LANDBAUFORSCHUNG VÖLKENRODE HEFT 4/1999 SEITE 177 - 184

A Contribution Towards Sustainable Agriculture - Identification of Low Input Sorghum Genotypes: I. Biomass and Yield

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1 Introduction

There is a growing awareness about the need to adopt more sustainable and integrated systems of agricultural production that depend less on chemical and other energy based inputs. Such systems can maintain yield, reduce the cost of inputs, increase farm profits and reduce ecological problems. A sustainable system should involve the successful management of resources for agriculture to satisfy human needs whilist maintaining or enhancing the natural resource base and avoiding environmental degradation (El Bassam, 1998).

Fertile soils are one of the most important resources on earth. Sustainable agriculture should use this resource in such a way that not only the present growing needs for food and energy are met but its productivity is maintained or rejuvenated and managed for future agricultural needs. The concept of Low-Input and Sustainable Agriculture (LISA) is receiving priority considerations since early 1980s onward which places greater reliance on biological processes by adopting plant genotypes to diverse soil conditions, enhancing soil biological activities and optimising nutrient cycling to minimise fertiliser inputs and also enhance their efficiency. The soil nutrient is the most crucial element of soil sustainability. The moderation of low-input technology which is a fundamental stone of sustainable agriculture dwell on least resilient nutrient factor. Addition of the organic residues as organic amendments has been shown one of the well accepted approaches to maintain the nutrient capacity factor. Urban residues are being increasingly used on agricultural lands in an attempt to alleviate the serious environmental and health problems caused by their accumulation. However, their nutritional value has to be judged against possible contamination by undesired organic xenobiotics and heavy metals accumulation. If purified wastes with respect to heavy metals and pathogens are used on farm lands, they still are considered a sound alternative to mineral fertilisers. It should be mentioned, however, for the contamination with organic xenobiotics that a bias-free risk assessment is nearly impossible and thus bears an incalculable risk in long term application (Haneklaus et al., 1999).

Apart from traditional role of agriculture as a source of food and fodder, the modern use of crop biomass for industry and energy has been well documented, as a novel alternative to meet the future energy needs (El Bassam, 1998). Among the potential energy crops, sorghum is one of the most interesting crops because of its diverse end uses. It can be phrased as a 4F crop i. e. sorghum for Food, Fodder, Fibre and Fuel.

The breeders wish to see their cultivars succeed under high input systems and have selected under these conditions anticipating a continuous trend of intensification. However, in arid and semi-arid regions where marginal fertility predominates, the poor performance of these high input cultivars is largely attributed to limited agricultural resources. On the other hand, under intensive cultivation systems, a high dose of fertiliser not only adds to the cost of production but also influences the environment (NO_3 pollution) adversely. Therefore, special emphasis should be placed on aspects related to identification, selection and utilisation of high yielding and low input plant species in which production systems should be sustainable and environmentally acceptable.

The objective of this study was to evaluate the genotypic differences of sorghum varieties under a low input nutrient system via an organic source as a viable and sustainable alternative to a high nutrient input system.

2 Materials and Methods

In order to evaluate the genotypic behaviour of sorghum varieties and the agronomic effectiveness of organo top (OT) as a possible substitute of conventional fertilisers, a glass house experiment was conducted. Bulk soil sample (0-30 cm) was collected from the experimental site of FAL, Braunschweig, Germany. Important physico-chemical properties of the experimental soil are: 61 % sand, 33.4 % silt, 5.61 % clay, (textural class-sandy loam); pH - 7.23; EC (1:5) - 216 dS m^{-1}; total C - 0.92 %; organic C - 0.85 %; total N - 0.09 %; $N_{min.}$ - 24.2 mg kg^{-1} soil; plant available P (0.6 % calcium lactate, CAL) - 174.6 mg kg^{-1} soil; plant available K (0.6 % calcium lactate, CAL) - 105.4 mg kg^{-1} soil, plant available S - 18.4 mg kg^{-1} soil, plant available Mg - 40 mg^{-1} soil. The soil was air dried, passed through a 2 mm sieve and mixed thoroughly. Mitscherlich pots were filled with 6 kg soil (oven dry weight basis). Mineral fertilisers of N, K, S and Organo Top in different amounts were used as inorganic and organic source of nutrition, respectively. A comprehensive treatment plan is presented in **table 1**. Urea, KCl and $MgSO_4$ as source of N, K and S, respectively, were applied in liquid form. The contents were thoroughly mixed with the help of an electric agitator in order to have a homogeneous growth medium. Organo top and ADK were not mixed with soil. The required amounts of these fertilisers were imbedded in a depth of 10

Table 1: Fertiliser application rates applied in the experiment

Symbol	Description
T_1	$N_0K_0S_0$ (Control)
T_2	$N_{120}K_{200}S_{60}$ (N @ 120, K @ 200, S @ 60 kg ha^{-1}; recommended dose, reference treatment)
T_3	$N_{60}K_{200}S_{60}$ (N @ 50 % of recommended dose, full dose of K and S)
T_4	N_{30}K200S_{60} (N @ 25 % of recommended dose, full dose of K and S)
T_5	$N_{120}K_{100}S_{60}$ (K @ 50 % of recommended dose, full dose of N and S)
T_6	$N_{120}K_{50}S_{60}$ (K @ 25 % of recommended dose, full dose of N and S)
T_7	$N_{120}K_{200}S_{30}$ (S @ 50 % of recommended dose, full dose of N and K)
T_8	$N_{120}K_{200}S_{15}$ (S @ 25 % of recommended dose, full dose of N and K)
T_9	OT_{120} (60 g OT pot^{-1} equivalent to 120 kg N ha^{-1})
T_{10}	OT_{60} (30 g OT pot^{-1} equivalent to 60 kg N ha^{-1})
T_{11}	OT_{30} (15 g OT pot-$^{-1}$ equivalent to 30 kg N ha^{-1})
T_{12}	$OT_{60}F_{60}$ (60 kg N ha^{-1} from OT + 60 kg N ha^{-1} from fertiliser)
T_{13}	$OT_{90}F_{30}$ (90 kg N ha^{-1} from OT + 30 kg N ha^{-1} from fertiliser)
T_{14}	$OT_{200}F_{75}$ (1 packet of organo top supplying N equivalent to 200 kg ha^{-1} + 1 pellet of ADK supplying N equivalent to 75 kg ha^{-1})

cm of the soil. At a moisture level of field capacity, 10 seeds of each variety (HS 9, H 30 and H 174) were sown at a uniform depth of 2 cm. After establishment, only one plant was allowed to grow. Deionised water was used for irrigation purposes when required. Plants were continuously monitored and agronomic practices such as weeding and control of insects and pests were performed. The plants were harvested at maturity, separated into straw and grain. Dried until constancy of the weight in a ventilated oven at 85 °C, the plant material was ground in a Wiley mill and analysed for N (Kjeldahl), P (Autoanalyser), K (flame emission photometer) and S (X-ray fluorescence spectroscopy, Schnug and Haneklaus, 1992).

The experiment was carried out in a completely randomised block design (CRD) with four replications and the data were statistically analysed using the SAS package.

2.1 Organo Top (OT) and ADK

Organo top (Recycling und Umweltschutz GmbH, Gerwisch, Germany) is a multinutrient (N - 2 %; P - 0.83 %; K - 0.43 %; Mg - 1.28 %; Ca - 1.72 %; pH (1:5) - 12.80; EC (1:5) - 6.35 mS cm^{-1}; total C - 18.09%; organic C - 13.37 % and C:N - 1:9) organic fertiliser which was prepared from sewage sludge after its processing so that the heavy metal level is kept distinctly below the critical threshold defined in the sewage sludge regulation (Anon, 1992). Other unwanted properties such as pathogens were eliminated through the process of pasteurisation. ADK (Ammonium-Depotkugeln) is a combination of ammonium sulphate and urea (PROMINERAL GmbH, Essen, Germany) in the form of large pellets of 2.5 cm diameter. Each pellet contains 0.75 g N.

3 Characteristics chosen for the comparison of varieties

The traits used to characterise and compare varieties were (I) plant height at different growth stages, (II) straw and grain yield, (III) total biomass, (IV) harvest index (grain dry weight divided by total biomass), (V) nutrient (N, P, K and S) concentration in straw and grain, (VI) nutrient (N, P, K and S) uptake by straw and grain, (VII) nutrient use effi-

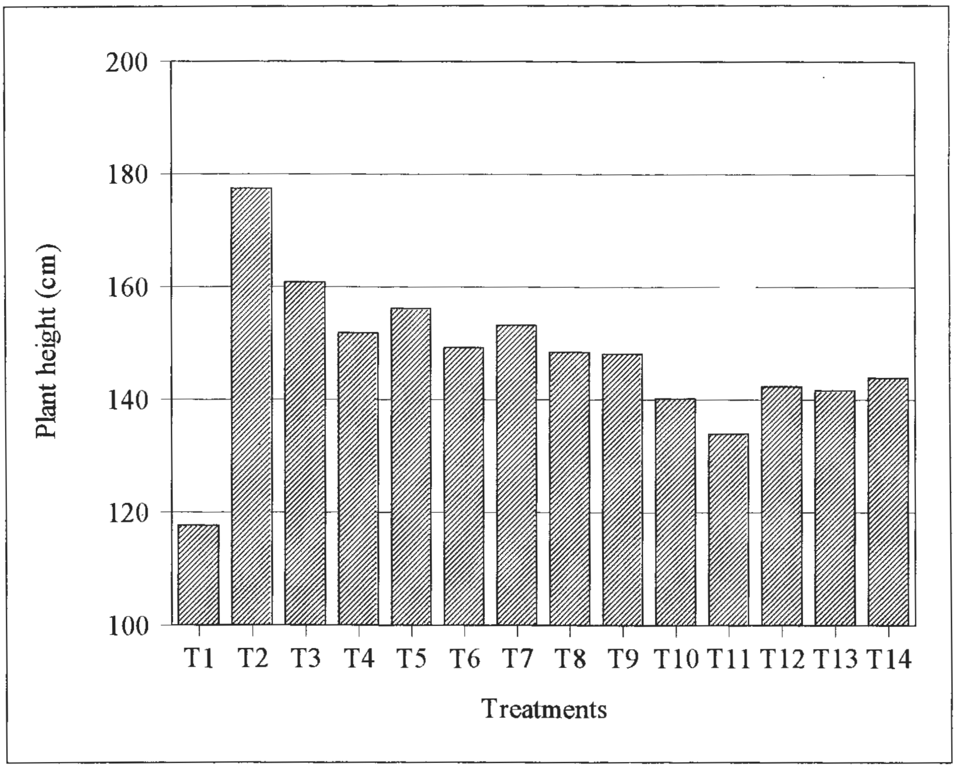

Figure 1: Effect of N K S and organo top fertilisation on mean plant height of fibre sorghum

ciency (total uptake of N, P, K and S divided by total biomass).

4 Results and Discussion

4.1 Plant Height

Plant height is an important determinant of biomass synthesis. The influence of different treatments on average plant height is presented in **figure 1**. The plant recorded the highest value under full dose treatment T_2; it was closely followed by treatment T_3 while other mineral treatments did not yield any statistically different effect. The plant height at organo top treatments T_9 and T_{12}-T_{14} was found comparable to low and moderate levels of mineral fertilisers. Navas et al. (1998) and Favaretto et al. (1997) also reported an increase in plant height of barley and maize due to sewage sludge application. **Figure 2** depicts the plant growth rate at different intervals. It is evident from figure 2 that with mineral fertilisation, the growth rate is substantially higher during the active growth period of biomass synthesis (60-120 DAS, days after sowing) whereas under organic fertilisation a higher growth rate was recorded during later growth stages. In the former case it was related to the instant availability of nutrients in the growth medium and in the latter case, it was related to a slow mineralisation of organo top and the subsequent release of nutrients into the rhizosphere. Surakod and Intal (1997) observed increased height of sorghum due to N application.

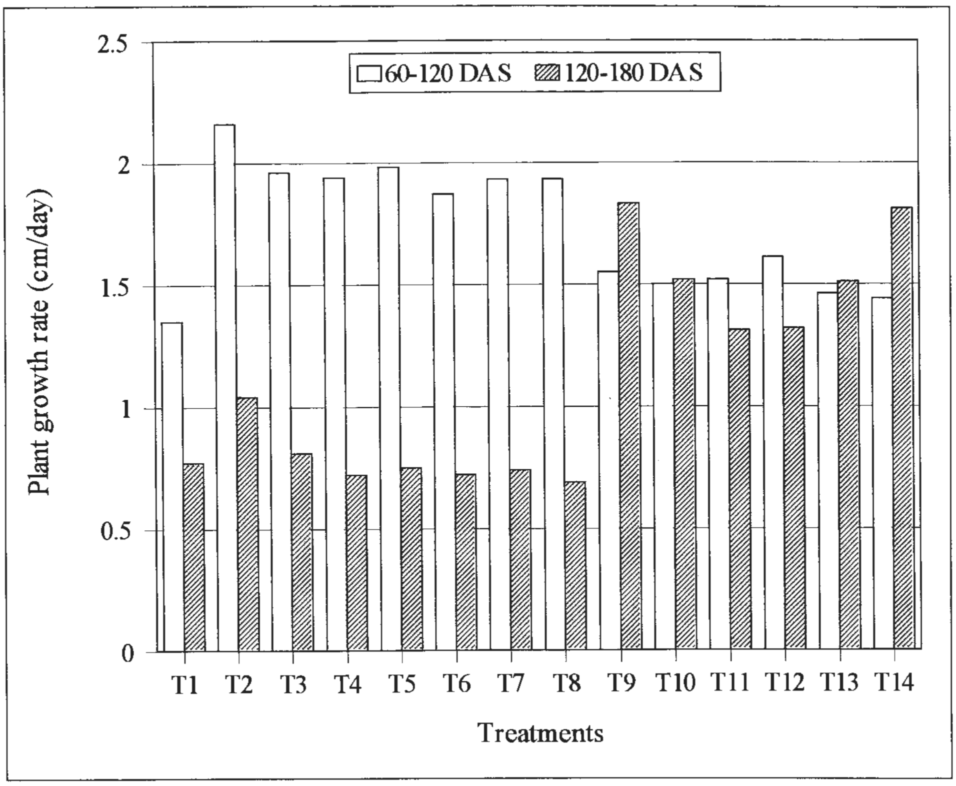

Figure 2: Effect of N K S and organo top fertilisation on mean growth rate of fibre sorghum (DAS-days after sowing)

Table 2: Effect of N K S and Organo Top fertilisation on dry matter yields (g pot^{-1}) of fibre sorghum

Treatments	Straw			Mean	Grain			Mean
	HS 9	H 30	H 174		HS 9	H 30	H 174	
T_1	44.9	40.2	35.3	40.1	3.1	5.1	10.1	6.1
T_2	102.4	105.4	59.9	89.2	21.6	32.2	47.4	33.7
T_3	77.6	72.5	41.7	63.9	17.3	27.5	33.5	26.1
T_4	73.3	66.5	35.9	58.6	8.7	24.2	26.9	19.9
T_5	68.3	72.6	52.5	64.4	9.9	21.0	26.9	19.3
T_6	67.9	61.6	41.6	57.0	6.8	29.6	35.8	24.1
T_7	69.3	58.5	53.7	60.5	16.2	33.6	21.8	23.9
T_8	69.4	57.1	45.2	57.3	14.7	38.7	22.5	25.3
T_9	80.9	88.4	57.3	75.5	11.2	10.9	23.3	15.1
T_{10}	68.5	64.8	48.5	60.6	5.0	14.0	22.2	13.7
T_{11}	64.5	57.5	44.1	55.4	4.1	12.8	16.0	10.9
T_{12}	95.8	66.5	47.2	69.9	8.9	27.5	38.4	24.9
T_{13}	98.9	81.4	50.5	76.9	11.8	13.9	34.2	20.0
T_{14}	88.3	97.4	56.6	80.7	6.8	19.9	31.3	19.3
Mean	76.4	70.7	47.9		10.4	22.2	27.9	
LSD (<0.05)								
Treatment		:	8.3			5.9		
Variety		:	3.8			2.7		
Treatment X variety		:	14.4			10.2		

4.2 Straw and Grain Yield

The perusal of data in **table 2** indicates that the productivity of sorghum has been substantially influenced by the application of fertilisers. Varieties HS 9 and H 30, significantly responded to added fertiliser (T_2-T_8) in comparison with the control but in case of H 174 the response was found confined to certain treatments i. e. T_2, T_5 and T_7. The varieties were found quite vulnerable to the reduced nutritional supply. As a consequence of this, significant reduction in straw yield of all varieties was being noticed at reduced levels of N (T_3 and T_4) against T_2. Reduced supply of K (T_5 and T_6) and S (T_7 and T_8) also had the same effect on var. HS 9 and H 30 but in case of var. H 174, significant reduction in straw yield was observed only at lowest application rate of these two nutrients (T_6 and T_8). It is also noticeable that these treatments of reduced individual nutrient do not vary with each other and are statistically at par. Application of organo top either alone or in combination with mineral fertiliser (T_9-T_{14}), significantly improved the straw yield of var. HS 9 and H 30 in comparison with control. In variety H 174 such response was observed only at treatment T_9 and T_{14}. Although the performance of var. HS 9 and H 30 was found poorer under the influence of organo top (T_9-T_{14}) in comparison with reference treatment T_2, still they out yielded the reduced fertility levels of N K S (T_3-T_8). On an average, 15, 22, 14 and 10 % reduction in straw yield was observed in organo top related treatments of T_9, T_{12}, T_{13} and T_{14}, respectively, over full recommended mineral dose (T_2). The corresponding reduction in straw yield due to reduced rates of mineral fertiliser treatments (T_3-T_8) ranged from 28 to 36 %. These figures suggest that organo top could be a better source of nutrition over moderate and low levels of mineral fertilisers. This kind of response has been already documented in figure 1.

The grain yield was also affected considerably as a result of mineral fertilisation particularly in var. H 30 and H 174 where a significant improvement in grain yield was found to occur at all treatments (T_3-T_8) over control. In variety HS 9 such response was observed only at T_2, T_3, T_7 and T_8. As in straw, reduced levels of individual nutrients N K S are statistically at par. Contrary to straw in case of grain production, var. H 174 demonstrated excellently under the auspices of organo top fertilisation and var. HS 9 absolutely did not respond to it.

The high response of sorghum to T_2 may be due to its balanced combination of N K S and their adequate availability in the plant rhizosphere where from they have been used in the biosynthesis of proteins and many other important biomolecules responsible for biomass synthesis. Several workers (Daurte et al., 1998; Kalpan and Orman, 1998; Kamoshita et al., 1998; Kamoshita et al., 1995; Utzurum et al., 1998; Belay et al., 1997; Kumbhare et al., 1997; Surakod and Intal, 1997; Balasubramanian and Ramamurthy, 1996; Kumawat and Bansal, 1996; Pal et al., 1996; Wanzari et al., 1996, Panwar et al., 1987 and Pal et al., 1982) have reported an increase in straw and grain yield, respectively of sorghum due to fertilisation with macronutrients (N P K S). The response of sorghum to organo top could be assigned to improved soil conditions and also an adequate supply of nutrients. Beneficial effects of various kinds of sewage sludge/city wastes on different plant species have been widely reported in literature (Cogger et al. 1998; Gerzabek et al., 1998; Kalpan and Orman, 1998; Partala et al., 1998; Silva et al. 1998; Kaczor, 1996; Rodenkirchen, 1996; Soltan et al. (1996); Hyll and Nestroy, 1993 etc.).

Comparing the varieties, it is possible to observe a significant difference for their straw and grain productivity. Variety HS 9 produced 60 and 8 % more straw over H 174 and H 30, respectively. Likewise, variety H 174 produced 167 and 26 % more grain over HS 9 and H 30, respectively. The wide differences in the ability to produce straw or grain indicate that these varieties differ widely in their genetics. Genotypic response of sorghum to N and P has been reported by Utzurrum et al., 1998; Deshmukh

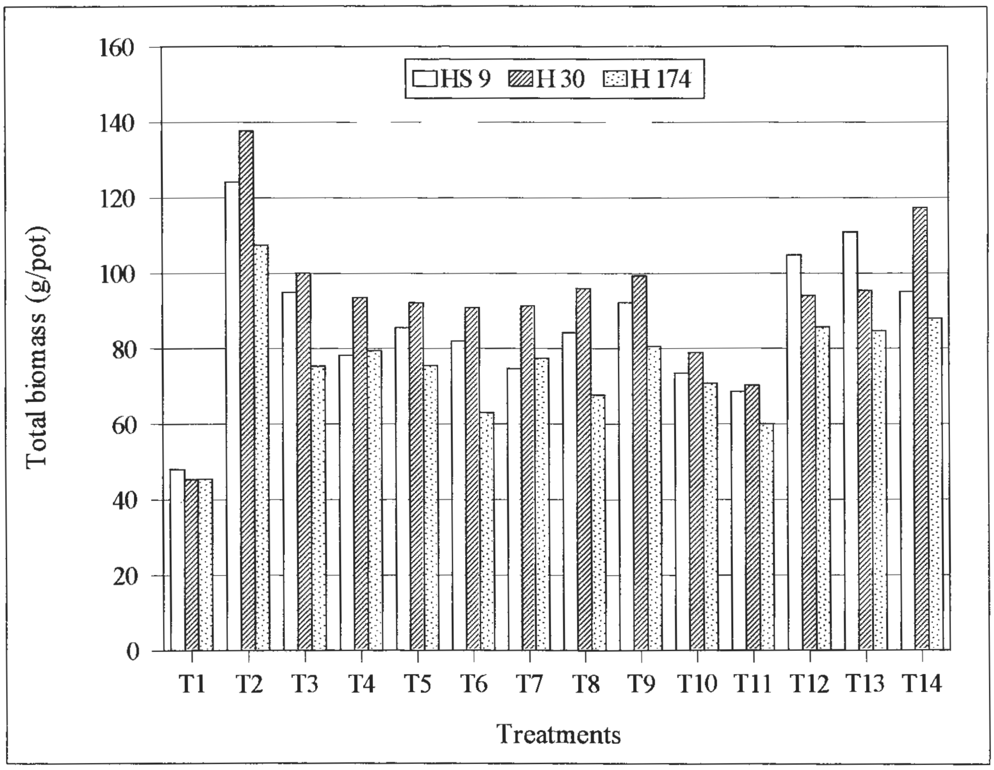

Figure 3: Effect of N K S and organo top fertilisation on total biomass of fibre sorghum

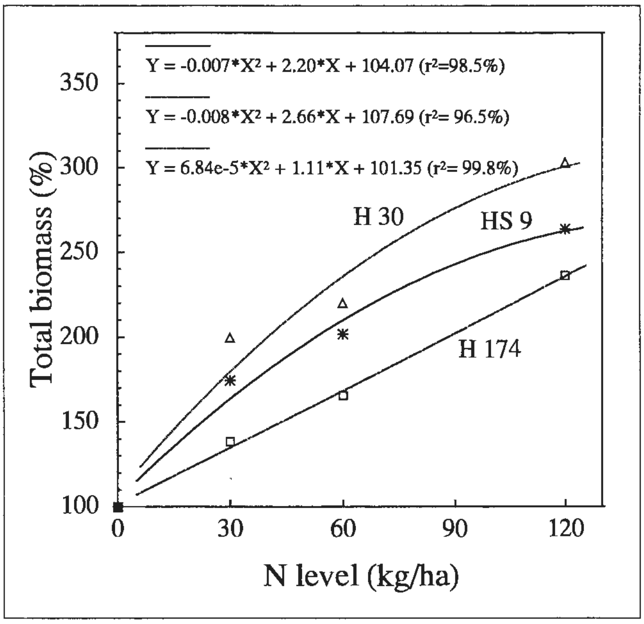

Figure 4a: Effect of N fertilisation (with full dose of K and S) on total biomass of fibre sorghum varieties (relative to control)

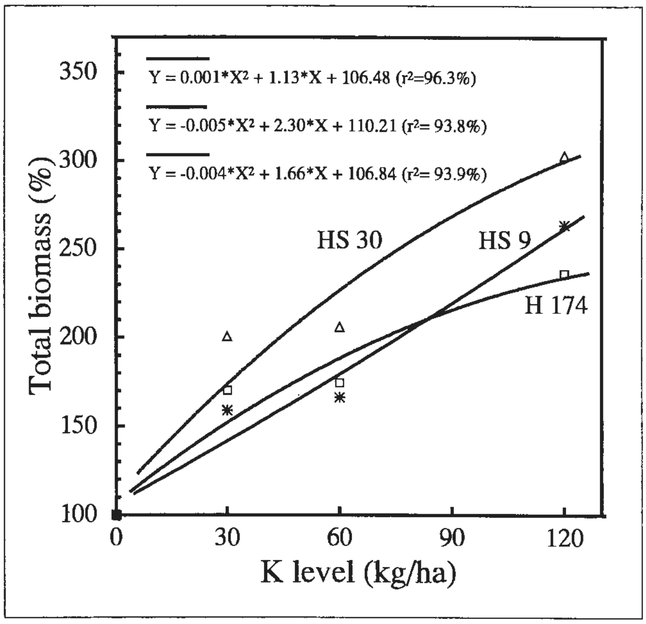

Figure 4b: Effect of K fertilisation (with full dose of N and S) on total biomass of fibre sorghum varieties (relative to control)

et al. 1996, Pal et al., 1996 and Crips and Matocha, 1987.

4.3 Total Biomass

It is apparent from **figure 3** that biomass synthesis is significantly higher at all treatments in comparison with control in all three varieties. The reduction of nutrient levels of N K S (T_3-T_8) from T_2 resulted in significant decline of biomass in all three varieties. However, the differences within these reduced levels of the individual nutrients were not significant. In case of organo top fertilisation, total biomass decreased with its decreasing application levels. It is apparent from the data that the application of organo top equal to 120 kg N ha^{-1} (T_9) and its integration with mineral fertiliser (T_{12}-T_{14}) yielded substantially higher amounts of biomass over the moderate and low fertility levels (T_3-T_8) supplied solely by mineral fertiliser. **Figure 4** (a-d)

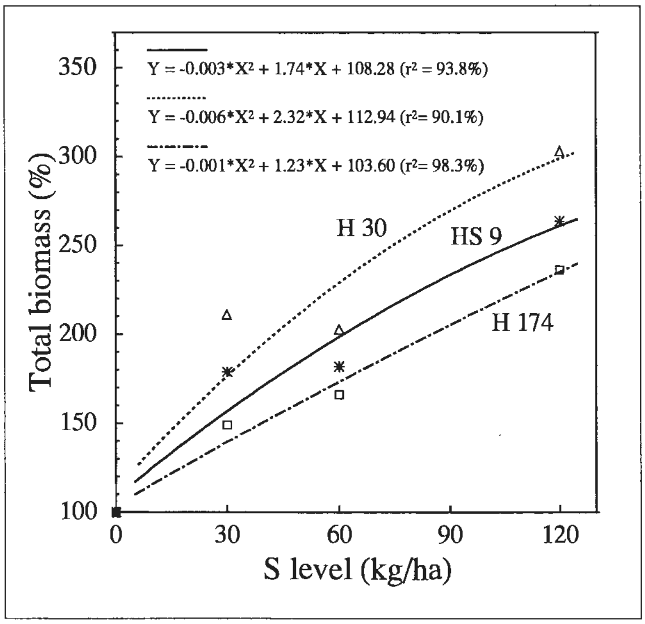

Figure 4c: Effect of S fertilisation (with full dose of N and K) on total biomass of fibre sorghum varieties (relative to control)

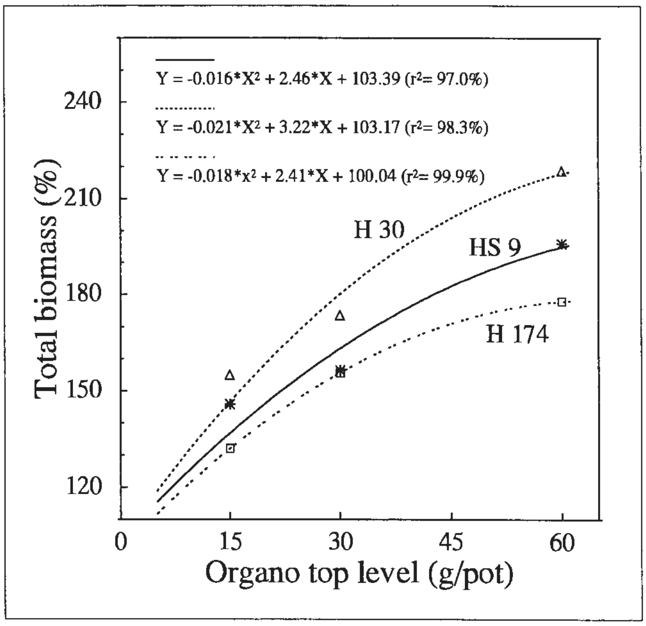

Figure 4d: Effect of organo top on total biomass of fibre sorghum varieties (relative to control)

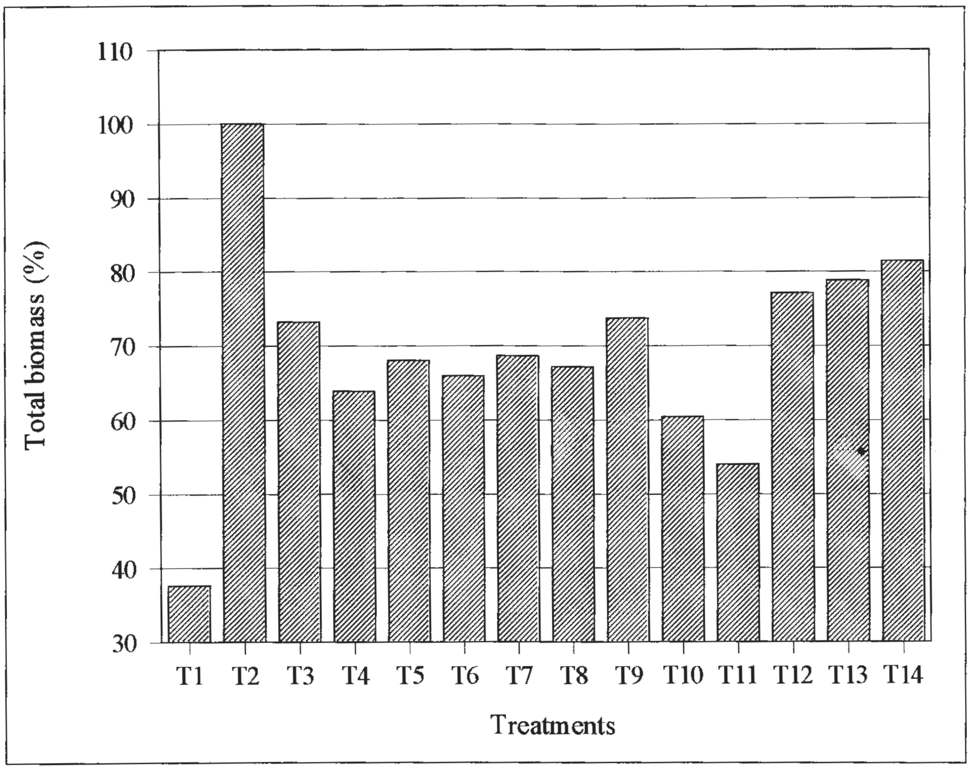

Figure 5: Effect of N K S and organo top fertilisation on total biomass of fibre sorghum (relative to T_2)

depict the genotypic differences of varieties with respect to individual nutrients (N K S and organo top) in terms of total biomass synthesis (relative to control, T_1). It is demonstrated that considerable genotypic differences exist between the varieties for individual nutrients and their levels, respectively. It is also seen that biomass synthesis by each variety increases progressively with increasing nutrient levels. **Figure 5** shows the precentual reduction in biomass compared to the reference treatment T_2. Under organic fertilisation the biomass production was reduced to 26, 23, 21 and 18 % at T_9, T_{12}, T_{13} and T_{14}, respectively, against T_2 where as in mineral fertilisation the percent decrease was recorded in the tune of 27, 32, 31, 36, 34 and 33 % at T_3, T_4, T_5, T_6, T_7 and T_8, respectively. The critical analysis of these values shows that the reduction in the biomass under organo top fertilisation was fairly lower than moderate and low supply of N K S (T_3-T_8). This behaviour is of particular interest whereby conventional fertilisation of N K S, if not fully, to a considerable level (at least 50 % fertiliser requirement) can be substituted by this methodology without compromising with production level. This kind of strategy strongly supports the basic hypothesis of HOLI (high output-low input) concept and assumes more significance where biomass with lower harvest index is grown for energy and other industrial purposes. Pierce et al. (1998) and El Maghraby and Abou Bakr (1997) observed higher biomass of perennial grass and sorghum respectively with the application of sewage sludge.

On an average H 30 produced significantly higher biomass than two others in the tune of 23 and 7 % of H 174 and HS 9, respectively.

4.4 Harvest Index

The harvest index, which reflects the ratio of economical yield and biological yield, is regarded as a measure of success in partitioning assimilated photosynthate to harvestable product. It assumes more significance when crops are cultivated for straw production for industry and energy purposes. In our present study (**table 3**), var. H 174 showed a significantly higher harvest index than its counterparts HS 9 and H 30 at all treatment levels (except at T_9 of H 30). This is probably due to higher grain yield produced by this variety. Conversely, the harvest index of var. HS 9 was found significantly lower than H 30 and H 174. This was obviously related to proportional higher straw yield. From these findings it can be deduced that var. HS 9 will be best suited for straw and H 174 for grain production while

Table 3: Effect of N K S and organo top fertilisation on harvest index of fibre sorghum

Treatments	Varieties			Mean
	HS 9	H 30	H 174	
T_1	0.06	0.11	0.22	0.13
T_2	0.17	0.24	0.44	0.28
T_3	0.18	0.27	0.44	0.30
T_4	0.11	0.26	0.43	0.26
T_5	0.13	0.23	0.33	0.23
T_6	0.10	0.32	0.46	0.29
T_7	0.19	0.36	0.29	0.28
T_8	0.17	0.39	0.33	0.30
T_9	0.12	0.11	0.29	0.17
T_{10}	0.07	0.18	0.31	0.18
T_{11}	0.06	0.18	0.27	0.16
T_{12}	0.08	0.30	0.45	0.28
T_{13}	0.11	0.15	0.40	0.22
T_{14}	0.07	0.16	0.37	0.20
Mean	0.11	0.23	0.36	

LSD (<0.05)
Treatment : 0.05
Variety : 0.02
Treatment X variety : 0.10

variety H 30 can be grown for both purposes. The harvest index of all three var. was found significantly improved at T_2 over control. Reducing nutrient supply from recommended level did not affect the harvest index of either of the variety. A striking difference for harvest index in var. HS 9 was being observed under organo top fertilisation (T_9-T_{14}) in comparison with T_2 where as var. H 174 failed to show any response towards this trait under these treatments. This kind of behaviour is due to differential response of these varieties for their straw or grain synthesis under organo top fertilisation.

Summary and Conclusion

In a green house experiment three sorghum varieties namely HS 9, H 30 and H 174 were evaluated for their performance under organic (organo top) and inorganic fertilisation. Results showed that genotypic differences for traits like straw and grain yield, total biomass and harvest index exists. Variety HS 9 produced the highest straw yield and hence showed the lowest harvest index. On the other hand var. H 174 produced the highest grain yield and therefore had highest harvest index. So far as production of total biomass as a function of individual nutrient is concerned, variety H 30 was superior to its counterparts. The influence of fertilisation on different traits was also visible. Highest yields were obtained at full dose treatment T_2, which were subsequently decreased at reduced input levels. Higher application rates of organo top (T_9) and its integrated treatments (T_{12}-T_{14}) produced comparable yields to that of reduced levels of mineral fertilisers.

From this study it is conclusive that there should be a good possibility to substitute at least 50 % of fertiliser requirement by organic fertiliser of sludge origin without compromising production levels. Genotypic variation among varieties under study could be exploited under such low input conditions for their end-use-target of low harvest index i. e. higher straw production for energy and industrial purposes. Cultivation under low input conditions with improved response to nutrients will help to reduce input and hence protect the environment.

Identifikation von Sorghum-Genotypen mit niedrigem Nährstoffbedarf als Beitrag zur nachhaltigen Landwirtschaft:

I. Biomasse und Erträge

Drei verschiedene Sorghum-Genotypen (HS 9, H 30 und H 174) wurden in einem Gewächshausversuch hinsichtlich ihrer Ertragsleistung bei organischer, mineralischer und organisch-mineralischer Düngung untersucht. Die Ergebnisse zeigten, dass genotypische Unterschiede im Stroh- und Kornertrag, in der Gesamtbiomasse und dem Ernteindex existierten. Der Genotyp HS 9 erbrachte den höchsten Strohertrag bei gleichzeitig niedrigstem Ernteindex. Dagegen erzielte der Genotyp H 174 den höchsten Kornertrag und auch den höchsten Ernteindex. Im Hinblick des Aufbaus von Gesamtbiomasse als Funktion des individuellen Nährstoffgehaltes war jedoch der Genotyp H 30 überlegen. Der Einfluß der Düngungsmenge zeigte sich ebenfalls deutlich: Die höchsten Erträge wurden bei voller Düngergabe (T_2) erzielt und sanken mit der Reduzierung der Aufwandmengen. Eine höhere Applikation von organischem Dünger (T_9) und die organisch-mineralischen Varianten (T_{12}-T_{14}) führten zu Erträgen, welche denen bei einer reduzierten mineralischen Düngung entsprachen. Die Ergebnisse dieser Untersuchung läßt sich dergestalt zusammenfassen, daß bis zu 50 % des Nährstoffbedarfes durch organische Dünger, welcher aus Klärschlamm aufbereitet wurde, gedeckt werden konnte ohne die Produktivität zu beeinträchtigen. Die genotypischen Unterschiede könnten genutzt werden, um bei einem geringen Nährstoffangebot Pflanzen mit einem niedrigen Ernteindex anzubauen, wobei das Stroh für energetische Zwecke genutzt werden könnte. Eine pflanzenbauliche Produktion unter Bedingungen einer geringen Nährstoffzufuhr bei gleichzeitig gesteigerter Nährstoffeffizienz ermöglicht es, Nährstoffeinträge zu reduzieren und dadurch die Umwelt zu schützen.

Acknowledgement

The senior author wishes to acknowledge German Academic Exchange Service (DAAD) for awarding him Post Doctoral Felloship. The contribution of Mr. Bernd Arnemann for his technical assistance is worth to be mentioned.

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