# SOIL FERTILITY

## Potassium Fertilization Effects on Alfalfa in a Mediterranean Climate

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### ABSTRACT

**Potassium fertilization rates for alfalfa (*Medicago sativa* L.) have been increasing with intensive cropping systems or decreasing with policies that generally lead to reduced fertilizer inputs. In this case, nutrient buildup or maintenance of high soil test levels may not be desirable and drawdown of K reserves may be beneficial in the short term. The objective of this research was to evaluate the effects of potassium fertilization of alfalfa in areas of high soil exchangeable K levels and long growing seasons. A field experiment was established under irrigation from 1993 to 1997 in the Mediterranean environment of the Ebro Valley (Spain) on a silty clay loam soil. The treatments were five annual rates of K (0, 41.5, 83, 166, and 332 kg K ha$^{-1}$) and two rates of K (166 and 332 kg K ha$^{-1}$) applied prior to seeding on two alfalfa cultivars. The average annual dry matter (DM) yield was 21.5 Mg ha$^{-1}$ and showed a small linear response to K fertilization (Pr > *F* = 0.0589). Total K removal in the herbage increased linearly with each rate of K and reached 1728 kg K ha$^{-1}$ with the application of 332 kg K ha$^{-1}$ yr$^{-1}$, compared with 1546 kg K ha$^{-1}$ without K fertilization. At the end of the experiment, soil ammonium acetate extractable K ($K_e$) increased little with K rates, and the differences were observed only in the first 30 cm of depth. Despite the uptake of 1546 kg K ha$^{-1}$, soil $K_e$ values did not change appreciably, suggesting that much of the K uptake was derived from the fertilizer and from nonexchangeable soil K fractions. Although K fertilization slightly increased alfalfa DM yields in this high testing Mediterranean soil, the economic benefit of this limited response does not justify the expense.**

Alfalfa fertilizer applications have been changing with production practices. They have been increasing with more intensive cropping systems (Smith, 1975; Lanyon and Griffith, 1988; Vough and Decker, 1992) or decreasing and even withheld (Havlin et al., 1984; Jouany et al., 1996; Swoboda, 1998) due to changes in agricultural and environmental policies (EU Commission, 1993) that lead generally to lower prices. With reducing agricultural profits, nutrient buildup or maintenance of high soil test levels may not be economically desirable and drawdown of K reserves may be economical in the short term (Havlin et al., 1984; Mallarino et al., 1991). Therefore, there is interest in designing field experiments to evaluate the response to K fertilization in alfalfa, which has a high K requirement, in order to maintain high yields in intensive production systems (Lanyon and Smith, 1985).

Research involving applications of K for alfalfa has been conducted mainly in the northeastern or midwestern regions of the USA on soils responsive to this nutrient with soil test K levels between 30 and 230 mg K kg$^{-1}$, using short-season dormant or semidormant cultivars with reported annual DM yields of alfalfa that ranged generally between 10 and 15 Mg ha$^{-1}$ in three to four harvests per season (Markus and Battle, 1965; Lutz, 1973; Smith, 1975; Rominger et al., 1976; Fixen and Ludwick, 1983; Barbarick, 1985; Alva et al., 1986; Sheaffer et al., 1986; Burmester et al., 1991; Razmjoo and Henderlong, 1997). The reported results of these trials show that the effects to the applications of K varied with production practices, growing conditions, and soil K contents, ranging from no DM yield response with the application of 300 kg K ha$^{-1}$ with a soil test level of 75 mg K kg$^{-1}$ (Lutz, 1973) to a maximum response with the application 448 kg K ha$^{-1}$ for a soil with extractable K of 55 mg K kg$^{-1}$ (Rominger et al., 1976). These studies show that in general, K application increased plant and soil K concentrations.

Although a survey of soil fertility and forage management specialists indicates that additional K is rarely recommended when the concentration of exchangeable K is greater than 300 kg ha$^{-1}$ (about 150 mg K kg$^{-1}$) in the surface soil layer (Lanyon and Smith, 1985), the sufficiency levels for adequate soil K are much less clear (Lanyon and Griffith, 1988). In fact, results from Colorado (Barbarick, 1985), on soils with high levels of exchangeable K (from 308 to 335 mg K kg$^{-1}$) under irrigation, found that application of 375 kg ha$^{-1}$ of K increased 4-yr DM yields from 52.7 to 55.6 Mg ha$^{-1}$, showing that alfalfa yield responses to K applied to a soil high in K are possible.

In France, Ballif and Duthil (1976) obtained the highest alfalfa DM yields with applications of 166 and 325 kg K ha$^{-1}$ yr$^{-1}$, raising the 2-yr DM production from 15.4 Mg ha$^{-1}$ to 17.6 Mg ha$^{-1}$. Soil exchangeable K levels in the top 20 cm of nonfertilized plots were reduced from 270 to 80 mg kg$^{-1}$. Higher responses to K were reported by Kafkafi et al. (1977), in irrigated eastern Mediterranean conditions, where yields were raised from 15.2 Mg ha$^{-1}$ with 0 K to 20.9 Mg DM ha$^{-1}$ with applications of 316 kg K ha$^{-1}$ in a soil with initial K values of about 180 mg K kg$^{-1}$.

Although it is known that alfalfa can remove large amounts of K in intensive production systems, there are limited data on K fertilization from areas with high soil K levels (Havlin et al., 1984) or long growing seasons with alfalfa dormancy ratings of 8 and 9 and crop yields of 20 to 25 Mg ha$^{-1}$ yr$^{-1}$ under irrigation (Dovrat, 1993; Kafkafi et al., 1977; Lloveras et al., 1998).

In the Mediterranean areas of southern Europe, pres-

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**Abbreviations:** DM, dry matter; $K_e$, soil ammonium acetate extractable potassium.

ent recommendations of between 200 and 350 kg K ha$^{-1}$ yr$^{-1}$ are normally based on the amounts of K removed by the crop (Hidalgo, 1969; Le Gall et al., 1992). In this research we evaluated the effect of K fertilization on alfalfa yield and nutrient uptake in irrigated production systems with high soil exchangeable K levels in a Mediterranean climate.

## MATERIALS AND METHODS

The experiments were conducted under irrigation during four growing seasons (1994 to 1997) at the IRTA-University of Lleida research fields at Palau de Anglesola (Ebro Valley, Spain, 41°39′ N, 0°51′ E, altitude 180 m). The soil was an Oxyaquic Xerofluvent, representative of the Ebro Valley, with a silty clay loam texture (397 g kg$^{-1}$ clay).

Analysis of a composite sample (0–30 cm depth) collected from the experimental site revealed that pH (water) was 8.4, available P was 14 mg kg$^{-1}$ (Olsen method), available K was 317 mg kg$^{-1}$ ($NH_4OAc$ method), organic matter was 14 g kg$^{-1}$, and $CaCO_3$ equivalent was 310 g kg$^{-1}$. The exchangeable bases Ca, Mg, Na, and K were 33, 4.91, 0.25, and 0.89 cmol$_c$ kg$^{-1}$ respectively, whereas at 30 to 60 cm they were 33, 4.92, 0.27, and 0.53 cmol$_c$ kg$^{-1}$ respectively. The total cation exchange capacity was 39.06 and 38.7 cmol$_c$ kg$^{-1}$ for the 0- to 30- and 30- to 60-cm depths, respectively. An estimation of minerals in the clay fraction with X-ray showed that illite was the dominant mineral (Roquero, 1979). The average temperature is 11.1°C and the average rainfall is 433 mm.

The treatments were seven K fertilizer rates broadcast on two adapted alfalfa cultivars, 'Aragón' and 'P5929' (dormancy ratings 8–9). The fertilizer treatments, applied as KCl, consisted of five annual broadcast rates of 0, 41.5, 83, 166, and 332 kg ha$^{-1}$ of K and two other treatments of 166 and 332 kg ha$^{-1}$ of K prior to seeding. Fertilizer treatments following the initial preplant applications were topdressed in winter (January). The crop also received an annual application of 44 kg P ha$^{-1}$. At seeding the plots were also fertilized with 3 kg B ha$^{-1}$, 49 kg Mg ha$^{-1}$, and 62 kg S ha$^{-1}$.

The experiment was seeded on 16 Sept. 1993 at a seeding rate of 20 kg ha$^{-1}$ in rows 20 cm apart. Plots were 1.5 × 6 m. The previous crop was wheat (*Triticum aestivum* L.). Plots were irrigated every 12 to 16 d from April to September, receiving a total of about 900 mm of water per growing season. The experimental design was a split-plot in space and time (Steel and Torrie, 1980) with four replications. The K treatments were the main plots and the alfalfa cultivars the subplots. The results were subjected to analysis of variance with the General Linear Model procedure of the Statistic Analysis System (SAS Institute, 1988).

Alfalfa yield was determined by harvesting the whole plot. Six cuttings were harvested each year at the mid to full flowering stage, except for the first and the last cut of the year, where the crop does not flower because of the photoperiod. The first harvest was about mid-April and the last at the end of October with a period of about 30 d between harvests (Lloveras et al., 1998). Insects were controlled by spraying 0.1 kg ha$^{-1}$ a.i. fenvalerate [cyano(3-phenoxyphenyl)methyl 4-cholo-(1-methylethyl)benzeneacetate] two to five times per year. Weeds were controlled by applying 1 kg ha$^{-1}$ a.i. hexazinone [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione] in January. The alleys between blocks were maintained weed free by rotary tilling.

A 500-g wet sample of herbage was collected from each plot at each harvest for moisture determination and subsequent chemical analysis. Samples were dried at 70°C and DM yields were calculated on this basis. Ground (1-mm screen) plant tissue samples were analyzed for several nutrients. Total N was analyzed by a conventional Kjeldahl method. Potassium, Ca, P, Mg, B, Cu, Fe, Mn, and Zn contents were analyzed by inductively coupled argon plasma spectrophotometry (Polyscan 61E; Thermo Jarrell-Ash Corporation, Franklin, MA) after digesting the calcinated plant ashes with hydrocholoric acid.

Soil samples for determination of exchangeable K were taken from every plot and from the 0- to 30- and 30- to 60-cm soil depths at the end of each growing season (prior to fertilization). In addition, at the final sampling on December 1997, core soil samples also were taken from a 60- to 90-cm depth. Soil samples collected prior to planting were air-dried but all subsequent soil samples were analyzed as field moist samples. Thus K data for the first year prior to seeding and from subsequent years unfortunately cannot be directly compared.

## RESULTS AND DISCUSSION

### Forage Yields

Although the main effect of K was not significant in any year or for the total 4-yr production, the total 4-yr herbage DM yields showed a linear response (Pr > $F$ = 0.0589) to K fertilization rates (Table 1). The mean of the two highest rates (166 and 332 kg K ha$^{-1}$ yr$^{-1}$) was 87.4 Mg DM ha$^{-1}$ whereas the control and the 41.5 kg K annual rate yielded a mean of 84.5 Mg DM ha$^{-1}$, which is a difference of about 2.8 Mg DM ha$^{-1}$ in 4 yr (0.70 Mg DM ha$^{-1}$ per year). The lower yields observed in the fourth year of production are common in the irrigated areas of the Ebro Valley, mainly due to stem nematode (*Ditylenchus dipsaci*) (Lloveras et al., 1994). The cultivar × fertilizer treatment interaction was not significant, although 'Aragón' alfalfa yielded (89.7 Mg DM ha$^{-1}$) significantly more than 'P5929' (82.3 Mg DM ha$^{-1}$). No significant yield differences were found when comparing annual fertilizer rates of 41.5 and 83 kg K ha$^{-1}$ yr$^{-1}$ applied topdressed with the same total 4-yr amount of K applied at once at seeding (166 and 332 kg K ha$^{-1}$). This result suggests that in medium textured soils, with the rates of K studied, all the fertilizer, at least up to 332 kg K ha$^{-1}$, could be applied at seeding without any yield depression.

The small yield increases obtained in this study (2.8

**Table 1. Alfalfa yield response to K fertilization. Mean of two cultivars.**

| Treatment | K | Dry matter yields | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cultivar | |
| | | 1994 | 1995 | 1996 | 1997 | Total | Aragón | P5929 |
| | kg ha$^{-1}$ | Mg ha$^{-1}$ | | | | | | |
| 1 | 0 | 24.0 | 24.8 | 22.7 | 13.5 | 85.0 | 88.0 | 82.1 |
| 2 | 41.5 annually | 23.7 | 24.8 | 21.9 | 13.7 | 84.0 | 87.8 | 80.3 |
| 3 | 83 annually | 23.1 | 24.6 | 22.6 | 15.4 | 85.8 | 89.7 | 81.9 |
| 4 | 166 annually | 24.6 | 24.8 | 23.0 | 14.7 | 87.2 | 91.7 | 82.6 |
| 5 | 332 annually | 23.9 | 25.5 | 23.6 | 14.6 | 87.6 | 90.2 | 85.1 |
| 6 | 166 at seeding | 23.9 | 25.0 | 22.9 | 14.1 | 85.9 | 89.4 | 82.5 |
| 7 | 332 at seeding | 23.7 | 25.2 | 22.3 | 15.1 | 86.4 | 90.8 | 81.9 |
| Main K treatment effect | | NS† | NS | NS | NS | NS | NS | NS |
| Linear (Treatments 1 to 5) | | NS | NS | NS | NS | * | NS | NS |

* Significant at the 0.05 probability level.
† Nonsignificant.

**Table 2. Annual and 4-yr weighted average concentrations of K, N, P, Ca, and Mg in alfalfa herbage under K fertilization treatments.**

| | | Annual K concentration | | | | 4-yr weighted average concentrations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | K | 1994 | 1995 | 1996 | 1997 | K | N | P | Ca | Mg |
| | kg ha$^{-1}$ | g kg$^{-1}$ | | | | g kg$^{-1}$ | | | | |
| 1 | 0 | 24.3 | 16.8 | 14.4 | 16.2 | 18.1 | 30.7 | 2.33 | 22.9 | 3.27 |
| 2 | 41.5 annually | 23.8 | 17.5 | 13.9 | 16.0 | 18.1 | 31.1 | 2.35 | 21.9 | 3.24 |
| 3 | 83 annually | 25.0 | 18.3 | 14.9 | 16.8 | 18.9 | 30.9 | 2.38 | 22.8 | 3.24 |
| 4 | 166 annually | 24.5 | 17.9 | 15.1 | 17.7 | 18.9 | 30.8 | 2.32 | 22.7 | 3.22 |
| 5 | 332 annually | 25.5 | 18.2 | 16.4 | 18.2 | 19.7 | 31.0 | 2.31 | 21.9 | 3.06 |
| 6 | 166 at seeding | 24.5 | 17.0 | 14.3 | 15.7 | 18.1 | 31.0 | 2.33 | 22.7 | 3.24 |
| 7 | 332 at seeding | 25.6 | 17.8 | 14.3 | 16.4 | 18.8 | 30.7 | 2.37 | 22.6 | 3.24 |
| Main K treatment effect | | * | NS† | ** | ** | ** | NS | NS | NS | ** |
| Linear (Treatments 1 to 5) | | ** | NS | ** | ** | ** | NS | NS | NS | ** |
| No. 6 and 7 vs No. 2 and 3 | | NS | NS | NS | NS | NS | NS | NS | NS | NS |

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† Nonsignificant.

Mg DM ha$^{-1}$ in 4 yr) are similar to the responses reported by others on soils high in K (Jones et al., 1974; Havlin et al., 1984; Barbarick, 1985). The yield increases in our study were lower than the increases reported by Kafkafi et al. (1977) in Mediterranean conditions. They increased DM yields from 15.2 Mg ha$^{-1}$ with 0 K fertilization to 20.9 Mg ha$^{-1}$ with 498 kg K ha$^{-1}$ in a soil with an initial K content of about 180 mg K kg$^{-1}$.

These results suggest that in high yielding conditions alfalfa yield increases with K fertilization are very limited in soils with high exchangeable K levels.

## Herbage Mineral Concentrations

The average 4-yr K concentration in the herbage and average annual concentrations in three of four growing seasons increased linearly with increasing K fertilization rates (Table 2). The small increase in K concentration, from 18.1 to 19.7 g kg$^{-1}$ with increasing K fertilization rates, is quite similar to the results reported Barbarick (1985) and Havlin et al. (1984) in soils high in K.

On soils responsive to K fertilization, the tissue concentration of K presented a much higher increase. Sheaffer et al. (1986), in a soil with 35 mg K kg$^{-1}$, found that K tissue contents increased from 11.4 to 25.3 g kg$^{-1}$ when K fertilization rates increased from 0 to 334 kg K ha$^{-1}$. Smith (1975), in a soil with about 128 mg kg$^{-1}$ of exchangeable K, found that the K concentration of the tissue increased from 8.9 to 20.5 g kg$^{-1}$ when K fertilization rates increased from 0 to 448 kg K ha$^{-1}$.

In this study, herbage K concentration differences between treatments varied little with the age of the stand, probably because the differences in soil test levels between K treatments also were small (Table 3). The total amount of K removed with the herbage increased linearly with applied K (Table 4). Removal of K reached 1728 kg ha$^{-1}$ with the application of 332 kg K ha$^{-1}$ yr$^{-1}$, compared with 1546 kg K ha$^{-1}$ for the 0 K fertilization treatment.

Average P and Ca concentrations in the herbage were not significantly affected by increasing K rates (Table 2). A linear decrease in Mg concentrations, however, was seen with K fertilization rates, as has been reported in other studies (Smith, 1975; Rominger et al., 1976; James et al., 1995). The observed P, Ca, and Mg concentration values were similar to those of other studies conducted in the Ebro Valley and in the USA (Heras and Montañes, 1974; Smith, 1975; Sheaffer et al., 1986; James et al., 1995).

The K treatments did not affect the N concentration of the herbage, which suggests that the supply of K was already adequate for maximum $N_2$ fixation (Collins et al., 1986).

**Table 3. Soil ammonium acetate extractable K ($K_e$) concentrations at different depths (cm) during the experiment.**

| | | $K_e$ concentration | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1993† | 1994 | | 1995 | | 1996 | | 1997 (final harvest) | | |
| Treatment | K | 0–30 | 0–30 | 30–60 | 0–30 | 30–60 | 0–30 | 30–60 | 0–30 | 30–60 | 60–90 |
| | kg ha$^{-1}$ | g kg$^{-1}$ | | | | | | | | | |
| 1 | 0 | 426 | 283 | 188 | 272 | 211 | 226 | 182 | 261 | 213 | 144 |
| 2 | 41.5 annually | 417 | 279 | 187 | 276 | 217 | 221 | 184 | 279 | 205 | 159 |
| 3 | 83 annually | 442 | 271 | 192 | 271 | 221 | 235 | 196 | 272 | 212 | 148 |
| 4 | 166 annually | 461 | 259 | 201 | 275 | 219 | 231 | 192 | 279 | 208 | 140 |
| 5 | 332 annually | 447 | 317 | 202 | 308 | 222 | 250 | 207 | 315 | 219 | 165 |
| 6 | 166 at seeding | 427 | 258 | 200 | 269 | 231 | 217 | 182 | 244 | 200 | 136 |
| 7 | 332 at seeding | 427 | 315 | 198 | 279 | 222 | 228 | 194 | 262 | 208 | 147 |
| Main effect | | – | NS‡ | NS | NS | NS | ** | NS | ** | NS | NS |
| Linear (Treatments 1 to 5) | | – | NS | NS | * | NS | ** | * | ** | NS | NS |
| No. 6 and 7 vs No. 2 and 3 | | – | NS | NS | NS | NS | NS | NS | NS | NS | NS |

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† Initial soil test levels. Air-dried soil samples.
‡ Nonsignificant.

**Table 4. Balance of K in K fertilization treatments, 1994–1997.**

| Treatment | K | Fertilizer inputs | Uptake | Balance |
|---|---|---|---|---|
| | kg ha$^{-1}$ | kg K ha$^{-1}$ | | |
| 1 | 0 | 0 | 1546 | −1546 |
| 2 | 41.5 annually | 166 | 1524 | −1358 |
| 3 | 83 annually | 332 | 1628 | −1296 |
| 4 | 166 annually | 664 | 1654 | −990 |
| 5 | 332 annually | 1328 | 1728 | −400 |
| 6 | 166 at seeding | 166 | 1561 | −1395 |
| 7 | 332 at seeding | 332 | 1631 | −1299 |
| Main effect | | | ** | ** |
| Linear (Treatments 1 to 5) | | | ** | ** |
| No. 6 and 7 vs No. 2 and 3 | | | NS† | NS |

** Significant at the 0.01 probability level.
† Nonsignificant.

## Soil Extractable Potassium

Soil extractable K values prior to alfalfa seeding cannot be used together with the values collected in other seasons. The seeding year values were higher than in any other year because in that year soil analyses were conducted only on dry samples, which often result in different values than determinations made with moist soils (Mengel and Kirkby, 1980).

Soil K measured at the end of each of the four growing seasons is shown in Table 3. The $K_e$ values in the 30-cm depth showed significant linear effects with K fertilization, although with low slope. The increase in soil $K_e$ concentration in the 30-cm depth (24 to 54 mg kg$^{-1}$) with the application of 332 kg K ha$^{-1}$ yr$^{-1}$ in the last two growing seasons was small compared with the high rate applied. The lack of significant differences or trends among treatments in soil layers below the 30-cm depth suggests that although alfalfa is a crop with a high potential for subsoil exploitation (De Nobili et al., 1990; Peterson and Smith, 1973), the upper 30 cm of soil was most affected by K removal. Moreover, the highest rates of K did not significantly increase subsoil $K_e$ values. The average $K_e$ at the 0- to 30- or 30- to 60-cm depths did not change appreciably from year to year. These results suggest that alfalfa uptake or K fertilization scarcely influenced the $K_e$ levels.

The balance between K uptake and fertilizer inputs (Table 4) shows that 332 kg K ha$^{-1}$ yr$^{-1}$ (1328 kg K ha$^{-1}$ in 4 yr) was not sufficient to offset the uptake of K. The differences in soil $K_e$ values in the 0- to 90-cm depth between plots that received no K fertilization and the plots with the highest rates (332 kg K ha$^{-1}$ yr$^{-1}$) were, in the 90-cm depth, only 81 mg K kg$^{-1}$ (699–618 mg K kg$^{-1}$). This amount seems to account for most of the differences in the K balance between the two treatments (−1546 and −400 kg K ha$^{-1}$), since 1 mg K kg$^{-1}$ of soil represents about 11.7 kg ha$^{-1}$ of $K_e$ for the 90-cm depth, assuming a soil bulk density of 1.3 g cm$^{-3}$.

The 198 kg ha$^{-1}$ (1146–948 kg ha$^{-1}$) of nonaccounted K could come from nonexchangeable K forms, as pointed out by Lee and Metson (1977) and Vough and Decker (1992). Similar findings were reported by others. Jounay et al. (1996), working with calcareous soils in southwest France, reported that the $K_e$ content of nonfertilized plots declined only slightly (over a 25-yr period) without reaching levels expected from nutrient balance estimates.

Havlin et al. (1984), also working in calcareous soils but with a low $K_e$ (126 mg K kg$^{-1}$), found a substantial buildup of $K_e$ for the high K application rates. But they also found that the $K_e$ for the treatment with 0 kg K ha$^{-1}$ changed little with time, suggesting that the high illite content may account for the observed K buffering capacity.

The results of this study showed that K fertilization had a limited ($p = 0.059$) effect on alfalfa DM yield in intensive Mediterranean production systems. However, the economical benefit of this limited response to K by alfalfa does not justify the cost of fertilization. The results also showed that rates of K usually considered high were not sufficient to offset the K removed by the alfalfa.

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