Sweet Sorghum and Nitrogen Fertilizer Application – A Review

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Abstract - Sweet sorghum is similar to the grain sorghum in every respect but with the added feature of accumulating sugar in its stalk, just like sugarcane, which has given the crop the ability to qualify as an energy crop. There has been a growing trend in the global interest in renewable energy sources as a result of the ever growing concern for the environment. In order to meet the increasing demand for energy crops, there is the need to boost their productivity, especially through optimum agronomic management practices. Nitrogen fertilizer is an important nutrient in crop productivity which has widely been reported to affect the productivity of sweet sorghum. The required application rates have been found to vary across seasons and location, and are also affected by the factors of the climate, soil type and genotype. Studies have however shown that the nitrogen fertilizer rate in the range of 60 and 120 kg N ha⁻¹ would result in optimum productivity depending on the location, the soil type and the native N of the soil determined through soil test.

Keywords: Sweet sorghum, nitrogen fertilizer, biomass, energy crop, ethanol

1. INTRODUCTION

The environmental pollution caused by heavy dependence on fossil fuel, the exhaustive nature of fossil resources and the quest for energy security have necessitated the recent global search for alternative sources of energy with sustainable features, and which have little or no negative impact on the environment. This search has brought about an increasing global interest in renewable energy sources to meet the world’s ever growing energy demand. Among the many alternative renewable energy options, biomass energy has been said to be gaining greater importance globally when compared with the conventional fossil sources and other alternative sources like nuclear energy [1, 2]. This is because many countries are introducing the mandatory blend of automotive fossil fuels with biofuels which has prompted research efforts into this sustainable and economically viable energy source [3]. Apart from the blending requirement of fossil fuels, many countries are also working towards meeting their heating and electricity needs using biomass. Examples of such countries are United States of America (USA), Brazil, China and India.

The term biomass energy, bioenergy or biofuel refers to any energy product derived from plant or animal or other organic materials [4]. Bioenergy derived from plant-based fuels has been the major thrust across countries to develop alternative energy sources, with bioethanol and biodiesel as the most common commercially exploited of these [3]. Biodiesel is commonly obtained from palm oil, other edible oils and Jatropha oil while the major commercial sources of bioethanol are sugarcane (e.g. Brazil), corn (e.g. USA) and sugar beets (e.g. Europe). In addition, sweet sorghum is recently gaining popularity as a major feedstock for commercial bioethanol production. This is because of its numerous advantages over other candidate bioethanol crops such as sugarcane, corn and sugar beet. One such advantage is the early maturity of sweet sorghum [5, 6, 7]. Others include low water requirement, high biomass and alcohol production potential with its resultant greater income potential [8].

Sweet sorghum is an annual crop that is readily established from seeds and can be incorporated into existing rotations. It favourably answers the “food or fuel” question as it does not compete with food or feed, and it can ratoon, following harvest, under favourable climatic conditions. These features have made sweet sorghum a choice bioethanol crop of the semi-arid tropics in the sub-Saharan Africa and India [9]. It is a crop of high universal value since it can be cultivated in tropical, subtropical, temperate, and semi-arid regions, as well as in poor quality soils of the world [10]. It is termed “the sugarcane of the desert” or “the camel among crops” due to its drought hardy characteristics [11].
Good crop management practices are important in attaining higher stalk yield, which one way or the other translates to high ethanol yield in sweet sorghum. Among the various inputs that improve the efficiency of a cultivar in realizing its potential, fertilizers, and nitrogen in particular, play a crucial role. Nitrogen is generally a limiting nutrient in crop, and especially in sorghum, as it has been said to be the most responsive nutrient for its production [12]. To achieve economically viable returns therefore, efficient use of available resources, like nitrogen, is necessary to maximize yields [13]. The application of nitrogen fertilizer has resulted in variable responses in sweet sorghum due to differences in climatic, soil and genotypic factors across seasons and locations [14, 15]. The aim of this review is to assess the impact of nitrogen on the productivity of sweet sorghum with particular focus on the biomass and ethanol yield.

II. SWEET SORGHUM: DESCRIPTION, PRODUCTION AND UTILIZATION

Sweet sorghum is similar to grain sorghum except for its juice rich sugary stalks that grows rapidly, yielding higher biomass. Ripe sweet sorghum typically consists of approximately 75% cane, 10% leaves, 5% seeds and 10% roots by weight [16]. The crop, like the grain sorghum, produces grain which can be harvested for human consumption and accumulates sweet juice in its stalk which can be extracted and processed to syrup or fermented to produce ethanol. The material remaining after the extraction of the juice, called bagasse, can be used as animal feed or pre-treated, hydrolysed and fermented to produce second generation ethanol. The starch from the grains may also be fermented to produce ethanol [17]. The fermentation of the starch obtained from the grains increases the bioethanol yield obtainable per hectare of sweet sorghum planted [18]. It is a bioenergy crop which accumulates large amounts of fermentable sugars in its stalks in a similar way to sugarcane. It is grown mainly for syrup production in the USA, especially on small scale and for bioethanol production in India and elsewhere [19, 20, 21]. Its ratooning ability enables multiple harvests per season, a feature that could expand the geographical range of sorghum cultivation [10].

Although sweet sorghum, like all other crop of the sub-tribe Sorghinae and genus Sorghum, is of African origin, it is cultivated in a wide range of environments not only in Africa, but also in China, USA, India, Mexico, etc., and is well adapted in all countries located between 45°N and 45°S latitudes on either sides of the equator, in areas receiving as low as 700 mm annual rainfall [19, 22]. And because of its multiple uses, sweet sorghum has been said to be cultivated in semi-arid to humid climates in about 100 countries on over 44 million hectares [23].

Ethanol from sweet sorghum can be produced utilizing the same infrastructure and equipment as that utilized in converting sugarcane into alcohol [24]. Therefore, researchers, policy makers and producers both in tropical and temperate countries around the world are promoting sweet sorghum as alternative bioenergy feedstock for ethanol production [25, 26, 27, 28]. It is considered one of the most promising crops for the production of ethanol at low cost because of fewer inputs and less water requirements [17, 29].

There are approximately four thousand varieties of sweet sorghum throughout the world [16], with sugar yields ranging between 1.6 to 13.2 t ha⁻¹, depending on the variety, period and location of production [9, 30, 31]. It has been established that the juice sugar content is dependent on the crop stage; fructose has been found to be more abundant at the early development stage, whereas sucrose tends to be dominant after heading [32]. The sweet sorghum juice sugar content has been reported by Ritter et al. [33] and Reddy et al. [9] to be in the range of 10 to 25 Brix% at maturity. Research at the International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT) has also shown that sweet sorghum juice yield ranges between 16.8 and 27.2 m³ ha⁻¹ (16,800 – 27,200 L ha⁻¹) [9] and accrues about 23% additional returns through the harvested grain [19].

Apart from the carbohydrates that can be fermented for the production of ethanol, sweet sorghum has high biomass yield potential. The bagasse that is left after juice extraction can be an excellent energy source for the ethanol processing facilities [34, 35]. Some of the co-products such as the leaves and grains may be utilized for animal feed. The bagasse can be used in paper production, as biofuel, livestock feed, or for soil application [35].
Generally, the stages of growth in sorghum have been distinctly classified into three; vegetative, reproductive and grain filling and maturity stages [36]. The three main stages have been further broken down to ten growth stages, numbered 0 to 9. The vegetative stage of the crop begins at seed sowing. It has been broken down to include emergence, 3-leaf stage, 5-leaf stage, and it ends at panicle initiation, spanning a period of about 30 days. The reproductive stage begins at panicle initiation, and it includes emergence of flag leaf and booting. It terminates at anthesis. The last stage of growth sets in. Under this third main growth stage, the plant goes through the soft and hard dough stages, and terminates at physiological maturity [37].

The vegetative stage is characterized by vegetative growth. The plant develops leaves and tillers, which ultimately support grain formation and growth. The duration of this stage is largely dependent on air temperature and the hybrid maturity. The more leaves formed by the plant, the longer the maturity. Early maturing hybrids typically produce 15 leaves per plant, while medium and late maturity hybrids produce 17 and 19 leaves each. At this stage of growth, the plant can tolerate stress from drought, hail and freezing temperatures with little negative effect on grain yields [38].

Tillering occur in some varieties when the plants are in the 4- to 6-leaf stage. Modern sorghum hybrids produce from zero to four fertile tillers in field conditions so that at plant densities below 4 m⁻², around 70 – 80 % of total plant leaf area and grain yield can be attributed to tillers [39, 40]. Panicles of tillers are often smaller and flower later than those of the main stem. Tillers formed can compensate somewhat for low plant populations [38].

The second growth stage begins with panicle initiation and continues to flowering. This is the period when reproductive structures of the panicle form and the maximum number of seeds per panicle is set [38]. During this period, plants are especially sensitive to any type of stress such as temperature extremes, nutrient deficiencies or water deficits or excess, any of which may reduce the potential seed numbers. It is considered the most critical period for grain production since seed number per plant accounts for 70% of the grain yield [41].

At the boot stage all leaves are now fully expanded, providing maximum light interception and the flag leaf appears. The head has now developed to nearly full size and is enclosed in the flag leaf sheath. Peduncle elongation is beginning and will result in exertion of the head from the flag leaf sheath. Potential head size has been determined at this stage of development. Moisture stress at the boot stage may prevent the head from exerting completely from the flag leaf sheath, which may cause harvest difficulty. Following the boot stage, the peduncle grows rapidly extending the head through the flag leaf sheath [38].

The final growth stage begins with flowering and continues until physiological maturity. Flowering begins when yellow anthers appear at the tip of the head five to seven days after head exertion. Over the next four to nine days, anther development progresses down the head. The plant is considered at half bloom when flowering has progressed half way down the head. Many grain sorghum hybrids grown in Arkansas require approximately 75 days from emergence for the plant to reach half bloom. The most critical time for moisture begins about one week before head emergence or the boot stage and continues through two weeks past flowering [38].

Scouting for sorghum midge is critical at flowering. One midge per head can lower grain yield 10 to 20% [41]. After flowering, seed development begins and progresses through development stages of milk, soft dough, hard dough and physiological maturity over a 25 to 45 day period after flowering, depending on the variety and growing conditions. Kernels reach their maximum volume approximately 10 days after flowering during the milk stage. The seed is soft and a white milky fluid appears when the seed is squeezed. The soft dough stage occurs approximately 15 to 25 days after flowering when 50% of the seed weight has been accumulated and little to no fluid appears when the seed is squeezed. The grain is very susceptible to bird and head webworm during the soft dough stage. When the seed is in the hard dough stage, the grain cannot be squeezed with the fingers and approximately 75% of the seed weight has been accumulated [38].

Drought stress during the soft or hard dough stage can result in shrivelled grain with a low test weight. Physiological maturity occurs when a black-layer appears immediately above the point of kernel attachment in the floret near the base of the kernel. The seed moisture is approximately 30 to 35 percent and has reached its full potential weight. Grain harvest can begin at approximately 20 percent moisture with no mechanical damage to the seed [38].
IV. SWEET SORGHUM AGRONOMY

The already standardized agronomic practices for grain sorghum are not entirely applicable to sweet sorghum because sweet sorghums produce more biomass along with sugars [10]. However, the cultivation and practices involved in the production of sweet sorghum are simple and readily adoptable [42]. Sweet sorghum is a short-day plant with most varieties requiring fairly high temperature for optimized growth and can do well in a wide range of soil conditions, from heavy clay soil to light sand [7]. Different varieties of sweet sorghum have been found to require different day lengths. Therefore, in low latitude zones, with short days, most varieties of sweet sorghum have lower biomass yields [43]. It is therefore necessary to select the genotype suitable to the local day length conditions to achieve good harvests. The crop can tolerate a pH range of between 5.0 and 8.5, and some degree of salinity, alkalinity and poor drainage [44, 45].

Although, seedling emergence and stand establishment is important for crop performance, this is relatively difficult to achieve in sweet sorghum because of the small seed size and often low germination rate compared with grain sorghum, especially with other constraints such as soil crusting, limited soil water after planting, uneven planting depth, weed competition, and insect pests [35]. Sweet sorghum is typically seeded in widely spaced rows (between 75 and 100 cm), while the ideal seeding rate for most sweet sorghum varieties is 3–4 seeds per linear foot (about 30 cm) of row with a final stand of 2-3 plants per 30 cm of row. If plant populations are too high, the stalks will be spindly and contain less juice [46]. This assertion may however not be generalized. According to Turgut et al. [47] in an experiment in Turkey, biomass yield was more with 15 plants m⁻² (150,000 plants ha⁻¹) than with lower plant populations of sweet sorghum. Also, Lueschen et al. [48] in an earlier experiment did not observe any effect of seedling rate on sweet sorghum fermentable carbohydrate or ethanol yield, while Ferraris and Charles-Edwards [49] found plant density effects on sugar concentration to be minimal.

Planting is usually done when the air temperature is above 12°C [45], a condition that prevails all through the year in the tropics. Late planting has been said to reduce the length of the growing season, yield and carbohydrate content [50]. Also, late planting may cause late and troublesome harvest and may expose the crop to pests and diseases and other hazards which are dominant at the end of the cropping season [45]. Thus planting should be planned appropriately.

Balanced fertilization can increase yield [51]. Nitrogen fertilizer and its application time have been demonstrated to promote sucrose content and growth rate in sweet sorghum [52]. Also, application of adequate amounts of K fertilizer increases yield responses than increasing levels of nitrogen fertilizer alone [45, 53, 54, 55, 56]. In a study in India, response of sweet sorghum to micronutrients (like B, Zn and S) in juice yield and quality was observed [57].

The grain and sugar yields have been proved to be best in the rainy and summer seasons, whereas in the post-rainy season, the grain yield is high, but with lower stalk and sugar yield. However, the results from tropical and temperate crosses have been shown to result in the development of few post-rainy season cultivars [10].

V. GROWTH AND YIELD RESPONSES OF SWEET SORGHUM TO NITROGEN FERTILIZER APPLICATION

Crop management is important to attain higher stalk yield in sweet sorghum. Among the various inputs that improve the efficiency of a cultivar in realizing its potential, fertilizers (nitrogen in particular) play a crucial role. Nitrogen is generally a limiting nutrient in crop production, and especially in sorghum, as it has been said to be the most responsive nutrient for its production [12]. To achieve economically viable returns, efficient use of available resources, like nitrogen, is necessary to maximize yields in all seasons. Variable responses to the application of nitrogen fertilizer have been observed in sorghum owing to differences in climatic, soil and genotypic factors across seasons and locations [14].
Uchino et al. [58] observed that the growth of sweet sorghum in Alfisols soil type during the rainy season in the Indian Semi-Arid Tropics (SAT) was poor without the application of N fertilizer in both years (2009 and 2010) of the study. They observed that the application of N fertilizer had significant positive effect on the plant height and the SPAD values, especially at the rate of between 90 and 120 kg N ha\(^{-1}\). This resulted in significant increase in both grain and sugar yields of the crop. This is similar to the outcome of the study carried out by Olugbemi and Abayomi [59] who demonstrated that nitrogen fertilizer significantly enhanced both growth and ethanol yield of sweet sorghum grown in the southern guinea savannah agro-ecological zone of Nigeria, and therefore recommended the application of 120 kg N ha\(^{-1}\) for optimum performance of sweet sorghum grown in that area. In Iran, nitrogen application rates have been demonstrated to affect growth parameters such as leaf area, leaf dry weight, stem dry weight, total dry weight and yield components examined at the various stages of growth of sweet sorghum varieties [55]. The study indicated that the application rate of 180 kg Urea ha\(^{-1}\) (82.8 kg N ha\(^{-1}\)) and 50 kg potassium sulfate ha\(^{-1}\) resulted in highest measured parameters in one of the two cultivars (cv. Keller) studied. Sawargaokar et al. [60] reported significant increase growth and yield with the application of 90 kg N ha\(^{-1}\). An increase beyond this rate however resulted in a decrease in the marginal gain.

In their bid to standardize the optimum fertilizer N dosage for the optimization of sugar yield in sweet sorghum in Patancheru, India, Reddy et al. [61] observed that a basal application and top-dressing of a total of 64 kg N ha\(^{-1}\) was sufficient to bring about an optimum sugar production in the sweet sorghum varieties studied in the rainy season, with no significant difference observed for higher rates. This result was found to be similar to the outcome of an experiment conducted by Sumantri and Lestari [62] who recorded a trendy increase in the stalk yield up to 90 kg N ha\(^{-1}\) where a maximum of 120 kg N ha\(^{-1}\) was applied.

Similarly, Coutinho et al. [63] have observed that cane and ethanol yields in sweet sorghum increased with application of up to 100 kg N ha\(^{-1}\). Other traits, apart from the stalk yield have also been demonstrated to be positively affected by an increase in N fertilizer application. Such traits include plant height, time to 50% flowering, juice volume, °Brix, grain yield, etc. The post-raining season trial by Reddy et al. [61] did show that the varieties used responded a little differently from what was obtained in the raining season trial. They however recommended an application rate of 64 kg N ha\(^{-1}\) for optimum yield in sweet sorghum.

Another study carried out by Amall et al. [64] in order to investigate the fertilizer N management in sweet sorghum in the United States of America indicated that there is significant economic benefit in increasing fertilizer N rate to and beyond 112 kg ha\(^{-1}\). It was observed that split application of fertilizer resulted in higher yields than single application rates of fertilizer, even at the rate as high as 168 kg N ha\(^{-1}\). Similarly, Almodares et al. [65] recommended three equal split applications of 300 kg urea (about 140 kg N) fertilizer ha\(^{-1}\) at planting, four-leaf and booting stages for optimum crop performance.

On the contrary, Almodares et al. [66] reported that there was no significant effect of nitrogen treatments on the stalk yield, brix value and sucrose content at harvesting stage. The observation was corroborated with the view of Cosentino et al. [67] who noted that the crop, when examined with the supply of different amount of nitrogen, seems to be insensitive to mineral nitrogen supply and seems to have a great potentiality in semi-arid environment in terms of yield production. This view of insensitivity of sweet sorghum to mineral nitrogen supply is in disagreement with the trends that have been observed by several other workers who have embarked on similar investigation [13, 55, 59, 68, 69, 70].

**VI. CONCLUSION**

Nitrogen is an important nutrient for optimum crop growth and yield performance. Although its effect on the growth and yield of sweet sorghum has been demonstrated to be dependent on the factors of climate, soil type and genotype which also vary across seasons and locations, the application nitrogen generally results in increase in the biomass and yield of sweet sorghum until an optimum rate is reached. This optimum rate varies from one location to another and from one season to another. However, from this, the optimum rate can be said to lie within the range of 60 and 120 kg N ha\(^{-1}\) depending on the location, the soil type and the native N of the soil determined through soil test.
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