LIGNOCELLULOSIC CROPS IN ROTATION WITH FOOD CROPS

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ABSTRACT: Enhancing agricultural multifunctionality is viable in a multi-purpose crops intensification scenario. The cultivation of a sequence of food and energy crop has the potential to strengthen the crop rotation effect without reducing food land. Annual lignocellulosic crops for advanced biofuel could be introduced alongside conventional crops during the periods of the year on which the latter ones are not cultivated thus to increase the period of utilization of the land unit (increased LER). In this study a preliminary assessment of the effect of four dedicated lignocellulosic crops (sunn hemp, fiber sorghum, kenaf, and hemp) on a subsequent cereal is given in terms of biomass yields. The dedicated lignocellulosic crops have been tested within conventional sequential crop rotations (maize - wheat rotation). Preliminary results indicate that biomass sorghum and kenaf produced the highest and lowest yields, respectively. Whereas industrial hemp and sunn hemp were intermediate to such extremes. Kenaf negatively affected the yield of the subsequent wheat straw that decreased compared to the industrial hemp and sunn hemp by 15%. Whereas the production of wheat straw after biomass sorghum and conventional rotation was intermediate. This preliminary finding indicates that depending on the species characteristics it would be possible to introduce dedicated lignocellulosic crops within conventional crop rotations. Moreover, the biomass characterization highlighted whether the investigated feedstocks were suitable to thermo/biochemical conversion. Further investigations, however, are required to assess the overall systems feasibility and sustainability.
Keywords: advanced biofuel; agricultural intensification; bioenergy crop; bioethanol; crop rotation

1 INTRODUCION

The introduction of annual lignocellulosic crops to advanced biofuel production represent an effective solution to increase the share of renewable fuels in the transport sector [1]. Biomass sorghum, sunn hemp, kenaf and hemp are annual low input high cellulose yielding crop which can be integrated into existing food/feed based cropping system or cultivated in marginal areas with the option to be double cropped to avoid indirect land use changes and direct negative environmental effects. Under optimal pedo-climatic conditions biomass sorghum, kenaf and industrial hemp are able to reach up to 30, 20 and 23 Mg ha^{-1}, respectively [2-6]. Besides, sunn hemp was also able to yield around 14 Mg ha^{-1} in a single experiment in northern Italy [7]. The effect of such crops in rotation with food crops has been investigated only partially and little information are available on the performance of such crops in rotation with winter wheat in temperate climates of Europe. Zegada-Lizarazu et al. [8] reported that the effect of the cultivation of industrial hemp on a following wheat can increase the grain production. Roth et al. [9] revealed how winter wheat succeeding sorghum showed allelopathic effect under several tillage systems. Otherwise, sunn hemp is a legume crop, able to increase nitrogen through biological N fixation suggesting that its effect on a following cereal crop might be positive [10,11]. Additional benefits from a crop rotation diversification relies in the contribution of the control of pest and disease, amelioration of soil structure and increased yields [8,12,13]. Besides, the composition of the biomass is important to identify the potential best suited feedstock to biofuel production. High cellulose and hemicellulose paired with low lignin, ash and inorganic elements are essential in the thermochemical conversion to maximize the process efficiency and reduce slugging, fouling, and corrosion tendencies [14,15].

2 MATERIALS AND METHODS

Crop rotations were established in 2018 at the experimental farm of the University of Bologna in Cadriano (32 a.s.l., 44° 33' N, 11° 21' E) in a loam silty soil, neutral (pH 6.6-7.3), rich in K_2O (~159 mg kg-1), with average N, P_2O_5 and organic matter contents of about 1.1 g kg^{-1}, 69 mg kg^{-1} and 1.3%, respectively. The annual average temperature and precipitation resulted 1.75 °C higher and 68 mm lower than the 20 years data series (2000-2019).

Four innovative rotations were established in a randomized block design with four replications. Each plot was settled to allow a complete mechanical management for the simulation of near-to-practice solutions at a field scale. The plots were 231 m^2 each, with an overall area per treatment of 924 m^2. The four systems during the two years rotation (2018-2019) were designed as follow: i) sunn hemp-wheat (R1, rotation one), ii) biomass sorghum-wheat (R2, rotation two), iii) kenaf-wheat (R3, rotation three), iv) industrial hemp-wheat (R4, rotation four).

Figure 1: Experimental field with lignocellulosic crops in July 2018.

2.1 Lignocellulosic crop

Each dedicated lignocellulosic crop (Figure 1) was sown with a pneumatic planter (varying the settings in order to obtain different sowing densities and depth according to the crop-specific characteristics). 'Futura 75' industrial hemp (*Cannabis sativa* L.) (R4) variety was sown at 157 seeds m^2 on the 24th of April 2018 and 55 kg ha^{-1} of N were applied. Four days later 'Bulldozer' (by KWS) biomass sorghum hybrid (*Sorghum bicolor* x *Sorghum sudangrass*) (R2) was sown at 19 seeds m^2 on the 27th of April 2018 benefiting from a N fertilization of 156 kg ha^{-1}. In R3 and R1 plots the 'H328' kenaf (*Hibiscus cannabinus*) variety and 'Ecofix' variety of sunn hemp (*Crotalaria juncea* L.) were sown on the 8th and 25th of May 2018 at 25 and 52 seeds m^{-2}, respectively. Kenaf was fertilized with 75 kg $ha^{-1,}$ whereas sunn hemp with 36 kg ha^{-1} of N. On the 20th of August 2018 industrial hemp was manually and mechanically harvested, whereas for hemp and sunn hemp, biomass sorghum and kenaf the harvest occurred on the 25th of September 2018.

2.2 Food crop

During the last week of October 2018 the plots were all tilled with a spading machine and each of them was sown on the 19th November 2018 with a medium-early winter wheat (*Triticum aestivum*) 'Starpan' variety (marketed by RAGT; Figure 2) at 200 kg seeds ha^{-1} with a mechanical seeder.. The harvest was carried out on the 2nd of July 2019.

Figure 2: Winter wheat in February 2019.

2.3 Crop measurements

Aboveground biomass (AGB) was measured at harvest (25th September 2018 for sunn hemp, biomass sorghum and kenaf, whereas on 20th August 2018 for industrial hemp) on a representative randomly selected area per reps of 8 m^2; conversely on 1 m^2 on wheat (2nd July 2019). The harvest was carried out by manually cut and weight the plants in the sample area. Then, the dry biomass was determined by oven-drying the fresh mass at 105°C until constant weight. Ten plants per rep were then selected and weighted for the leaves, stems and grain components partitioning. The AGB plant components on the lignocellulosic crops were recorded four times about once per month sampling an area of 0.3 m^2 per plot, at each sampling date.

Separate subsamples of the biomass were oven dried to a constant mass at 60 C° and grounded to 1 mm diameter to determine the qualitative biomass parameters. Ash was extracted by incineration of the dry biomass in a furnace muffle at 550°C. Mineral composition was determined through a wet-digestion pre-treatment carried out with a microwave oven by inductive coupled plasma (ICP). Cell wall components (i.e. lignin, cellulose, and hemicellulose) were determined through the Filter Bag Technology (FBT, ANKOM technology) following the AOAC 991.43 and 985.29 methods. A CHN combustion analyzer was used to measure total N and C.

3 RESULT AND DISCUSSIONS

Biomass sorghum, hemp, sunn hemp and kenaf yielded an average of 31, 19, 15 and 10 Mg ha^{-1} of dry biomass, respectively. The following wheat grain yields were unaffected by the rotation with lignocellulosic crops, even though the wheat straw in R3 resulted significantly lower by a 15% compared to the R1 and R4 rotations. Wheat straw harvested in R2 was reduced by 11% compared to the R1/R4, but statistically not significant. The cumulated biomass yield over the two years averaged about 36 Mg ha^{-1} for R2, followed by R4 (25 Mg ha^{-1}), R1 (21 Mg ha^{-1}) and R3 (15 Mg ha^{-1}).

Sunn hemp and hemp showed the highest cellulose content over 40%, whereas biomass sorghum had the highest hemicellulose (about 30%) and lowest lignin (about 5%), ash (below 5%) and total N (below 1%). High cellulose and hemicellulose fractions determine higher fuel yields, besides low lignin is an important requirement for biochemical conversion. Low ash is a key parameter for thermochemical conversion, where the value of the 5% is generally considered the maximum threshold for an adequate feedstock. Sunn hemp, hemp and kenaf showed higher ash content (> 5%) compared to biomass sorghum by a 25, 34 and 47%, respectively. Low N concentration in the feedstock can reduce the NO_x emissions whether direct gasification or a pyrolysis pre-treatment is performed. In this light, biomass sorghum demonstrated to be exploitable for both conversion pathways, whereas sunn hemp, kenaf and hemp might be recommended for a biochemical conversion route, only. Biomass sorghum and hemp have the general lowest and highest mineral concentration, respectively, whereas sunn hemp and kenaf showed intermediate values. Ca, Fe, K, Na, P and S mineral concentration in biomass sorghum is about half the concentration compared to hemp, sunn hemp and kenaf, representing an important pro for the biomass processing cost and efficiency.

4 CONCLUSION

The evaluated systems produced adequate (R3) to high (R2) biomass feedstocks for advanced biofuels without affecting the following wheat grain production. Sunn hemp-wheat (R1) rotations stands out as it produced high yields with the lowest nitrogen fertilization of the lot (-77% of N compared to biomass sorghum-wheat R2 rotation). Besides, biomass sorghum demonstrated to be the most promising feedstock for the development of both thermo/biochemical-based advanced biofuels for its high yields, favorable biomass characteristics and wide seeds and variety availability for temperate climate. Conversely, sunn hemp, hemp and kenaf can represent a valuable feedstock alternative mainly for biochemical conversion, which can handle with a greater ease their higher ash and mineral concentration, compared to combustion processes. Further investigations, however, are required to assess the overall agronomic systems feasibility and sustainability over a longer period.

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7 LOGO SPACE