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The effect of nitrogen fertilization management on yield and nitrate contents in sorghum biomass and bagasse

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ABSTRACT

Improved nitrogen (N) management for sorghum production on sandy soils is necessary to maximize N use efficiency, increase yield and mitigate N losses contributing to environmental contamination. A three-year field experiment was conducted on Brunic Arenosols soil in the southwestern region of Poland in a moderate temperate climate to evaluate the effects of varied N fertilization management methods on sweet sorghum hybrid (Sucrosorgo 304) yield and nitrate (NO_3^-) contents in biomass and bagasse. Sorghum was grown under two levels of N supply – 90 and 180 kg N ha^{-1}, once or split applied as enhanced-efficiency N fertilizer – polymer coated urea and as common N sources – ammonium nitrate and urea. The experimental design included control treatment without N input. Sweet sorghum biomass yields did not significantly differ between N sources. The split application of conventional N sources did not improve sorghum biomass yield. No significant differences were observed in biomass yield averaged across years and N rates in response to the application strategy in the case of all N sources. Highly variable weather conditions during the three sorghum growing seasons resulted in significantly varied biomass yields, ranging from 9.1 to 14.8 Mg dry mass ha^{-1}. Nitrate content tended to be higher in biomass within each fertilizer compared with that in bagasse. This study demonstrates that polymer coated urea at the rate of 90 kg N ha^{-1} provides biomass with a safe level of NO_3- and can be recommended in sustainable sweet sorghum production for forage. In addition, in this study an indirect strategy based on Soil Plant Analysis Development (SPAD) readings measured during growing season was proposed to predict NO_3- level in biomass at harvest. Results showed that this non-invasive method could provide valuable information on potential NO_3^- accumulation and animal poisoning risk. However, further research is needed to establish the quantitative relationship between SPAD readings and NO_3^- level in relation to environmental factors and varied N supply.

1. Introduction

Modern intensive crop production systems are based on high nitrogen (N) fertilizer inputs to maximize crop yields in order to meet the demand of the growing world population (Le Noë et al., 2017). The world agricultural use of N fertilizers in 2015 was over 109 million tonnes and according to forecasts this amount will increase over the coming years (FAOSTAT, 2017). Improper N management, especially over-application of N fertilizers, has led to low N use efficiency limiting crop yields (Zhang et al., 2015). Low N recovery has resulted in N losses through ammonia (NH_3) volatilization, nitric oxide (NO) and nitrous oxide (N_2O) emissions, nitrate (NO_3^-) leaching and surface runoff and has consequently contributed to air pollution, groundwater contamination and problems connected with the eutrophication of surface waters (Benoit et al., 2015; Demurtas et al., 2016; Pan et al., 2016; Yan et al., 2015). Therefore, more sustainable N management is necessary to increase low N use efficiency in modern agricultural systems and mitigate the environmental pollution resulting from N losses (Zhang et al., 2017). Sustainable N management is particularly crucial in environments prone to N leaching such as coarse-textured (sandy) soils with a poor sorption complex and limited retention capacity (Herrera et al., 2016). Split fertilizer application is considered one such improved N management practice providing higher crop uptake efficiency due to minimizing the length of time that inorganic N is present in the soil solution prior to uptake by the plant (Grant et al., 2012; Kilcer et al., 2002). However, the split application system has some drawbacks. It requires an extra field operation and, as a result, is more time- and labor-consuming than single fertilizer use (Trenkel, 2010). Moreover, studies on the benefits of N rate splitting have strongly inconsistent results. In brown midrib (BMR) sorghum (*Sorghum bicolor* (L.) Moench)

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× Sudangrass (*Sorghum sudanense* (Piper) Stapf.) hybrid production in the northwestern USA and in grain sorghum production in Ethiopian highland Vertisols, split application has shown advantages as compared to the single application of full N rate (Kilcer et al., 2002; Melaku et al., 2017). However, under the growing conditions of northern Ethiopia splitting the N application does not enhance the biomass yield of sweet sorghum (Gebremedhin et al., 2016).

Applying slow- or controlled-release fertilizer, such as polymer coated urea, which more closely matches N release to uptake by crops, is a promising alternative practice to split fertilizer application (Trenkel, 2010; Du et al., 2006). Many recent studies have indicated that the application of controlled-release fertilizer significantly increases N use efficiency and crop yield and decreases the risk of N loss (Kabała et al., 2017; Sowiński et al., 2016b; Yan et al., 2015; Yang et al., 2017). In contrast, outcomes of studies conducted in northeastern Australia have shown that urea coated with a nitrification inhibitor does not provide substantial improvements in sorghum grain yield (De Antoni Migliorati et al., 2016; Lester et al., 2016).

In recent years, researchers have made significant efforts to devise N management strategies for maximizing N use efficiency, taking into account the 4R nutrient management principles (right source, right rate, right time, and right placement) (IPNI, 2018). Keeping this in mind, monitoring of crop N status and in-season N dynamics plays a pivotal role in delivering correct N recommendations. The Soil Plant Analysis Development (SPAD) meter (also known as a chlorophyll meter) is a well-known tool for determining crop N status that can be useful in the adjustment of fertilizer level during the growing season (Herrera et al., 2016). In this study, we evaluated the utility of SPAD measurements as a tool to predict NO_3^- content in sorghum biomass and bagasse.

N fertilization management significantly affects not only crop yield, but also plant chemical composition, thus influencing quality. Applying N fertilizer at rates exceeding crop demand decreases forage quality as a consequence of NO_3^- accumulation (Liu et al., 2016). Many sorghum hybrids, the related Sudangrass and hybrids between these two species are important forage crops, particularly in warm, dry regions (Pino and Heinrichs, 2016). However, feeding with sorghum or Sudangrass can pose the threat of inadvertent NO_3- poisoning (Bhatti et al., 2011). The fast growing C4 grasses from the sorghum genus (*Sorghum* Moench) tend to accumulate allelochemicals (Głąb et al., 2017), as well as toxic NO_3^- levels, particularly when grown under stress conditions such as low temperature, drought or high humidity (Bhatti et al., 2011; Bolan and Kemp, 2003; Sidhu et al., 2011). Moreover, the problem of NO_3^- accumulation can escalate as a result of an increasing frequency of drought.

Very few studies have included measurements of the response of NO_3^- accumulation in crop biomass to controlled-release fertilizer or split N fertilizer application. Furthermore, the outcomes of these studies are inconsistent (Gagnon et al., 2016; Payne et al., 2015; Shapiro et al., 2016). In maize (*Zea mays* L.) production in the midwestern United States on loamy sand soil, polymer coated urea application resulted in greater stalk NO_3-N as compared with urea ammonium nitrate (Shapiro et al., 2016). Under similar climatic and soil conditions, both polymer coated urea and urea amended with urease and nitrification inhibitors decreased the amount of NO_3-N in maize stems as compared with a split application of urea (Maharjan et al., 2016). It is also worth mentioning that so far there is a lack of such studies conducted in the temperate climate of Central Europe. Until now, to the best of our knowledge no reports are available on the NO_3^- content in sorghum bagasse; an important by-product in the sweet sorghum-based ethanol industry which remains after extraction of juice from sorghum biomass and is considered a promising alternative livestock feed resource (Rao et al., 2013).

Given this, the objectives of this study were to assess the forage yield and NO_3^- content in sorghum biomass and bagasse in response to: (i) polymer coated urea and conventional N fertilizers: non-coated urea and ammonium nitrate, (ii) N rate and (iii) N fertilizer application strategy. Based on a determination of the relationship between SPAD readings and NO_3- content, the possibility of using SPAD as a quick, early method for forecasting NO_3^- content in biomass at harvest was evaluated.

The results of this study will help to devise sustainable N fertilization management in the production of sweet sorghum with safe NO_3^- levels under moderate climatic conditions.

2. Materials and methods

2.1. Study site and experimental materials

A three-year (2013–2015) field experiment to test the impact of N fertilization management on sweet sorghum yield and NO_3^- accumulation in sorghum biomass and bagasse was conducted at the Agricultural Research Station belonging to the Institute of Agroecology and Plant Production of Wroclaw University of Environmental and Life Sciences. The study site (51°10′25″N and 17°07′02″E) is located in the Lower Silesia region of southwestern Poland. The area is characterized by a temperate and moderate climate, with oceanic influences from the west and continental weather masses from the east (Dubicki et al., 2002). The annual mean air temperature is 9.0 °C, with a monthly minimum of −0.4 °C in January and a maximum of 18.8 °C in July. The annual mean precipitation is 583 mm. The growing season is characterized by daily mean temperatures ≥5 °C for 237 days (Tomczyk and Szyga-Pluta, 2016). The monthly rainfall and temperature at the experimental site during the period of the experiment were recorded at 10-minute intervals using an AsterMet automatic meteorological station (temperature sensor and hygrometer HMP-155; rain gauge station TPG-

Table 1
Monthly temperature and precipitation for site where sorghum trial was conducted during three growing seasons (2013–2015). Data were obtained from automatic weather station (Agricultural Research Station of Wroclaw University of Environmental and Life Sciences, southwestern Poland).

Month	$T_{average}$ (°C)				Precipitation (mm)			
	2013	2014	2015	Long-term average (1981–2010)	2013	2014	2015	Long-term average (1981–2010)
April	9.2	10.6	8.9	8.9	42.7	55.2	15.8	30.5
May	14.6	13.3	13.5	14.4	135.9	101.4	21.0	51.3
June	17.7	16.6	16.6	17.1	171.7	40.2	73.3	59.5
July	20.5	21.2	20.3	19.3	36.3	52.9	55.6	78.9
August	19.0	17.3	22.7	18.3	68.2	75.0	5.6	61.7
September	12.9	15.5	15.1	13.6	105.8	72.2	23.2	45.3
October	10.8	10.7	8.4	9.1	7.8	59.4	20.0	32.3
Mean/sum for period Apr.-Oct.	14.9	15.0	15.1	14.4	568.4	456.3	191.3	359.5

The long-term (30-yr) average weather data (1981–2010) was obtained from the meteorological station of Wroclaw University.