Impact of Management Practices on Chestnut Grove Nutrient Budgets

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Abstract

A 4-year study in two adjacent chestnut groves, within Northern Portugal, examined the effect of intensifying management, by means of fertilization, pruning and tilling, on the quantity of litter production and on soil macronutrient inputs and outputs. One of the stands (F) was fertilized, pruned and tilled 3-4 times per year, while the other (NF) was only tilled 2-3 times. Total litter biomass was similar in both plots but in the NF plot leaves were the main component, while in the F plot fruits made the highest contribution to total litter. Management intensification increased nut production by an average of 50%. In the F plot, the biggest proportion of N, P K and S released by the trees was in nuts while in the NF plot it was in leaves. Due to the low concentration of Ca and Mg in fruits, on both plots, these nutrients were released in higher amounts in leaves than in fruits. Nutrient output by leaching was low even in the F plot despite fertilization and a more intense soil cultivation. These results may be related to the small amounts of fertilizer applied and to the capacity of these eco-systems to conserve nutrients. The unusual low N loss, even when it was applied, suggests that N may be in short supply. In both plots, the 4-year average nutrient budgets were positive. In the NF plot fruit nutrient export was replenished by natural inputs. In the F plot the applied fertilizers and the natural nutrient inputs were enough to compensate for the higher nutrient output mainly due to the increased nut production and pruning. These results showed that intensification of management has contributed to an increase of fruit production and the low rates of fertilizers added were enough to minimize losses by leaching. Removal of pruned biomass, however, was not a suitable practice due to the high nutrient outputs. The finer material, the richest in nutrients, should at least be left on the soil.

INTRODUCTION

Chestnut fruit production is one of the most important sources of income for farmers in Trás-os-Montes, Northern Portugal. In the last years, to increase production, management practices have been intensified through cultivation, pruning and chemical fertilization. Intensification of management, however, may lead to a reduction in soil fertility, due to higher nutrient export from the site and elevated leaching losses, if not carefully designed to fit the site conditions (McColl and Powers, 1984; Pritchett and Fisher, 1987; Worrel and Hampson, 1997).

Although tilling may have beneficial effects on plant growth, especially due to reduced weed competition for water and nutrients, it may also lead to nutrient losses both through erosion and leaching (McColl and Powers, 1984; Attiwil, 1995). Pruning also increases soil temperature, due to higher soil exposure to direct sunlight, which stimulates microbial activity. Consequently the decomposition of organic matter increases. In addition, pruning can lead to an important nutrient output if the nutrient rich branch material is removed from the field (Pires and Portela, 1993, 2000).

Fertilization, together with tilling, may also enhance the loss of nutrients from the root zone by surface runoff and by leaching into ground water and streams. Leaching losses will increase when fertilizer is added during the dormant season or by rainfall after fertilization (Sands, 1984). In undisturbed forests, however, leaching losses are slight in dry areas and, even in humid areas where the amount of leaching water is greater, uptake by roots may be sufficient to retain the added elements and prevent significant leaching (Cole and Rapp, 1981; Sands, 1984). Since most studies have been made in undisturbed forests no quantitative data about leaching losses is available in more intensively cultivated plantation forests or in agro forest systems like the chestnut stands. So, the objectives of this study were to determine the effect of fertilization, pruning and tilling on the amount of chestnut litter production and on soil macronutrient inputs (litterfall, stemflow, throughfall, fertilization) and outputs (fruit, pruned biomass, leaching water).

MATERIALS AND METHODS

This study was conducted in two adjacent chestnut groves, established in 1943 at Carrazedo de Montenegro (41°35' N, 7°25' W; altitude: 831 m), Northern Portugal. Mean annual temperature is 12.5°C and mean annual precipitation is 1133 mm. On these groves two plots, each one with 61 trees, were selected. The two plots, NF and F, were submitted to different management practices (Table 1). Chestnut tree varieties are 'Judia', the dominant, and 'Lada'. Other characteristics of the chosen stands are in Table 2. The soils are sandy loam to loam, derived from mica schists and classified as Humic Cambisols (Agroconsultores and Coba, 1991), with good drainage. Depth of limiting layer is 70 cm and the layer of maximum root density is 20-50 cm depth. Soil chemical properties, determined during July 1993 and July 1996, are shown in Table 3. These soil samples were collected beneath the canopies.

To collect the litterfall, 27.8 x 47.5 cm plastic boxes were established on each plot. The number of litterfall traps varied, according to the characteristics of the plots (open space area, canopy projection area and tree spacing): NF - 30 boxes (eight beneath the crown of three trees and three on two selected open spaces) and F - 32 boxes (eight beneath the crown of three trees and four on two selected open spaces). Litterfall was collected from April 1992 to March 1996. After being sorted to separate leaves, inflorescences, burs, nuts (shell and kernel), twigs and moss-lichens, each litter component was dried at 60°C and weighted. Litter component of each year were then combined and the bulk sample was ground to pass through a 1-mm screen and analysed. The analytical methods used are described elsewhere (Pires and Portela, 2000). During June/July of 1992/93 to 1994/95, the F plot was pruned and in 1995/96, strong winds broke several branches in both plots. Following determination of this material dry matter, analyses were carried out after separation into leaves, burs, inflorescences, twigs and branches. These were sorted by diameter: 1-3 cm, 3-5 cm, 5-7 cm and greater than 7 cm. Branch analysis was done after splitting the wood from the bark.

To measure stemflow, in each of the plots, on the three selected trees, a through made of 4 cm plastic tubing was glued to the stem of each tree and fed into a 60 L opaque plastic barrel. Beneath the crown of the selected trees four pluviometric collectors (15 cm diameter) were placed at 130 cm above ground, connected to 5 L polythene bottles in order to measure throughfall. On the two selected open areas pluviometric collectors were placed, three on the F plot and two on the NF plot. Black net was fixed underneath the rain collectors to avoid perching birds. Bulk precipitation was sampled in an open area, adjacent to the groves and the collector was open to dry deposition. Since throughfall collected directly beneath the canopy was significantly different from the values for the open spaces, when calculating throughfall per hectare, both estimates were taken into account. In both plots, beneath the crown of three trees and in two open areas, at 50 cm depth, two lysimiters (700 cm^2) connected to 5 L polythene bottles, were also installed to collect soil leaching water. Bulk precipitation, throughfall, stemflow and soil leaching water were collected at 15-day intervals during the wet season and monthly at other times. For the purpose of analysis, the period of water collection was divided into three season intervals: active growing period (April to July), fall (August to Nov.) and dormant season (Dec. to March). Samples were filtered, stored in the refrigerator at 0-4°C, and an average sample was analysed at the end of each period considered.

Analysis of variance and mean separation test, Fisher PLSD, were calculated using the Stat View program (Abacus Concepts Inc., 1987).

RESULTS AND DISCUSSION

The average amount of litterfall collected in the F and NF plots, from 1992 to 1996 was similar (Table 4) and comparable to the values reported by Vogt et al. (1986) for warm temperate broadleaf deciduous forest (3.4 to 5.4 Mg ha^{-1} yr^{-1}) and by Gallardo et al. (1995) for chestnut coppices (4.7 Mg ha^{-1} yr^{-1}). Due to the differences in grove management (Table 1), however, the contribution of each litter component to the total was different. Since trees in the NF plot were not pruned, leaf production was higher ($P<0.05$) than in F Plot, representing 56.1% of total weight while in the F plot it represented only 34.5%. In this plot, the more intense management significantly increased fruit production being, on average, 50% higher than in the NF plot. However, the amount of inflorescences and burs, in both plots, was not significantly different. Management intensifycation, mainly fertilization, does not always increase their production (Binkley, 1986). So, the increase in fruits might have been related to the effect of fertilizers in preventing or decreasing nut abortion, in addition to the effect of management intensification on increasing nut size. Pritchett and Fisher (1987) reported that techniques such as fertilization and pruning have been successfully used to increase fruit production of many broadleaf deciduous species, although the factors responsible for such increase are not yet fully understood.

The different litter composition affected the amount of nutrients that reached the soil (Tables 5 and 6) and, therefore, the amounts that could potentially be reused by trees. In the F plot the biggest amount of N, P, K and S released by trees was in nuts while in the NF plot it was in leaves. Due to the much lower concentrations of Ca and Mg in fruits than in leaves (Pires and Portela, 1993), these nutrients were released in higher amounts in leaves than in fruits, in both plots. The higher amounts of nutrients in fruits were N and K which are the nutrients present in the highest concentrations in chestnuts. The amount of nutrients released by all the other litter components was higher than nut nutrient output, except for K in F plot (Tables 5 and 6). In this plot, K nut output exceeded by 2.6 kg ha^{-1} the amount added by all the other litter components.

On both plots, stemflow (SF) made such a negligible contribution to nutrient deposition from combined SF + throughfall (TF) that is referred to below merely as throughfall. TF was an important source of K and S, the amounts of these nutrients being comparable (K) or higher (S) to those in litterfall. Nutrient deposition by throughfall was lower in the F plot than in the NF plot, although not different ($P<0.05$). The lower TF inputs in this plot may be explained by the limited amount of foliage since, as the F plot is regularly pruned, it has a narrower canopy projection area (Table 2). Denser foliage results in greater amounts of nutrients leached out and a larger leaf area increases the capture of dry deposition and the wash off of trapped substances. This latter mechanism may be responsible for most S inputs, while foliar leaching is mostly important for nutrients such as K (Bellot and Escarré, 1991). There was an enrichment of nutrients in TF relative to free precipitation, except for N (Table 7). Throughfall contained, on average, 25% less N than rainfall, which reflects retention of N by canopy. Such retention has also been reported elsewhere (Bellot and Escarré, 1991; Callaway and Nadkarni, 1991; Helmisaari, 1995).

The nutrients in higher amounts in soil leaching water (LW) were K, Ca and S, on both plots. These were also the nutrients added in larger amounts by throughfall (Tables 5 and 6). However, their amounts in LW were small even in the F plot where they were added by fertilizers. These results may be related, among other factors, to the small amounts of fertilizers used (Table 1). It has been indicated that application of small doses of fertilizer results in a very efficient use of added nutrients (Binkley, 1986). Despite the tillage operations, fertilization and soil exposure to direct sunlight, the magnitude of nutrient losses by leaching obtained in this study did not differ from data reported for undisturbed forests (Binkley, 1986; Pritchett and Fisher, 1987; Attiwill, 1995). Usually these ecosystems retain nutrients so efficiently that leaching losses are small. Following soil disturbances, nutrient leaching, particularly of NO_3^-, may temporarily increase (Attiwill, 1995) but, as stated by Worrel and Hampson (1997), the changes are probably not significant in terms of site nutrient loss. If disturbance occurs during the active period of growth, leaching may not even happen because of uptake by the growing vegetation (Attiwill, 1995). However, unusually low N loss was observed in this study, even in the fertilized plot (Table 5). Results summarized by Cole and Rapp (1981) for several forest ecosystems, including sites where N was applied as fertilizer, indicated an average loss of 4.5 kg ha^{-1} yr^{-1}. Binkley (1986) and Cole (1995) also indicated somewhat higher leaching losses. The low N losses together with the N canopy retention suggest that this nutrient might have been in short supply even in the fertilized plot. The inputs of N by fertilizers were relatively low and a high amount of N was exported by fruits. Thus, an appreciably retention of this nutrient within the ecosystem may have occurred.

Due to pruning, from 1992 to 1996, a total of 6.5 Mg of DM ha^{-1} (4.1 Mg of branch wood, 1.5 Mg of branch bark and 1.2 Mg of leaves+burs+inflorescences+twigs) was removed from the F plot. In 1995/96 strong winds broke several branches in both plots. This material was also taken out of the field: 0.1 Mg of DM ha^{-1} in the F plot and 0.4 Mg of DM ha^{-1} in the NF plot. Although the removal of these small quantities of DM did not have effect on the annual nutrient output, the removal of the pruned biomass (average of 1.6 Mg of DM ha^{-1} yr^{-1}) exported larger amount of Ca and Mg than fruits and more N and P than leaching from the soil (Tables 5 and 6). Due to the high Ca concentration in pruned biomass (Pires and Portela, 1993), the amount of Ca exported in relation to the other nutrients considered, was the largest, followed by N, K, Mg, S and P. Such high output of nutrients could be minimized if the finer material stayed in the field since it was the richest in nutrients (Pires and Portela, 1993). In relation to Ca, however, it would be difficult to minimize the export because this element is mainly concentrated in the bark of thicker branches (Pires and Portela, 1993). So, removal of pruned biomass may contribute to a long-term decrease in soil fertility, especially in unpolluted areas where natural inputs are low and when nutrients are not added by fertilizers. Such a decrease, however, was not observed in the F plot. The results of soil analysis collected in July 1996 were similar to the ones obtained in July 1993 (Table 3), probably because all nutrients have been applied as fertilizers, although in small amounts, and leaching losses were relatively low.

In both plots, the 4-year average nutrient input-output balances were positive. In NF plot, fruit nutrient export and leaching losses were outweighed by the natural inputs. In F plot, the small amounts of fertilizer applied together with the natural nutrient inputs were enough to compensate the higher nutrient output mainly due to increased nut production and pruning.

CONCLUSIONS

This study showed that intensification of management has contributed to an increase of nut production. The higher fruit output did not have a negative effect on soil nutrient budgets and the rates of fertilizers added were low enough to minimize the losses due to leaching. These losses were in general very low. However, an unusually low N loss was observed, even in the fertilized plot, which suggests that N might have been in short supply at the outset of the study.

Removal of pruned biomass was not a suitable practice due to the high amount of nutrients exported. Its high nutrient output could be minimized if, at least, the finer material stayed in the field.

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Tables

Table 1. Management practices.

	NF plot	F plot
Fertilization	none	300 kg ha^{-1} 7:14:14 (March 1991)[a] 238 kg ha^{-1} 7:14:14 (March 1992)[a] 238 kg ha^{-1} $Ca(NO_3)_2$ (March 1993)[b] 238 kg ha^{-1} 4:16:12 (March 1994)[c] 178 kg ha^{-1} 4:16:12 (Jan. 1995)[c] 2078 kg ha^{-1} of org. fertilizer (Jan. 1995)[d]
Soil tillage	1 plowing (Nov.) 2 tillages (May, Sept.)	1 plowing (Nov.) 3 tillages (May, July, Sept.)
Pruning	none	each tree every 2 years

[a] 7% N, 14% P_2O_5 and K_2O, 10% Ca, S
[b] 15% N, 21% Ca
[c] 4% N, 16% P_2O_5, 12% K_2O, 16% Ca, 2% Mg
[d] 70% OM, 1.1% P, 1.3% K, 1.6% Ca, 0.7% Mg, 0.4% S

Table 2. Stand characteristics.

	1991		1994	
	NF	F	NF	F
Tree density (trees ha^{-1})	67	85	67	85
Average height (m)	9.9	9.0	10.3	8.9
Average breast height diameter (cm)	40.5	38.6	41.8	39.8
Canopy projection area (%)	80.3	58.4	81.3	57.6
Open space area (%)	19.7	41.6	18.7	42.4

Table 3. Soil chemical properties (under tree crowns, 0-20 cm depth).

	NF		F	
	1993	1996	1993	1996
$pH(H_2O)$	5.1 a	5.0 a	5.1 a	4.9 a
Organic matter (%)	2.35 a	2.02 a	2.08 a	1.99 a
Ca^{2+} ($cmol_c$ kg^{-1})	0.64 a	0.50 a	0.79 a	0.61 a
Mg^{2+} ($cmol_c$ kg^{-1})	0.27 a	0.18 a	0.23 a	0.21 a
K^+ ($cmol_c$ kg^{-1})	0.33 a	0.32 a	0.37 a	0.29 a
H^++Al^{3+} ($cmol_c$ kg^{-1})	0.88 a	1.53 b	0.91 a	1.79 a
Base saturation (%)	60 a	41 b	60 a	39 b
Extractable P (mg kg^{-1})	33 a	18 b	40 a	22 b

Means followed by the same letter, in each line and plot, are not different ($P<0.05$).

Table 4. Mean dry weight and percentage of litter components collected in the NF and F plots (1992/96).

	NF	F	NF	F
	--------- kg ha^{-1} $year^{-1}$--------		------------ % -----------	
Leaves	2285.0 a	1509.0 b	56.1	34.5
Inflorecences	190.0 a	233.7 a	4.7	5.3
Burs	627.1 a	731.4 a	15.4	16.7
Twigs	35.6 a	46.7 a	0.9	0.1
Moss/lichens	2.2 a	5.7 b	0.1	0.1
Chestnuts	929.8 a	1844.8 b	22.8	42.2
Total	4069.7	4371.2	100.0	100.0

Means followed by the same letter, in each line, are not different (P<0.05).

Table 5. Average N, P and K balance, kg ha^{-1} yr^{-1}, in NF and F plots (1992/96).

	N		P		K	
	NF	F	NF	F	NF	F
Input						
Leaves	16.0 a	11.1 b	3.2 a	1.5 b	11.5 a	6.5 b
Other	4.6 a	6.9 a	0.7 a	0.9 a	7.1 a	6.8 a
SF+TF	1.6 a	1.4 a	2.5 a	1.7 a	17.3 a	14.3 a
Fertilizer	0	25.1	0	16.7	0	24.2
Total	22.2	44.5	6.4	20.8	35.9	51.8
Output						
Fruit	10.3 a	16.3 b	1.5 a	2.5 b	8.9 a	15.9 b
PB*	0.3	4.9	0.1	0.8	0.2	3.9
LW	0.4 a	0.7 a	0.3 a	0.5 a	6.4 a	8.1 a
Total	11.0	21.9	1.9	3.8	15.5	27.9
Balance	+11.2	+22.6	+4.5	+17.0	+20.4	+23.9

SF+TF - Stemflow+throughfall; PB - pruned biomass; LW - leaching water. Means followed by the same letter, in each line and nutrient, are not different (P<0.05). * impossible to perform the statistics.

Table 6. Average Ca, Mg and S balance, kg ha^{-1} yr^{-1}, in NF and F plots (1992/96).

	Ca		Mg		S	
	NF	F	NF	F	NF	F
Input						
Leaves	14.7 a	11.3 b	5.5 a	3.2 b	1.6 a	1.2 b
Other	3.0 a	4.0 a	1.3 a	1.4 a	0.4 a	0.8 a
SF+TF	8.8 a	9.5 a	3.1 a	2.6 a	18.1 a	14.4 a
Fertilizer	0	43.4	0	5.7	0	2.1
Total	26.5	68.2	9.9	12.9	20.1	18.5
Output						
Fruit	0.8 a	2.1 b	0.7 a	1.3 b	0.9 a	1.5 b
PB*	0.4	8.0	0.1	1.4	0.1	0.9
LW	3.4 a	7.6 a	1.0 a	2.2 a	2.7 a	6.8 a
Total	4.6	17.7	1.8	4.9	3.7	9.2
Balance	+21.9	+50.5	+8.1	+8.0	+16.4	+9.3

SF+TF - Stemflow+throughfall; PB - pruned biomass; LW - leaching water. Means followed by the same letter, in each line and nutrient, are not different ($P<0.05$). * impossible to perform the statistics.

Table 7. Average rainfall (R), weighted mean nutrient concentration and nutrient amount.

	R	N	P	K	Ca	Mg	S
Amount of rainfall (mm)	993						
Weighted mean concentration (mg L^{-1})		0.25	0.04	0.24	0.79	0.15	0.39
Nutrient amount (kg ha^{-1})		2.04	0.32	2.29	7.35	1.38	3.75