEC, soil nutrients are easily lost by leaching (Buerkert et al., 2000). Brouwer and Powell (1995, 1998) reported that the amounts of nutrients ($ha^{-1}$) lost with leaching were 1070 kg C, 91 kg N, and 19 kg P after 9–10 t $ha^{-1}$ of manure had been applied in the Sahel region of Niger.

The depletion of N and P nutrients is a very serious constraint for crop production in the region (van Keulen and Breman, 1990; Baidu-Forson and Bationo, 1992). According to our latest results in the long-term experiment at the Niamey Center of International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), N and P nutrients significantly affect the grain yield and total dry matter (TDM) of pearl millet. In particular, the total amount of applied N has a significant effect on TDM (Suzuki et al., 2016). Given the dominant role of the N nutrient for crop growth, soil management to avoid N loss and restore N nutrient content is very important (Giller et al., 1997; Zougmoré et al., 2004).

To restore soil fertility in the Sahel region, farmers used to employ a long fallow, more than 15 years (Wezel and Haigis, 2002). However, due to the high population pressure (World Bank, 2015) farmers have been employing short fallows (Hiernaux and Ayantunde, 2004) or using arable fields continuously with the affordable amendments: small amounts of fertilizer, livestock manure, household waste, and crop residue (Schlecht and Buerkert, 2004; Suzuki et al., 2014).

The accumulated results of previous studies in the long-term experimental fields of some countries in West Africa have explained that soil management which integrates fertilizer and organic matters, manure and crop residue, is optimum for improving crop production in the Sudano-Sahelian regions (Pieri, 1992). In the Niamey Center, another long-term experiment has been conducted since 1983 to elucidate the effects of the integrated application of fertilizer and crop residue. According to the data of previous studies, this integrated application can contribute to enhance grain yield and TDM of pearl millet (Hafner et al., 1993; Bationo et al., 1993, 1995, 1998; Yamoah et al., 2002; Abdou et al., 2012) also N uptake, N nutrient content in the soil surface, N balance (Hafner et al., 1993), organic matter content in the soil surface (Bationo et al., 1993, 1998; Abdou et al., 2012), and fertilizer use efficiency (Bationo et al., 1995; Yamoah et al., 2002). According to our latest results (Suzuki et al., 2016) in the Niamey Center, the integrated application of fertilizer and crop residue has the high potential to enhance TN and TC in soil surface and the N use efficiency (NUE) of pearl millet. However, in the data

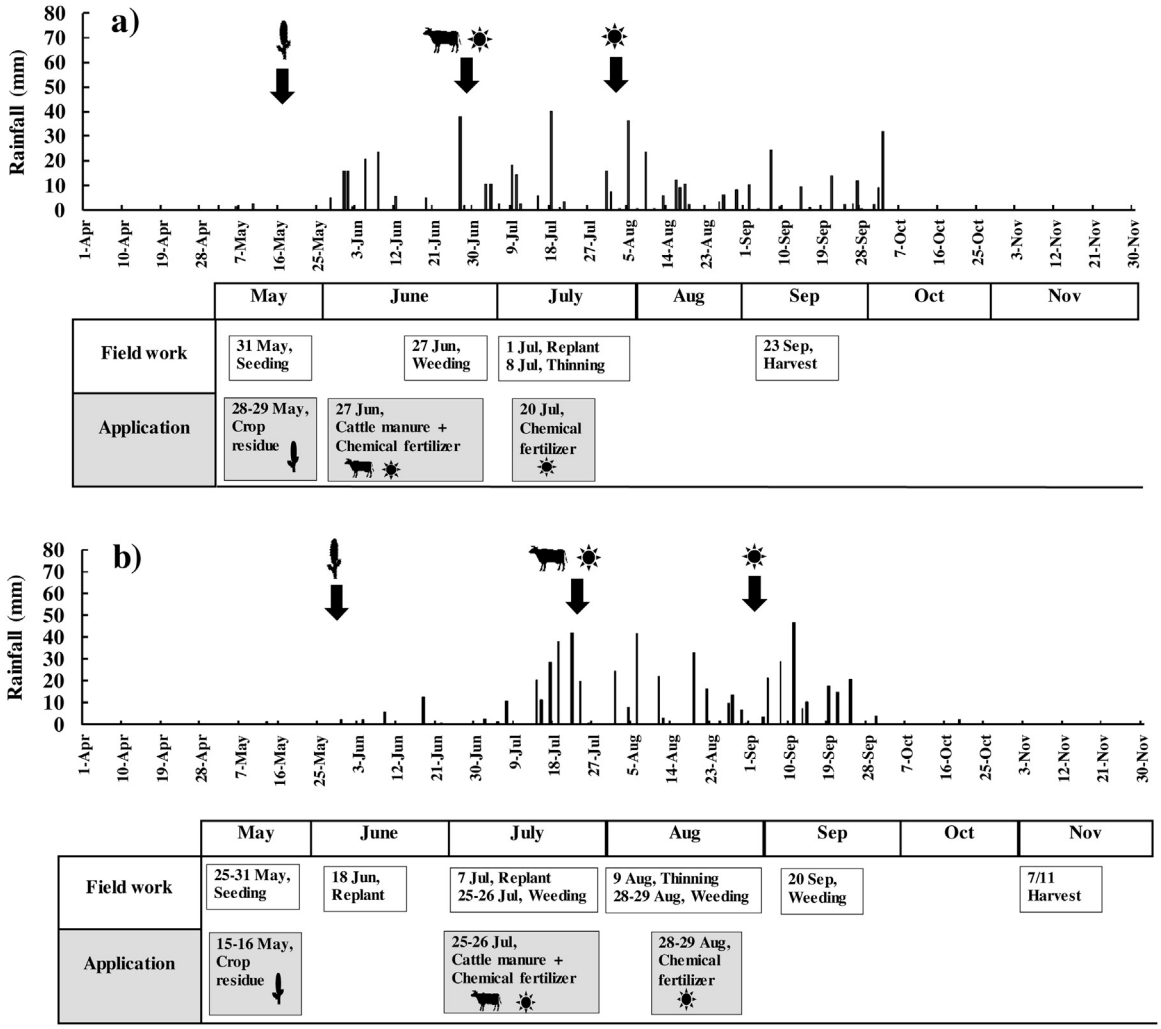


**Fig. 1.** Rainfall patterns and schedules for field work and applications conducted in (a) 2005 and (b) 2006.
The crop, cow, and sun represent the application of crop residue, cattle manure, and fertilizer, respectively.