INTERCROPPING DEDICATED GRASS AND LEGUME CROPS FOR ADVANCED BIOFUEL PRODUCTION

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ABSTRACT: Intercropping dedicated annual summer grass and legume crops could provide local lignocellulosic biomass feedstocks, increase the land resources use efficiency, crop diversification, tolerance and resilience to biotic and abiotic stresses, and the overall sustainability of the system over time. This study aims at evaluating: i) the residual effects of precedent crop (legume or cereal) on the performance of a subsequent biomass sorghum-sunn hemp (Bs x Sh) and pearl millet-sunn hemp (Pm x Sh) intercropping system with and without the application of N-fertilizer; ii) the feasibility and the biomass yield for biofuel conversion of the mentioned intercropping systems, in comparison to the sole crops. The N fertilization had a negligible effect on yields when compared to the effect of the precedent legume (Sh). A similar amount of dry biomass yield (DBY) was observed both in cereal monocropping and intercropping ranging from 19 to 24 Mg ha^{-1}, whereas the sole sunn hemp reached 14 Mg ha^{-1}. Pm x Sh outperformed Bs x Sh in terms of evenness with 0.9 and 0.6, respectively, albeit their overall LER is similar and slightly higher than 1. In summary, all cropping systems yielded acceptable amounts of biomass. Among these, the Pm x Sh intercropping system seems more feasible for sustainable lignocellulosic feedstock production.

1. INTRODUCION

Species complementarity [1], boosted productivity, increased efficiency in the available resources use [2], increased yield stability are some of the advantages of intercropping systems [3]. Long term effects on soil conducted in China observed an increased carbon sequestration of intercrop compared to sole crop resulting in a 23% higher above and belowground biomass production, together with an increased 11% of total N soil content [4]. Strip cropping, in particular, is adopted in modern cropping systems due to its adaptability to the intensive use of machinery [3]. One of the EU BECOOL project objectives is the intensification of land use (increased land equivalent ratio; LER) without land competition issues, so to diversify and increase the feedstock availability for well-defined advanced biofuel value chains [5]. In this framework, little is known on intercropping high lignocellulosic cereals such as biomass sorghum and pearl millet with sunn hemp in the European temperate climate. Biomass sorghum (*Sorghum bicolor* L.) yields can reach over 30 Mg ha^{-1} [6] and it is utmost resistant to drought due to the ability of slowing down growth and development [7]. Pearl millet (*Pennisetum glaucum* L.) is native of West Africa where it is widely grown for food purposes withstanding harsh weather conditions like drought and flood [8]–[11]. In a severe water deficit experiment pearl millet yielded similar dry biomass to sorghum [12]. Sunn hemp (*Crotalaria juncea* L.) is a tropical fast growing and highly productive legume crop able to reach over 10 Mg ha^{-1} of dry biomass in 90 days [13]–[15]. It is, besides, well performing when cultivated in rotational systems under no tillage conditions [16]. The mentioned characteristics makes sunn hemp a good candidate as bioenergy feedstock.

This study aims at evaluating the N residual effects of precedent crop (legume or cereal) on the performance of a subsequent biomass sorghum (Bs)/pearl millet (Pm) and sunn hemp (Sh) intercropping system with and without the application of N-fertilizer

2. MATERIALS AND METHODS

The field trial was carried out in 2018 at the experimental farm of the University of Bologna, in Cadriano (32 a.s.l., 44° 33' N, 11° 21' E). The experimental set up was a split plot with two nitrogen levels as the main plots and five cropping systems as the sub-plots (Tab. I) in a randomized block design with four replications. The intercropping layout was a 3:3 replacement strip cropping system (Fig. 1). Sowing was performed the 8th May with a pneumatic planter at 0.45 m rows spaced at 22, 19 and 39 seeds m^{-2} for Pm, Bs and Sh, respectively together with a granular soil sterilant application 'Ercole' 10 kg ha^{-1}.

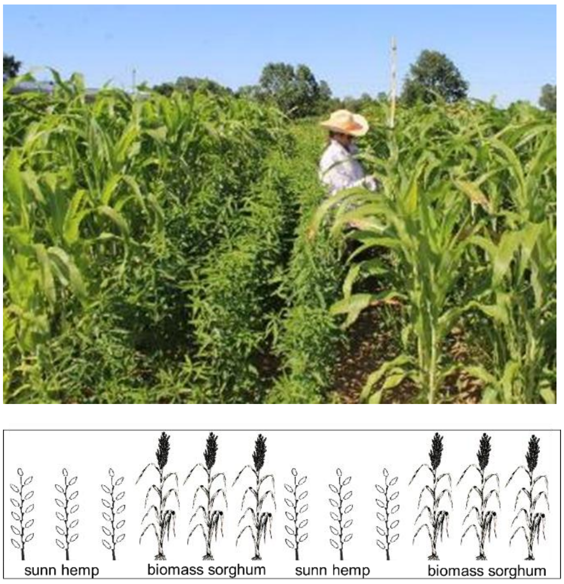

Figure 1: Biomass sorghum-sunn hemp (Bs x Sh) strip cropping pictures.

A basal fertilization with 92 kg of P_2O_5 was made before sowing. Two rescue irrigation for an overall 26 mm of supplemental water were sprinkled at crops establishment. The weed control was carried out mechanically at the Bs third leave together with the N fertilization of field A.

Table I: The precedent crops were biomass sorghum for Field A and sunn hemp for Field B.

	Field A	Field B
Nitrogen	150 kg ha^{-1}	0 kg ha^{-1}
System	Pearl millet (Pm) Biomass sorghum (Bs) Sunn hemp (Sh) Pearl millet-sunn hemp (Pm x Sh) Biomass sorghum-sunn hemp (Bs x Sh)	

Harvesting occurred the 29th September, assessing the global DBY for each system on a destructive 5.4 m^2 sample area. Contextually, on a sub sample, the crop components were separated into leaves and stems, then the leaves, branches and tillers were counted and the former scanned with a LI-COR LI 3100C area meter for the Leaf Area Index determination. Plants height and basal stem diameter were measured on 10 randomly selected plants each plot.

The intercrop performance was evaluated through LER index calculated as the sum of the ratios of the biomass of a species in an intercrop to the biomass of the same species in a sole crop [17]. Species evenness within the total biomass was calculated to assess the relative yield of each species in the intercrop and species dominance.

All parameters were subjected to the analysis of variance ($P < 0.05$), then tested using Tukey's HSD.

3. RESULT AND DISCUSSIONS

The nitrogen application did not boost any of the evaluated systems as far as the yields were comparable reaching the peak of 24 Mg ha^{-1} of DBY for the sole Bs, then 23, 21, 19 and 14 Mg ha^{-1} DBY for Bs x Sh, Pm, Pm x Sh and Sh, respectively. The intercrop performance of the two systems was slightly over one even though not significantly higher, moreover looking further into the intercrop species evenness Pm x Sh outperformed Bs x Sh with 0.9 and 0.6, respectively.

The partial LER's calculated for the overall, leaves and stems DBY (Tab. II) show a similar trend, even though for LAI it is not significant.

Table II Partial LER for the two intercrop systems. Same letters within a row indicate no significant differences between treatments at $P < 0.05$.

	pearl millet-sunn hemp		biomass sorghum-sunn hemp	
	Pm	Sh	Bs	Sh
Overall DBY	0.64 b	0.46 b	0.85 a	0.22 c
Leaves DBY	0.62 ab	0.50 b	0.85 a	0.20 c
Stems DBY	0.64 b	0.45 b	0.85 a	0.22 c
LAI	0.58 a	0.65 a	0.57 a	0.38 a

Plants height showed an 8% reduction for Bs intercrop compared to the sole Bs, but no other differences were observed between the sole crops and their intercrops. Otherwise, the basal stem diameter of Sh decreased in intercrop treatments by 14 and 29% in Pm x Sh and Bs x Sh, respectively. The Sh architecture in Bs x Sh treatment showed a marked decrease in the number of leaves m^{-2} by 66% and in the number of branches m^{-2} by 69%, whereas no differences were found between cereal sole crops and intercrops.

Taking note of the non-significant difference in the DBY between cereal sole crops and intercrops, it is possible to state that the precedent legume crop has compensated the 150 kg ha^{-1} of the N fertilization in terms of yield, leading to an increased cost-effective system with a higher sustainability. The sole Sh had the lowest DBY but still reached a remarkable amount of biomass for a legume, showing a high potential in the European temperate climate.

The Bs x Sh intercrop is the most feasible system as demonstrated by the highest species evenness and the partial LER's value close to 0.5 for all measured parameters such as DBY (leaves and stems) and LAI. It is worth highlighting that in the Bs x Sh intercrop an asymmetric competition occurred with the thrive of Bs that outperforms Sh by suppressing its growth, producing partial LERs that are higher and lower than 0.5, respectively. The competition for light could be the main candidate that suppress Sh, in fact the fast growth of Bs forces Sh to an utmost apical dominance resulting in plants that reach the same height as in the sole crop but with remarkable reduction in basal stem diameter, leaves and branches number, stems and leaves DBY. Nonetheless, the competition for water could have played a secondary role too, causing the observed asymmetric competition, even though there are no tangible evidences.

4. CONCLUSION

All cropping systems yielded from adequate to high biomass, in particular the Bs x Sh system can provide about 20 Mg ha^{-1} DBY to feed the pre-treatment plant for advanced biofuel production, maximizing the advantages of intercrop such as: resource partitioning, mutualism, crop diversification, reduced crop failure among abnormal years, reduction of the N input guaranteeing an overall higher sustainability.

5. REFERENCES

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7. LOGO SPACE