Intercropping cover crops with a poplar short rotation coppice: Effects on nutrient uptake and biomass production

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Abstract

The risks of soil erosion and nutrient leaching can be considered appreciable in short rotation coppices especially in the first growth phases because of the absence of any plant cover. The temporary intercropping with legumes or grasses used as cover crops can help to overcome these environmental issues. The present research work aims to evaluate the effects of the introduction of cover crops in a short rotation poplar (*Populus deltoides* W. Bartram ex Marshall) with two-year harvest cycle. The plantation was located in a Typic Xerofluvent, silty-loam soil of the coastal Central Italy. Two different species of cover crops, *Trifolium subterraneum* L. (TS) and *Lolium perenne* L. (LP), were compared along with an untreated control, colonised by spontaneous vegetation (CO). Several plant and soil parameters were evaluated: the above ground biomass and nutrient accumulation for the three different soil cover types, the nitrate and water content in two soil layers (0.00-0.30 and 0.30-0.60 m), the poplar yield and nutrient content in branches and leaves.

TS returned to the soil about 70 kg ha^{-1} of nitrogen at the end of its biological cycle, thanks to the high N content (over 2%) and to the noticeable amount of dry matter produced (3.46 t ha^{-1} of dry matter). This value was considerably higher than those of the LP (23 kg ha^{-1} of N) or CO (10 kg ha^{-1}). The different amount of nitrogen returned to the soil affected both nitrate concentration in topsoil (0.00-0.30 m) and accumulation of nitrogen in poplar organs. Concerning phosphorous, the differences among treatments were less evident and the amount of P returned to the soil ranged from 2 (CO) to 10 (TS) kg ha^{-1}. However, the effect of soil cover type on P uptake in poplar was still appreciable. Generally, the soil water content was slightly affected by the soil cover types. Indeed, the differences between the cover crops and the control became significant only in the shallowest soil layer and over the summer season. In the first year, LP induced a significant decrease in poplar yield (10.1 t ha^{-1} of dry matter) in comparison with TS (14.7 t ha^{-1}) and CO (13.4 t ha^{-1}), whereas in the second year there were no significant differences among treatments due to the weak regrowth of cover crops.

These results show how to make it feasible a long lasting coexistence between cover crops and SRC, a clever design of agro-forestry systems is therefore needed.

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Introduction

Short rotation coppice (SRC) management includes the establishment of closely spaced stands of fast growing trees and the application of intensive cultivation practices such as repeated harvesting using short cutting cycles, regeneration of subsequent crops via sprouts or suckers and the use of a high degree of mechanisation (Hytönen, 1995; Kauter *et al*., 2003; Laureysens *et al*., 2004). However, one of the hindrances to a wider development of this energy source is the possible impact on the environment and on landscape that an increasing spread of biomass crops could cause (Roedl, 2010).

Generally, the SRC cultivation is supposed to be environmental friendly in comparison with the traditional row crops (Rowe *et al*., 2009; Langeveld *et al*., 2012). The reduced frequency of tillage operations (often limited to the stand plantation phase) and the high level of soil cover, ensured by the high plant density and development, as well as by the thick litter originated by the fallen leaves, are all factors able to limit sediment losses by protecting soil from the raindrop impact, increasing water infiltration and reducing run-off speed. On the other hand, the restrained use of fertilisers and pesticides in SRC cultivation reduces pollution risks also for ground water (Dimitriou *et al*., 2009). However, the risks of erosion and nutrient leaching can be substantial in the first growing stages of the tree crops because of the absence of an adequate protective canopy and also in the months following the harvest because of the soil compaction along wheel tracks produced by high-weight harvesting machines (Nisb *et al*., 2011; Vanguelova and Pitman, 2011; Bergante *et al*., 2015).

In this case, the use of cover crops can represent a useful agronomic measure since it can provide and maintain an appreciable soil cover especially during the winter, when the rainfall erosivity is high and the soil is otherwise bare (Malik *et al*., 2000; Blanco-Canqui *et al*., 2015). Cover crops can protect soil from water erosion also thanks to the anchoring action of their root systems that can bind soil aggregates either physically (especially in the case of grass cover crops), and chemically, through the release of root exudates with colloidal properties (Laloy and Bielders, 2010).

Moreover, cover crops can offer other benefits by increasing the organic matter content and nutrient availability in the soil (Lal, 2009; Mazzoncini *et al*., 2011), by reducing the nitrate leaching (Quemada *et al*., 2013), by favouring the telluric cenosis development (Sapkota *et al*., 2012; Berthrong *et al*., 2013; Blanco-Canqui *et al*., 2015), by attracting beneficials (Nicholls and Altieri, 2012) and also by reducing the competition effects from weeds (Corre-Helloua *et al*., 2011). Finally, the cover crop intercropping increased the capability of soil to withstand the traffic by agricultural machinery during the wet season, particularly during SRC harvest times.

It is important to choose species with a complementary biological cycle respect to that of the companion SRC species and/or to manage intercropping in order to minimise, as far as possible, negative effects of competition. In poplar SRC, the critical period for weed control, *i.e*. the weed free interval to prevent significant yield loss, is quite long (60-70 days) and it begins 20-30 days after planting (Otto *et al*., 2010). At this regard, the interaction of cover crops with water and nutrient availability in the soil should be carefully evaluated, but also competition for light and space can play an important role (Sage, 1999). Nitrogen starving or nitrogen-fixing plants, quantity and quality of produced biomass, decomposition dynamics of residues, evapotranspiration rate, and weed suppressiveness are all cover crop's aspects that can affect significantly the growth of the companion SRC crops (Willey, 1979).

Another trait to be considered in the cover crop choice is the capability of the species to remain in cultivation for more years thanks to their perennial nature or to the self-propagation capability by means of specialised reproductive organs (stolons, rhizomes, *etc*.), or thanks to the self-re-seeding attitude.

The aim of this study was to evaluate the suitability of intercropping with two different multiannual cover crops (*i.e*. *Trifolium subterraneum* L. and *Lolium perenne* L.) in a poplar short rotation coppice plantation in comparison to the no-sowing inter-row management.

Materials and methods

Experimental site

The hybrid poplar plantation was located at the *Centro di Ricerche Agro-Ambientali* of University of Pisa situated in the lower part of the Arno valley in Tuscany, Central Italy (43°40' N, 10°19' E, 2 m a.m.s.l.). The soil (Typic Xerofluvent, USDA classification) is a silty-loam and had previously been almost continuously grown with maize (*Zea mays* L.). The main physical-chemical characteristics in the 0.00-0.30 m layer were the following: clay 19%, silt 52%, sand 29%; pH 7.9, organic matter 1.5 g 100 g^{-1} (Walkley-Black method), total nitrogen 0.14 g 100 g^{-1} (Kjeldhal method) and assimilable phosphorus 20.5 mg kg^{-1} (Olsen method).

Climatic conditions are representative of Mediterranean coastal areas, with average annual values of cumulative rainfall and mean temperature of 826 mm and 15°C, respectively. Figure 1 shows the climatic trend during the experimental period (years 2013 and 2014).

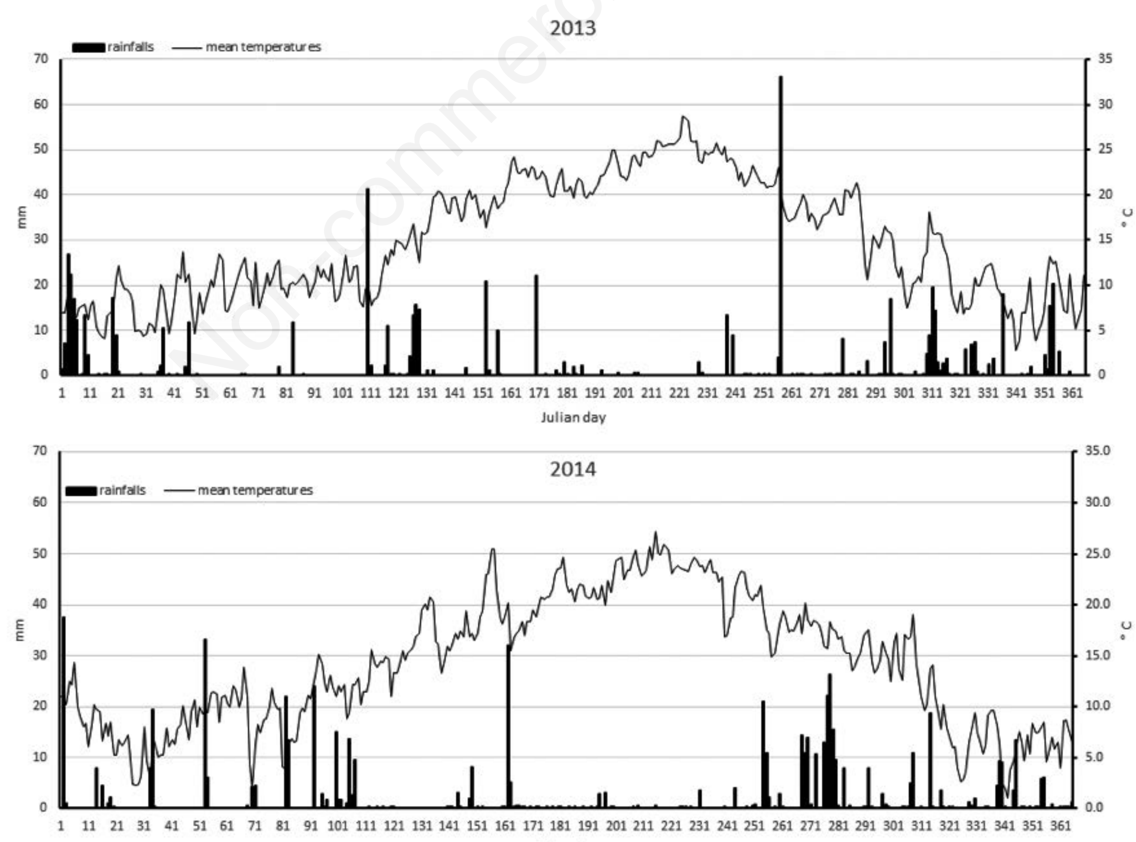

Figure 1. Mean temperatures and rainfalls recorded in the years 2013 and 2014.

Field experiment set-up

The soil preparation was carried out in autumn (mouldboard ploughing) and in spring (harrowing). A liquid multinutrient fertiliser was applied before the plantation (0.6 t ha^{-1}), equivalent to 48-63-120 kg ha^{-1} of N-P-K. The poplar grove (*Populus deltoides* W. Bartram ex Marshall, cv LUX) was planted on 29th March 2012 using one-year-old dormant cuttings with a density of 8000 plants ha^{-1} (2.5 m inter-row and 0.5 m on the row). In the first year, natural vegetation was mechanically controlled by two cuttings carried out on 3rd May and on 4th September. Neither top-dressing fertilisation nor irrigation was foreseen. On 2nd October, the experimental plots (25×20 m) were laid out and broadcast sown with two multiannual cover crop species: i) a self-re-seeding legume, subterranean clover (*Trifolium subterraneum* L., cv Clare, 35 kg seeds ha^{-1}, with thousand seed weight equal to 9.1 g) hereinafter named TS and a perennial grass, ryegrass (*Lolium perenne* L., cv Argo, 30 kg seeds ha^{-1}, with thousand seed weight equal to 2.7 g) hereinafter named LP. The plots used as untreated control (without cover crop) were left to normal colonisation by the natural flora (CO). At the end of spring (on 27th May), when the cover crops had already reached the peak of their vegetative growth, a cut was carried out on all treatments to mitigate the competition for water and nutrients against the poplar and to allow the formation of dead mulch.

In this way, the competition between cover crops and poplar was minimised both because during the period following the plantation (the most sensitive for poplar) there was any cover crop and because after the cover crop sowing, the poplar was under the winter dormancy (from November to early April in our climatic region). Therefore, considering that all the covers (TS, LP and CO) were cut at the end of May, the overlapping with the biological cycle of poplar was very short (April and May).

Data collection and processing

Nitrate and water soil content were monthly monitored over the main poplar-growing season (from June to October) for the two soil layers, 0.00-0.30 and 0.30-0.60 m depth. The soil samples were weighed twice (before and after oven drying at 60°C until constant weight) to determine the soil humidity and then sent to the laboratory for the determination of nitrate content (ion chromatography method, Dx-500 ion chromatograph; Dionex, Sunnyvale, CA). On the same dates, samples of poplar branches and leaves were taken to evaluate the N and P content within the plant tissues. The plant material (about 25 kg d.m.) was randomly collected from four different plants for each experimental plot and oven-dried at 60°C until constant weight to determine the dry matter content. The dried samples were ground to 1 mm and used for nutrient analyses following digestion of 200 mg of plant material by H_2SO_4/H_2O_2 (Bremner, 1965). N concentration was determined according to the Kjeldahl method, while P concentration was determined with the molybdenum blue method using a Perkin Elmer Lambda 25 spectrophotometer (Giannini *et al*., 2015). At the peak of the cover crop's growth, one 1×1 m wide destructive sample was taken from each experimental plot to evaluate the above ground biomass and the nutrient content of the cover crop and weed plants. The samples were oven-dried at 60°C until constant weight and, after weighting, the samples were milled and analysed as above-mentioned.

Poplar plant density was measured over a 30 m linear distance on 12th July 2013. At harvest maturity (on 18th December 2013 and on 15th December 2014), two representative transects of four consecutive poplar plants were collected for each replicate. The fresh weights of the plants were recorded on the field using a forestry scale and one subsample was taken to determine the humidity and N/P content (Kjeldahl and molybdenum blue in spectrophotometry method, respectively). Biomass yield per hectare was calculated relating the weight of the four plants to the plant density values measured for each plot.

Data were analysed with ANOVA according to a randomised complete block design, with the soil cover type as unique factor replicated three times (with each elementary plot being of a size of about 500 m^2). The Duncan honest significant difference test was used for post-hoc means comparison at the 0.05 *p*-level. The Bartlett's test and the Shapiro-Wilk test were performed to test the homogeneity of error variances and the normality of residual distribution, respectively (Gomez and Gomez, 1984). The N and P concentration data were transformed in arcsine or natural logarithm to fulfil the assumptions of ANOVA (version 9.1; SAS Institute Inc., Cary, NC, USA).

Results and discussion

Cover crop biomass and nutrient accumulation

The natural flora species identified at the end of May on the plots used as control (without cover crops) are reported in Table 1. The identified weeds were almost entirely dicotyledonous species. In terms of dry weight, the most represented species was *Symphyotrichum squamatum* (*Spreng.*) *G.L. Nesom* (53%) followed by *Chenopodium album* L. (11%) and *Amaranthus retroflexus* L. (7%). In the untreated control, total weed biomass was about 0.75 t ha^{-1} of dry matter (Table 2), a value significantly lower than the biomass produced by cover crops in TS and LP. *T. subterraneum* (3.46 t ha^{-1}) showed an almost double growth than *L. perenne* (1.79 t ha^{-1}). Both the cover crops were able to hinder the development of natural plants, with the result that the TS and LP plots were weed-free at the cutting time.

Table 1. The list of the spontaneous vegetation present on the plots used as control (without cover crops) and the percentage (on dry weight basis) of their corresponding biomass.

Species	Botanical family	Dry weight (%)
Symphyotrichum squamatum (Spreng.) G.L. Nesom	Compositae	53
Chenopodum album L.	Amaranthaceae	11
Amaranthus retroflexus L.	Amaranthaceae	7
Sonchus arvenis L.	Compositae	6
Senecio vulgaris L.	Compositae	4
Alopecurus myosuroides Huds.	Poaceae	3
Polygonum aviculare L.	Polygonaceae	3
Verbena officinalis L.	Verbenaceae	3
Calystegia sepium (L.) R. Br.	Convolvoluceae	3
Convolvolus arvensis L.	Convolvoluceae	2
Mercurialis annua L.	Euphorbiaceae	1
Veronica hederifolia L.	Verbenaceae	1
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	1
Anagallis arvensis L.	Primulaceae	1
Papaver rhoeas L.	Papaveraceae	1

Nitrogen concentration (Table 2) in TS aboveground biomass (2.1 g 100 g^{-1}) was significantly higher than that of the LP and the CO, whose concentrations was about 1.3-1.4 g 100 g^{-1}. Nitrogen accumulated in the aboveground biomass of the legume species (about 74 kg ha^{-1}) was decidedly greater than that returned either by LP (23 kg ha^{-1}) or by CO (10 kg ha^{-1}).

No significant difference was found among treatments with respect to the P concentration in above ground biomass, ranging from 0.23 (LP) to 0.30 g 100 g^{-1} (CO), with the level of biomass production being the main determinant of the amount of phosphorus returned to the soil with the cover cutting (from 2 to 10 kg ha^{-1} of P) (Table 2).

The nutrient concentrations measured for the two cover crop species fell within the range reported in literature (Talamucci, 2002; Munkholm and Hansen, 2012) whereas the aboveground biomass produced was lower than the productivity of the two species in single cropping reported by others studies (Frenda *et al*., 2009; Munkholm and Hansen, 2012). The long-lasting shading conditions due to poplar leaves fallen at soil level during the winter period and to the new leaves produced by the poplar at the beginning of the growing season are likely the main reasons behind the limited development of the cover crops in our conditions. For this reason, the amount of nutrients returned to the soil with the cover crops cutting was smaller than that found by other Authors. This was especially significant in the case of N for TS, which is well known to fix up to 180 kg ha^{-1} of nitrogen into the soil (White *et al*., 2000).

Soil nitrate and water content

The temporal trends of nitrate concentration in the soil as affected by the three treatments are depicted in Figure 2. The concentrations measured for the TS plots in the 0.00-0.30 m soil layer were significantly higher than those observed for the other two soil cover types in three different dates: 3rd June, 18th July and 27th August (Figure 2A). On the contrary, the LP plots showed a reduction in nitrate content also in comparison with the control both on 18th and 27th August.

This pattern can be explained by considering two different processes partially overlapping. The first one linked to the increased nitrate availability in TS plots due to the activity of N_2-fixing bacteria, able to justify the initial high concentration within the TS plots a few days after the cover crop cutting. The second one was the natural increase in nitrate content due to the mineralisation of soil organic matter that becomes considerable during the summer season and it was well drawn by the nitrate trend recorded in the CO plots where the amount of the plant biomass returned to the soil was almost negligible. The scattering of cover crop residues can interact with the usual nitrate dynamics within the shallowest soil layer leading to different effects in relation to the composition of cover crop biomass (Cohan *et al*., 2014). In the case of LP, it is likely that the high C:N ratio of the biomass caused the immobilisation of nitrates produced by the organic matter mineralisation, thus reducing their availability in the soil. Conversely, the presence of plant residues with a low C:N ratio, such as in the case of TS, might have increased the nitrate availability and enhanced the mineralisation process.

These differences tended to disappear in the 0.30-0.60 m soil layer (Figure 2B) where the nitrate content values were statistically equivalent among the three soil cover types. Our explanation was that the plant residues were not able to reach such depth in absence of deep tillage operations and thus they did not affect the soil nitrogen availability.

Overall, the nitrate content at a depth of 0.00-0.30 m was higher than in the 0.30-0.60 m soil layer, although the dynamics over time were similar between the two soil layers.

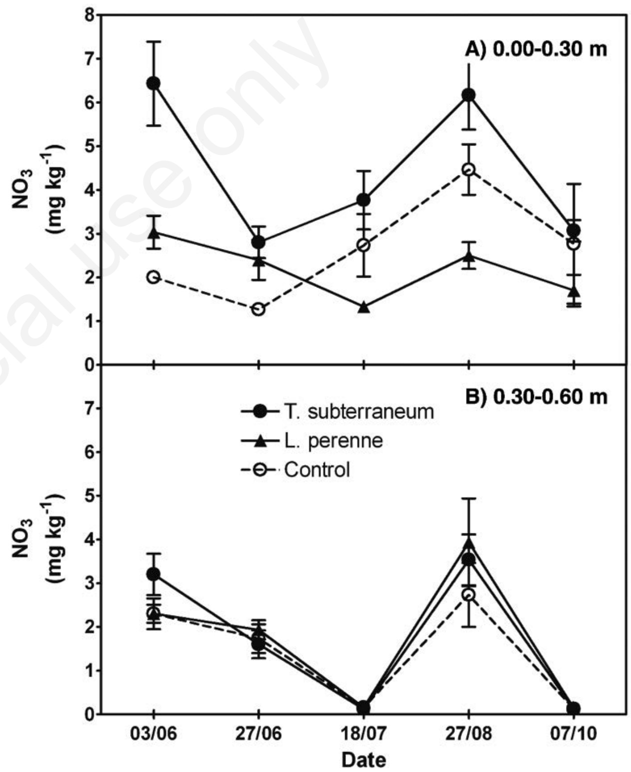

Figure 2. Soil nitrate content measured at five different dates in two soil layers (A = 0.00-0.30 m and B = 0.30-0.60 m) as affected by the soil cover type: *Trifolium subterraneum* (TS), *Lolium perenne* (LP) and the untreated control (CO). Vertical bars represent the standard errors of the mean.

Table 2. Above ground biomass dry weight, nutrient (N and P) content and uptake as affected by the soil cover type: *Trifolium subterraneum* (TS), *Lolium perenne* (LP) and the untreated control (CO).

Soil cover type	Above ground biomass t d.m. ha^{-1}	N concentration g 100 g^{-1}	N uptake kg ha^{-1}	P concentration g 100 g^{-1}	P uptake kg ha^{-1}
TS	3.46[a]	2.14[a]	74.2[a]	0.29[a]	10.2[a]
LP	1.79[b]	1.28[b]	23.3[b]	0.23[a]	4.0[b]
CO	0.75[c]	1.39[b]	10.6[b]	0.30[a]	2.1[b]
P value	0.0019	0.0456	0.0049	0.1024	0.0056

[a-c]Within each factor, letters indicate significant differences P<0.05 (Duncan's test).

The cover type also influenced the soil water content. In the 0.00-0.30 m soil layer (Figure 3A), the control plot always gave the lowest values, often less than 15% of soil humidity (w/w) whereas the presence of a cover crop resulted in an increase in the soil water content irrespective of the species. This means that the larger soil cover ensured by the cover crop residues was able to keep a higher soil humidity level in comparison with CO but also that the differences in the biomass composition and yield between TS an LP did not influence significantly the soil water content. The residual effect of the cover crops on soil humidity seemed to be significant during the warm season when the high temperatures enhanced the evaporation process (on 18th July and 27th August) and especially in the days immediately following rainstorms when the water in the soil was not drained or evaporated yet (on 27th August). Therefore, we argue that the reduction of soil evaporation level due to the protective effect of the cover crop mulch (Smith *et al*., 1987) allowed retaining a higher humidity level only temporarily (in summer season and after a rainstorm) and only limited to the shallowest soil layer. Indeed, the soil water content in the plots with/without cover crops tended again to converge along with the temperature decrease occurring from late summer, as reported in other studies carried out in colder regions (Aronsson, 2000).

In the 0.30-0.60 m soil layer, no significant differences were observed among the treatments (Figure 3B) and the fluctuations within the same treatment were very limited over time (no more than two w/w percentage points). These results might be related to the above-mentioned loose nature of the soil and to the possible rising of water for capillarity action. Actually, the water table level in the experimental area is quite shallow ranging over the year from –1.20 and –0.60 m a.m.s.l. (Silvestri *et al*., 2001).

Poplar biomass and nutrient uptakes

The nitrogen content in the branches and the leaves (Figure 4A and B) was significantly higher for poplar plants grown on the plots with TS than on the other soil cover types, with the only exception of the first sampling date (3rd June), when all treatments were equivalent. The N concentrations in LP poplar were always the lowest since 18th July, even if statistically equivalent to the control. Only the N content in the LP-leaves collected on the last sampling date (7th October) was significantly lower than that of CO.

This pattern was consistent with the trend of the nitrate concentration in the shallowest soil layer discussed above, where the TS and LP plots showed the highest and lowest availability of the nitrogen soluble form, respectively. Other Authors confirmed the positive correlation in poplar between fertilisation and nitrogen uptake (Stolarski *et al*., 2013; Ceotto *et al*., 2016).

Generally, the nitrogen content, whether in the branches or in the leaves, tended to decrease along with the poplar-growing season. In fact, initial values of about 2.1-2.6% nitrogen in the branches (Figure 4A) and about 5.6-5.9% in the leaves (Figure 4B) decreased to 0.5-07% and 1.5-2.5% respectively, at the last sampling date. This means that the rising soil nitrate content observed at end of August did not produce an increase of poplar N uptake presumably because the senescence process in poplar was already started. Anyway, the observed values of nitrogen content can be considered consistent with those reported in literature for different species of poplar at harvest time (Kauter *et al*., 2003; Pellis *et al*., 2004; Ceotto *et al*., 2016; Giannini *et al*., 2017).

About the phosphorus content (Figure 5A and B), the results confirmed partially the nitrogen pattern although with less marked effects. The differences among treatments were statistically significant only for the central dates of the sampling period (*i.e*., on 27th June, 18th July and 27th August) when the P concentration in TS-

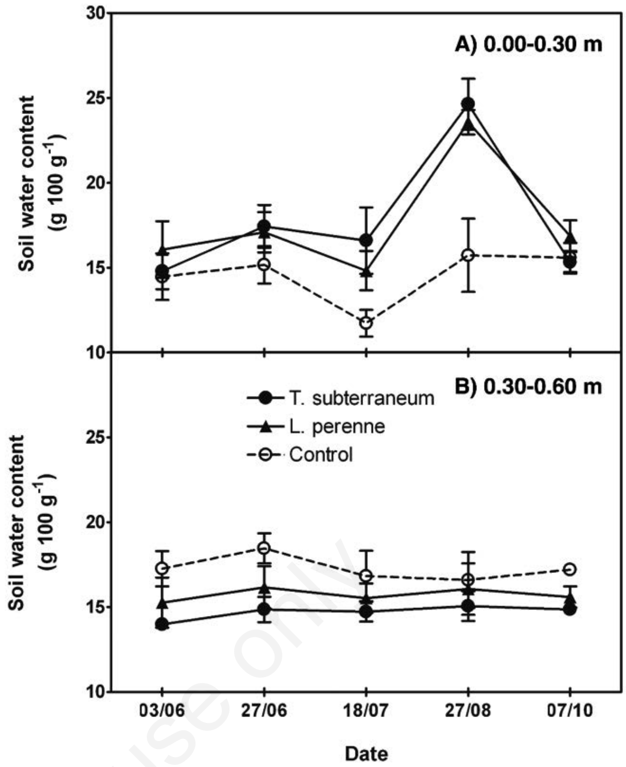

Figure 3. Soil water content at five dates in two soil layers (A = 0.00-0.30 m and B = 0.30-0.60 m) as affected by the soil cover type: *Trifolium subterraneum* (TS), *Lolium perenne* (LP) and the untreated control (CO). Vertical bars represent the standard errors of the mean.

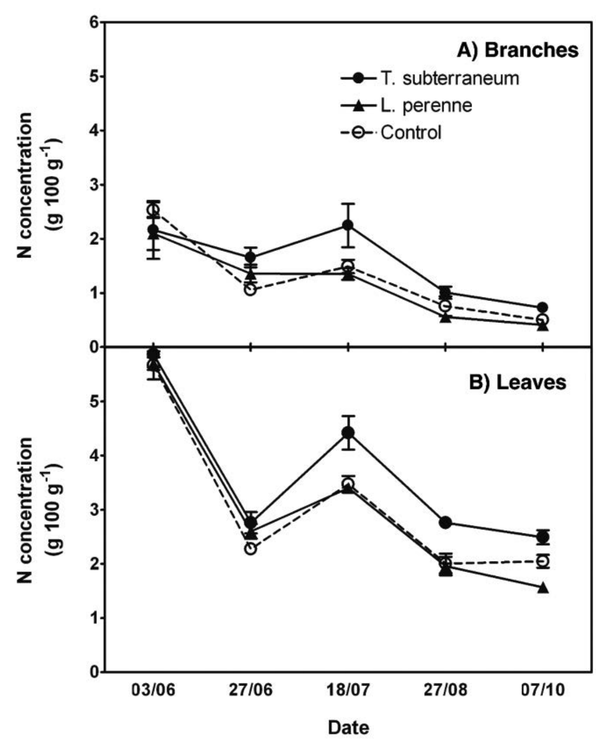

Figure 4. Nitrogen content of poplar branches (A) and leaves (B) at five different dates as affected by the soil cover type: *Trifolium subterraneum* (TS), *Lolium perenne* (LP) and the untreated control (CO). Vertical bars represent the standard errors of the mean.

and CO-poplar plants showed higher values in comparison with the LP-poplar ones. The negative effect of LP on P concentration might have been probably due to the depressive action on telluric biocenosis activity, with a slowdown of the soil organic matter mineralisation rate and a lower P availability. Conversely, the incorporation of residues with well-balanced C/N can contribute to an overall increase in soil P soluble forms through enhanced organic P mineralisation (Randhawa *et al*., 2005).

The measured values of P content were, also in this case, in line with what reported in literature (Giannini *et al*., 2017).

Finally, the two different cover crops were also able to influence the biomass yield of poplar harvested in 2013 (second growing season) (Table 3), whereas no significant difference among treatments was found for plant density (ranging from 0.58 to 0.63 m^{-2}). The presence of TS favoured the development of poplar plants reaching the highest yield (14.65 t ha^{-1} of dry matter), significantly different in respect to the other two soil cover types. On the other hand, the use of LP caused a significant reduction in biomass production (10.12 t ha^{-1}) in comparison also with the control (13.38 t ha^{-1}). These yield levels were consistent with the findings reported by Pannacci *et al*. (2009) for different poplar clones under two-year harvest cycle in an inland district of Central Italy (from 10.49 to 12.86 t ha^{-1} of dry matter).

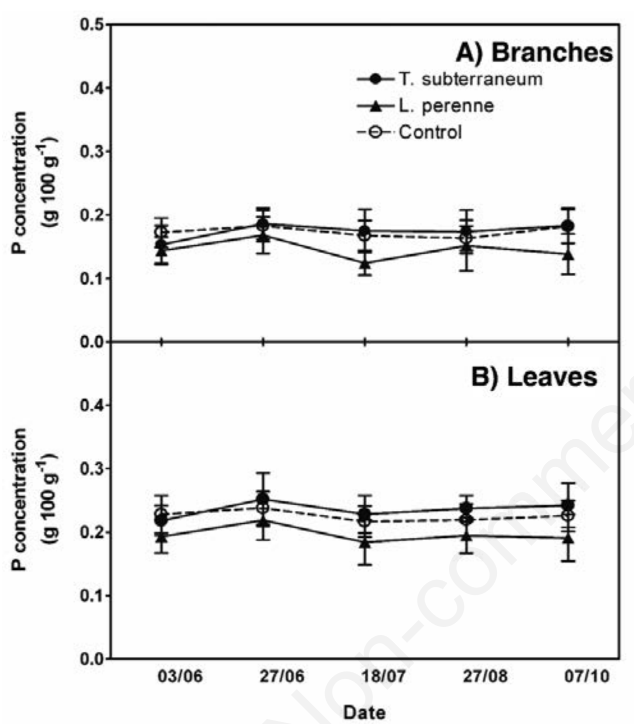

Figure 5. Phosphorous content of poplar branches (A) and leaves (B) at five different dates as affected by the soil cover type: *Trifolium subterraneum* (TS), *Lolium perenne* (LP) and the untreated control (CO). Vertical bars represent the standard errors of the mean.

Table 3. Poplar biomass production as affected by the soil cover type: *Trifolium subterraneum* (TS), *Lolium perenne* (LP) and the untreated control (CO).

Soil cover type	Poplar biomass production (t d.m. ha^{-1}) 2013	2014
TS	14.65[a]	52.89[a]
LP	10.12[c]	48.66[a]
CO	13.38[b]	51.20[a]
P value	0.001	0.1881

[a–c]Within each factor, letters indicate significant differences P<0.05 (Duncan's test).

The results obtained in 2014, at the end of the third growing season (Table 3), highlighted a recovery both of the CO- and of LP-poplar, whose yield (51.20 and 48.66 t ha^{-1} of dry matter, respectively) was statistically equivalent to that of the TS (52.89 t ha^{-1}). These levels of poplar biomass production were comparable with those obtained by other Authors in the same area (Nassi o di Nasso *et al*., 2010).

The reasons behind the positive effects of TS on poplar yield could be found in the different availability of nutrients in the soil layer mostly explored by the roots (0.00-0.30 m) and, consequently, in the higher poplar nutrient uptake, as proved by the higher TS values of nutrient concentration in leaves and branches. The yield gap of the LP can be related instead to the negative effect that the addition of high C:N biomass to the soil had on the activity of the telluric biocenosis reducing the nutrient availability for plants. In literature, there are studies that confirmed (Coleman *et al*., 2006; Stolarski *et al*., 2015) or denied (Liberloo *et al*., 2006; Ceotto *et al*., 2016) the effect of nutrient supply on poplar yield. These differences are presumably to put in relation to different fertility condition of the soil where the research activities have been carried out (Moscatelli *et al*., 2008).

The effect of cover type on soil water content seemed to not affect poplar yield since it was limited to particular conditions with occurrence of high temperatures and rainstorms. Indeed, the monitored values of soil humidity were very similar between the two cover crop treatments, whereas the yield results were significantly different.

The yields of the third growing season were unaffected by soil cover type treatments (Table 3). This result could be explained with the higher competition level exerted by the *T. subterraneum*, the most developed cover, on the poplar re-sprouting in the early spring of 2014. Anyway, this effect was short lasting because the poplar growing dominated soon all the cover crops, whose development was substantially stopped with the closure of inter-row spaces by the poplar crown. Therefore, the cover crops failed to thrive in the years following their sowing despite the choice of short harvest-cycle for poplar (2 years). The objective of long-lasting permanence of cover crops in SRC seems thus hard to achieve with the use of traditional SRC planting distances.

Conclusions

The biomass produced by the cover crops intercropped with poplar was considerable and it can be considered useful to maintain an adequate soil cover and organic matter content during the first year of poplar establishment. The use of *T. subterraneum* can represent a promising option to increase soluble nitrogen availability in the soil without using any mineral fertiliser, and to favour biomass production of poplar plants under limited soil fertility conditions. The introduction of *L. perenne* played instead a negative role on poplar nutrient uptake and could be recommended only if sown in mixtures with legume species.

During the summer, the presence of cover crop residues ensured a higher soil humidity in comparison with the untreated control but without significant differences between the two cover crop species tested. For these reasons, the yield gap of LP-poplar in our study can be essentially attributed to the addition to the soil of a biomass with a high C:N ratio, which depressed the telluric biocenosis activity reducing the nutrient availability for plants.

The satisfactory yields achieved proved that intercropping was well tolerated by poplar provided that the interspecific competition level is minimised by shifting both poplar and cover crop establishment. In addition, the choice of a high plant density for SRC can contribute to reduce the interspecific competition.

The goal to keep growing cover crops in SRC intercropping beyond the first growing season is hard to achieve, unless we decide to modify deeply the SRC system management by increasing the traditional planting distances and by shortening furthermore the harvest cycle. These options could make sense only in the perspective to transform the SRCs in real agro-forestry systems.

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