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Evaluation of cover-cropping managements on productivity and N-utilization efficiency of kenaf (*Hibiscus cannabinus* L.), under different nitrogen fertilization rates and soil types

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ABSTRACT

Biomass productivity, nitrogen recovery fraction and nitrogen utilization efficiency (NUE) of kenaf (*Hibiscus cannabinus* L.) cultivar Tainung 2 were tested, under three *Lens culinaries* treatments (incorporated, harvested before the sowing of the energy crop and mono-cropping) and four nitrogen dressings (0, 50, 100 and 150 kg ha^{-1}), in two field experiments carried out on a fertile, clayey to loamy soil, and on a sandy soil of moderate fertility, in central Greece, over the period 2007–2009. The obtained results showed a positive response in *L. culinaries* cover cropping on kenaf total yield, on both experimental sites. Total dry biomass fluctuated from 16.07 to 21.46 t ha^{-1} for incorporated plots and from 13.63 to 16.55 t ha^{-1} for control treatments (relied only on applications of N-fertilization) for sandy soil, and from 14.98 to 19.28 t ha^{-1} in case of legume incorporation and from 12.34 to 16.69 t ha^{-1} for control plots, for clayey soil, respectively. The evaluated NUE was 76 kg kg^{-1}, for sandy soil, and 72 kg kg^{-1}, for clay soil. The recovery fraction escalated from 41% in control plots to 70% in plots with previous *L. culinaries* cultivation for sandy soil, while for clayey soil an increase of 20% was recorded, indicating a prominent effect of legume cover-cropping management.

1. Introduction

There is a continuously increasing interest concerning bio-energy, bio-fuels and bio-based products implementation worldwide, mainly because of environmental protection and energy supply security reasons. European Union (EU) strongly encourages the use of renewable energy through a number of Directives. In that direction, the use of biomass for energy production offers significant opportunities to reduce greenhouse gas emissions and secure raw material supply. In EU-27, biomass accounted for 70% of the renewable energy consumed in 2007 (Eurostat, 2010). One of the leading candidates that could be grown on Mediterranean regions specifically for biomass production is kenaf (Biokenaf Project, 2003).

Kenaf (*Hibiscus cannabinus* L., *Malvaceae*) is a short day, annual, herbaceous plant, with a C_3-photosynthetic pathway, native to central Africa and well adapted to a wide geographical and climatic range. Kenaf has been identified as an excellent source of cellulose fiber, for manufacturing a large range of paper products (Nelson et al., 1962) and can be also used as live feedstock, due to its high protein concentration in dry biomass (Webber, 1993; Webber et al., 2002). The last decade there is a growing interest for energy production use, due to the ability to produce stable amount of lignocellulosic biomass (Ardente et al., 2008), as well as for second generation bio ethanol production, due to high cellulose and hemicellulose content (Amaducci et al., 2000).

Considerable information on kenaf agronomy and biomass productivity have been reported for southern Europe (Alexopoulou et al., 2000; Amaducci et al., 1998; Danalatos and Archontoulis, 2010; Kipriotis et al., 1998; Mambelli and Grandi, 1995; Manzanares et al., 1993; Petrini et al., 1994; Quaranta et al., 2000) but it was only after 2003 that kenaf research has been directed toward possible uses in the bio-energy sector. In that direction, there is a wide range of reported responses of kenaf to N fertilization, with conflicting results, in regard to kenaf biomass yield. Many researchers have reported both positive (Adamson et al., 1979; Bhangoo et al., 1986; Kuchindra et al., 2001; Muchow, 1992; Webber, 1996) and no benefits (Kipriotis et al., 2007; Manzanares et al., 1997; Massey, 1974; Patane et al., 2007) to N application,

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as a result of the inherent differences between soil types and climatic conditions. However, data concerning the inclusion of kenaf in cover-cropping systems worldwide and especially in Greece are scarce.

The importance of cover-cropping systems has long been recognized due to yield advantage (Pierce and Rice, 1988; Stute and Posner, 1995), soil quality improvement (Dabney, 1998) and soil erosion reduction (Kaspar et al., 2001). Furthermore, among cover cropping and green manure benefits are improved water and nutrient use efficiency and reduced allelopathy, while legume winter cover cropping may also be beneficial for disease, insect, and weed management, leading to decrease in the need for pesticides (Buhler et al., 1998; Fisk et al., 2001; Vandermeer, 1989). In a cover-cropping system, legumes are included mainly for the ability to fix atmospheric N (Blevins et al., 1990; Hesterman et al., 1992), which potentially could improve Nitrogen use efficiency (Biederbeck et al., 1996; McGuire et al., 1998) and reduce N requirements of the succeeding crops. Legumes are desirable cover crops because they improve soil structure and maintain soil organic matter (Reicosky and Forcella, 1998; Smith et al., 1987), enhance availability and conservation of N, but also because they can be used as a substitute for commercial N fertilizer in cropping systems (Welty et al., 1988; Follett et al., 1991). Among legume species that could be used as cover crops in such systems, lentil (*Lens culinaries*) has a great potential, since it is a well adapted crop in Mediterranean type environments, with thriving cultivation techniques (Miller et al., 2003; Shah et al., 2003; Yau et al., 2003). Furthermore, Mediterranean appears to be the area of origin of a clear group of lentil genotypes which are able to produce larger amounts of biomass compared to other legume crops, making them highly advantageous for use as green manures (Erskine et al., 1989).

On the other hand, energy plants, as kenaf is consider to be, are renewable energy sources, and will have a prospect in the future if their cultivation and utilization do not cause any impermissible pollution and if the net energy gain per area unit is sufficiently high (Scholz and Ellerbrockb, 2002), necessities that could be accomplished by the inclusion of kenaf in an appropriate legume cover-cropping system.

Over the above, legume cove cropping and green manure are among the best external alternatives that can be applied to improve NUE (Jorgensen and Schelde, 2001) and nitrogen recovery fraction (Fageria and Baligar, 2003). Moll et al. (1982) defined Nitrogen use efficiency (NUE) as being the yield of crop per unit of available N in the soil (including the residual N present in the soil and the fertilizer). This NUE can be divided into two processes: uptake efficiency (the ability of the plant to remove N from the soil as nitrate and ammonium ions) and utilization efficiency (the ability to use N to produce yield). Higher efficient use of N in crop production is crucial for increasing crop yield and quality, environmental safety and economic considerations (Campbell et al., 1995; Grant et al., 2002), while at the same time fertilizer input costs could be reduced and the rate of nutrient losses decreased. Likewise, the need to improve N recovery fraction (Nrf) is imperative, because N fertilizer is the largest source of N input to, and losses from, cropping systems. Hence, crop-management practices that increase Nrf have a substantial impact on the amount of N that escapes from production systems and is associated with losses by volatilization, leaching, surface run off and denitrification (Staggenborg et al., 2003).

Under that acknowledgment, the objectives of this study were to estimate the total biomass production as well as NUE and N recovery fraction, of Mediterranean land use systems, cultivated with kenaf, cover-cropped with *L. culinaries*, either harvested or incorporated in the soil before the sowing of the energy crop.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at two experimental sites in Central Greece during three consecutive years in 2007, 2008 and 2009, involving the cultivation of *Hibiscus cannabinus* cv. Tainung 2 as energy crop, after a winter cover-crop cultivation of *L. culinaries*. The soil of the first experimental field, located in Trikala (coordinates: 39°32′16.85″N, 21°46′19.33″E, elevation 120 m ASL) was classified as Typic Xerofluvent (USDA, 1975). The texture was loamy sand, with low nutrient concentration and loose structure. Soil particle size distribution was clay 22%, silt 18%, sand 60%, pH = 7.2 and organic matter content 1.7%. The second experimental field, located in Larissa (coordinates: 39°30′02.85″N, 22°42′50.37″E, elevation 60 m ASL) was classified as Vertisol (USDA, 1975; Soil Survey Staff, 2010). The texture was silty clay to loamy clay, and soil particle size distribution was clay 63%, silt 35%, sand 2%, pH = 7.8, and organic matter content 1.8%. Both study soils had a moderately shallow groundwater table, fluctuating from some 200 to 250 cm below the surface early in the spring, to deeper layers later in the summer.

2.2. Field experiments and management

The experimental design was a factorial split plot with three replications. Three treatments of *L. culinaries*: (i) incorporated into the topsoil upon 50% anthesis, (ii) harvested before the sowing of the energy crop, and (iii) no cover crop, where placed in sub-plots, while four nitrogen dressings: $N_0 = 0$, $N_1 = 50\,kg\,N\,ha^{-1}$, $N_2 = 100\,kg\,N\,ha^{-1}$, $N_3 = 150\,kg\,N\,ha^{-1}$ for kenaf cultivation, were placed in main plots. Each plot measured 3 × 3 m and treatments (both fertilization and legume) were maintained in the same plot position for 3 years. Control plots were left without cultivation of legume. A local lentil cultivar, Samos, was used in all studies, with average plant density of 150 pl m^{-2}. Lentil was grown rainfeded and showed good performance in establishment, tolerance/resistance to pests and diseases, biomass production and seed production. No macronutrient or water stress were recorded during the cultivation periods of lentil, although no fertilization, neither irrigation were applied. Analytically, the available amount of dry biomass of lentil that was incorporated into the topsoil upon 50% anthesis reached a mean of 3.5 t ha^{-1} in Trikala and 3.1 t ha^{-1} in Sotirio, for both experimental years, while on average the crop performed well, producing a final seed production of 1.7 t ha^{-1} for both regions and both years. Planting distances of kenaf cultivar Tainung 2 were 0.50 m, between the rows and 0.10 m, within the rows. The two extreme rows of kenaf were considered as border rows. In order to prevent N leaching and improve NUE (Martin et al., 1994; Mullen et al., 2003) fertilization was applied in two doses. The first was applied at sowing as basal dressing with 50 kg N ha^{-1}, 50 kg P ha^{-1} and 50 kg K ha^{-1} in all plots, except N_0 plots in which only P and K fertilization was applied. The second dose was applied on the onset vegetative phase, when plant height was approximately at 50 cm. All plots received a light irrigation after sowing to insure crop emergence. A surface drip irrigation system was installed soon after kenaf crop emergence, along the main rows to ensure high accuracy to water inputs. The quantity of water application was determined by the maximum evapotranspiration (ETm). The total amount of irrigation water for kenaf cultivation and other relevant agronomic data for both kenaf and lentil are summarized in Table 1 for 2008 and 2009.

Weather data for the Sotirio experimental field, such as incident solar radiation, air temperature, rainfall, wind speed and class-A pan evaporation rate, were recorded hourly on an automatic meteorological station installed next to experimental site, while for the Trikala experimental field, proportional weather data were