Mineral balance and absorption from soil of Pennisetum sp at different stages

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Abstract— *Forage availability, in quantity and quality, is essential for livestock development. In this context, the aim of this study was to characterize the macro and micro elements of Maralfalfa grass (Pennisetum sp) in function of different harvest frequencies under subsurface drip irrigation. The results showed that mineral concentration in plants depends on: (i) the retention in soil and/or elapsed time for nutrient to be available after a manure application. In this sense, due to the large P retention capacity of Andosols, soil P and Mg mineralization were very slow, in spite of root activity and its influence in the soil balance (ii) the age of the plant: all element concentrations decreased as the plant grew old, except Na. The concentration values between leaf and sheath showed significant differences for all elements except for P and Cu. Thus Ca, Mg, B, Fe and Mn contents were significantly higher in leaf than in sheath while K, Na and Zn were lower in leaf. B contents were also higher in leaves. The ratio K/ (Ca+Mg) for all ages of the plant was higher than 2.2, increasing the possibility of induced hypocalcaemia.*

Keywords— Maralfafa, mineral uptake, nutrient concentration, ratio K/Ca, soil depletion.

I. INTRODUCTION

Forage availability is a crucial issue for livestock development. In arid and semi arid regions, marked seasonal fluctuations in nutritional quality of natural pastures compromise livestock productivity (Madzonga and Mogotsi, 2014). To avoid this problem, it is necessary to import the forage or to continuously produce it using irrigation. In the Canary Islands, a large percentage of production costs depend on imported feed, representing economical and strategically problems for the farmer (Palacios et al., 2013). Recently Maralfalfa grass has been introduced in Canary Islands for animal diet. This grass has a high yield. The nutritional value of Maralfalfa grass has been described by Clavero and Razz (2009), Macoon et al. (2001), Correa (2006), Marquez et al. (2007) and Palacios et al. (2013). All authors agree in plant-age dependence of the mineral nutritive values. Although there is not enough information about mineral composition, it has an important role into the metabolic routes in healthy and productive animals. Mineral deficiencies can have devastating consequences on animal health. An inadequate diet can be induced lower animal production. Usually if forage harvested and offered to animals has low quality, limiting animal performance, leading the producer to make use of complementary feeding of the flock, burdening production costs (Townsend et al., 1994). The availability of mineral nutrients in appropriate quantities is a major factor for livestock, but their study is often scarce, not taking into account the fertilization and the mineral availability in the soil at harvest. A correct soil nutrient balance is essential for obtaining a sustainable high productivity. The plant must obtain all nutrients from the specific soil with which has content; therefore in this sense the soil-plant relationship is direct (Reid and Horvath, 1980). There appears to be a definitive role of mineral deficient soils to cause deficient levels in ration (Mcdowell and Conrad, 1990), but the concentration of a mineral in a soil in is an uncertain guide to its concentration in the forage (Khan et al., 2004). In a sustainable point of view, the nutrient quantities absorbed by plants must be added to the cultivated soils to avoid future deficiencies.

Manure is the main source of organic fertilizer and its appropriate management is an excellent alternative to provide nutrients to plants while improving the soil physical and chemical characteristics. This work has the objective to characterize the mineral composition of Maralfalfa grass (Pennisetum sp) grown on a recent volcanic soil through different cut-off frequencies under drip irrigation in Canary Island conditions, to obtain the optimum nutritive values.

II. MATERIAL AND METHOD

2.1 Experimental plot

During 2009 a Maralfalfa grass experiment was conducted in a field of 8000 m^2 situated at sea level in El Hierro Island (Canary Island). Rainfalls were 157 mm during the experimental period of seven months. More detailed climate description is presented in Palacios et al, 2013 Absolute minimum temperatures for the experimental period was always above 10°C, which is mentioned by Cook et al. (2005) as the growth ceasing temperature.

The field soil is of recent volcanic origin and contains large amounts of amorphous materials (Vitric Andosol). This soil was sampled three different times (Table 1): the first one was at the beginning of the experiment (before manure, BM), the second one was after goat manure and gypsum amendment application (after manure, AM) and the last sampling was 7 months after the plant transplant (AT). Table 1 also shows the nutrient balance in soil after and before manure application and seven months later. The goat manure application consisted on 62,500 kg ha^{-1}.

Maralfalfa rows were 0.75 m apart and were planted in May 2009.

TABLE 1
SOIL CHARACTERIZATION AND SOIL BALANCE: OLSEN PHOSPHORUS, P(MGKG–1); EXCHANGEABLE CATIONS, (CMOLC.KG–1): K, CA, MG AND NA, BEFORE (BM) AND AFTER MANURE AND GYPSUM APPLICATION (AM), BEFORE PLANTING, AND SEVEN MONTHS AFTER THE PLANT TRANSPLANT (AT). MICRONUTRIENTS (MGKG–1): B, CU, FE, MN AND ZN WERE ALSO DETERMINED.

Soil	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
BM	24.7	2.3	11.9	5.5	3.3	0.9	0.5	22.0	0.5	1.4
AM	27.5	3.9	24.9	5.4	3.7	0.7	0.8	29.7	0.6	1.2
AT	27.0	3.1	21.2	7.9	4.3					
Balance AM-BM	2.8	627.9	1986	–1.2	82.8					
Balance AT-AM	–0.5	–315.9	–134	294	138					
Nutrient mineralization BM to AM	2	121.0	2222	–1.0	33.9					

2.2 Soil Analysis

Organic Matter, OM, electrical conductivity, EC of the 1:5 (soil to water ratio), available nitrate and sulphate were determined and presented in Palacios et al. 2013. Available soil phosphorus, P, was determined according to Olsen and Sommers (1982). Exchangeable cations were extracted with buffered ammonium acetate at pH 7, K, Ca, Mg, Na, B, Cu, Fe, Mn and Zn were analyzed by ICP (Table 1).

2.3 Forage characterization

One linear meter from three different rows was sampled in the experimental field, for each of the plant ages considered (120, 30, 50, 60, 70 and 90 days) for obtaining total production in experimental conditions (Table 2). The first cut off was 120 days after the transplant. For a second harvest, the plot was divided in six parts that were cut after 30 50, 60, 70 and 90 days of regrowth. A third cut of plants aged 40 and 56 days was collected in lines that had been cut in the second harvest after 30 days. Cumulative production obtained in late November as a sum of 120 days (first harvest) and 90 days (second harvest) or 120 days (first harvest), 30 days (second harvest) and 56 day (third harvest) were 59,159 and 56,400 kg DM ha^{-1}, respectively.

The percentage of dry matter (DM) was estimated by drying in an oven at 60º to constant weight. After digestion with nitric acid in microwave, the following elements were analyzed by inductively coupled plasma optical emission spectrometry (ICP_OES): P, K, Ca, Mg, Na, B, Cu, Fe, Mn and Zn (Table 3) by method of nitric acid digestion in microwave.

Separate nutritive values from leaf and sheath of Maralfalfa grass from samples 70 and 90 (second harvest) and 40 and 56 (third harvest) were also determined (Table 4).

TABLE 2
HARVEST NUMBER, PLANT AGE (IN DAYS OF REGROWTH AFTER HARVEST), CUT OFF DATES AND TOTAL PRODUCTION (KG DM HA^{-1}).

Harvest	Plant age and cut off dates/ (total production)					
1	120* days/(38,400) sep,1					
2	30days / (6,000) Sep,30		50days Oct,19	60days Oct,30	70days Nov,10	90days/ (20,750) Nov,30
3	40days Nov,10	56days/(12,000) Nov,26				

***days after transplant.**

TABLE 3
MEAN AND STANDARD DEVIATION (STD) THE FIRST, SECOND AND THE THIRD HARVEST: PHOSPHORUS, P, POTASSIUM, K, CALCIUM, CA, MAGNESIUM, MG AND SODIUM, NA, IN % FROM THE TOTAL DRY MATTER, DM, AND BORON, B, CUPPER, CU, IRON, FE, MANGANESE, MN, AND ZINC, ZN IN MG KG–1 FROM THE TOTAL DM.

Date	Age	Harvest	P		K		Ca		Mg		Na	
			mean	std	mean	std	mean	std	mean	std	mean	std
30-sep	30	2	0.21^{ab}	0.01	3.66^{cd}	0.31	0.60^{c}	0.87	0.21^{b}	0.03	0.22^{b}	0.02
10-nov	40	3	0.32^{d}	0.02	3.98^{d}	0.07	0.47^{b}	0.15	0.28^{c}	0.01	0.29^{cd}	0.02
19-nov	50	2	0.29^{cd}	0.02	5.76^{e}	0.29	0.60^{c}	0.04	0.28^{c}	0.01	0.25^{bc}	0.0
30-nov	56	3	0.34^{d}	0.02	3.31^{bc}	0.15	0.26^{a}	0.03	0.22^{b}	0.01	0.26^{bc}	0.02
30-nov	60	2	0.22^{b}	0.01	5.53^{e}	0.32	0.48^{b}	0.10	0.24^{b}	0.03	0.25^{bc}	0.001
10-nov	70	2	0.29^{cd}	0.01	3.81^{cd}	0.24	0.46^{b}	0.05	0.24^{b}	0.02	0.31^{de}	0.02
26-nov	90	2	0.26^{bc}	0.04	3.49^{bcd}	0.46	0.30^{a}	0.02	0.23^{b}	0.02	0.33^{de}	0.05
01-sep	120	1	0.17^{a}	0.05	2.61^{a}	0.13	0.23^{a}	0.04	0.22^{b}	0.03	0.11^{a}	0.02
Date	Age	Harvest	B		Cu		Fe		Mn		Zn	
			mean	std	mean	std	mean	std	mean	std	mean	std
30-sep	30	2	5.67^{cd}	0.58	11.33^{c}	0.58	156.33^{a}	15.70	30.33^{abc}	2.08	33.33^{ab}	1.52
10-nov	40	3	5.21^{c}	0.37	4.41^{a}	0.24	166.40^{a}	2.96	41.73^{d}	3.04	37.33^{b}	2.35
19-nov	50	2	6.00^{d}	0.01	11.00^{c}	0.01	312.67^{b}	4.04	32.67^{bcd}	1.52	47.67^{b}	5.90
30-nov	56	3	4.38^{ab}	0.01	24.26^{d}	1.40	118.63^{a}	38.36	24.43^{ab}	2.4	33.34^{ab}	2.30
30-nov	60	2	4.33^{ab}	0.58	9.67^{bc}	1.20	697.00^{c}	40.63	32.33^{bcd}	1.52	34.33^{ab}	4.73
10-nov	70	2	4.58^{b}	0.27	5.04^{ab}	1.10	125.84^{a}	13.00	26.36^{ab}	1.63	42.37^{b}	5.95
26-nov	90	2	4.00^{a}	0.01	29.00^{d}	6.01	233.92^{ab}	187.1	39.17^{cd}	9.24	43.83^{b}	14.31
01-sep	120	1	7.67^{e}	0.58	11.67^{abc}	2.50	327.67^{b}	85.04	20.67^{a}	2.51	19.33^{a}	3.50

Numbers with the same letter superscript are not significantly different ($P < 0.05$).

2.4 Irrigation system

Integral drippers spaced 0.3 m in lateral lines 0.75 m apart, with used delivery rates at 8 L hour^{-1}. Irrigation system applied ground water provided during 2 hours and approximately 3 times per week, according to the water management practices applied by the local farmers.

TABLE 4
MEAN AND STANDARD DEVIATION (STD) DATA OF LEAF AND SHEATH OF MARALFALFA IN THE SECOND 70 AND 86) AND THE THIRD HARVEST (40 AND 56): PHOSPHORUS, P, POTASSIUM, K, CALCIUM, CA, MAGNESIUM, MG AND SODIUM, NA, IN % FROM THE TOTAL DRY MATTER, DM AND BORON, B, CUPPER, CU, IRON, FE, MANGANESE, MN, AND ZINC, ZN IN MG KG^{-1} FROM THE TOTAL DM.

Date	Age	Harvest		P		K		Ca		Mg		Na	
				mean	std	mean	std	mean	std	mean	std	mean	std
10-nov	40	3	leaf	0.30^{bc}	0.01	3.20^{c}	0.10	0.75^{d}	0.02	0.41^{e}	0.01	0.25^{ab}	0.01
			sheath	0.33^{c}	0.03	4.52^{e}	0.04	0.29^{ab}	0.11	0.18^{b}	0.03	0.31^{c}	0.02
30-nov	56	3	leaf	0.33^{bc}	0.03	2.51^{b}	0.37	0.40^{b}	0.02	0.34^{d}	0.00	0.20^{a}	0.01
			sheath	0.35^{c}	0.02	3.80^{d}	0.17	0.17^{a}	0.04	0.14^{ab}	0.01	0.29^{bc}	0.03
10-nov	70	2	leaf	0.31^{bc}	0.02	2.86^{bc}	0.09	0.58^{c}	0.06	0.36^{d}	0.01	0.33^{c}	0.02
			sheath	0.29^{b}	0.02	4.32^{e}	0.22	0.39^{b}	0.06	0.17^{b}	0.03	0.30^{bc}	0.02
26-nov	90	2	leaf	0.24^{a}	0.02	1.82^{a}	0.17	0.33^{b}	0.02	0.25^{c}	0.02	0.25^{ab}	0.02
			sheath	0.24^{a}	0.02	3.49^{cd}	0.07	0.20^{a}	0.05	0.13^{a}	0.03	0.40^{d}	0.06
Date	Age	Harvest		B		Cu		Fe		Mn		Zn	
				mean	std	mean	std	mean	std	mean	std	mean	std
10-nov	40	3	leaf	7.00^{c}	1.00	6.00^{a}	0.00	342.00^{b}	22.87	57.00^{c}	2.65	28.00^{a}	1.00
			sheath	4.00^{a}	0.00	3.33^{a}	0.58	47.00^{a}	17.06	31.33^{b}	7.37	43.67^{bc}	3.21
30-nov	56	3	leaf	5.00^{ab}	0.00	22.00^{b}	1.00	321.67^{b}	153.12	31.67^{b}	4.51	29.00^{ab}	1.73
			sheath	4.00^{a}	0.00	25.00^{bc}	2.00	51.67^{a}	5.03	20.00^{a}	1.73	36.00^{bc}	3.00
10-nov	70	2	leaf	5.67^{b}	1.15	6.33^{a}	0.58	267.33^{b}	33.29	35.67^{b}	4.04	31.33^{ab}	3.06
			sheath	4.00a	0.00	4.33^{a}	1.53	49.33^{a}	13.01	21.33^{a}	1.53	48.33^{c}	11.02
26-nov	90	2	leaf	5.00^{ab}	0.00	26.67^{bc}	1.53	368.33^{b}	89.39	31.33^{b}	2.08	29.67^{ab}	0.58
			sheath	4.00^{a}	0.00	29.33^{c}	7.64	77.33^{a}	27.57	27.67^{ab}	4.93	50.00^{c}	13.00

Numbers with the same letter superscript are not significantly different ($P < 0.05$).

2.5 Statistical analysis

Analyses of variance (ANOVA) were carried out using statistical Packaged SPSS (version 20) by the Generalized Linear Model procedures for nutritive values of Maralfalfa. The model includes the effect of age of cutting, harvest and their interactions and also the effect of leaf and sheath separately considered. Mean separation was tested using the least significant difference (LSD), considering P= 0.05.

For more information about material and method see Palacios et al., 2013

III. RESULTS

Table 1 shows the soil evolution during the experience. Manure nutrient mineralization, as calculated by the increase of soil nutrients analysis (AM-BM expressed in kg ha–1 considering bulk density (1 t m-3) and buried depth (0.1 m)) divided by nutrients provided by manure (kg), is presented in Table 1. As observed, P and Mg mineralization are very slow and there are other sources than manure providing available nutrients. At the beginning of the experiment the Mg concentration was high, yet over time a significant amount was released, when root activity influence the soil balance (AT-AM). The same happened to the Na.

As presented in Table 3, P and Na in plants had significant lower contents at the beginning of the experiment (September: 120 and 30 days) than in November, and Na seemed to be sooner available from organic source than P. While P reached the maximum values in November and decreased as the plant grew old (although showed significant higher contents for the 3td harvest), Na increased its values as the plant grew old. Significant lower values for K and Ca were obtained for the 3th harvest (56 day), probably due to the decreasing of soil reserves as a result of plant extractions. This depletion was not observed for the rest of the nutrients, which seemed to respond only to plant age: in this sense, K and Ca which seemed to be available just after the manure application, had the maximum contents for 50–60 days and showed lower contents as the plant grew old. Micronutrients contents were highly variable (especially for Fe) and also showed medium contents around 50–60 days. B content was low and diminished as plant grew old. Cu needed time to be available to plant absorption (the same as for P and Na), accumulated over time and showed significant higher contents at the end of the experiment. Results showed some outliers, probably due to sampling issues.

Table 4 presents separately the nutritive values in leaf and sheath as influenced by the age of the plant and the harvest number. The values between leaf and sheath showed significant differences for all elements except for P and Cu. Ca, Mg, B, Fe and Mn contents were higher in leaf than in sheath while K, Na and Zn were lower in leaf. B contents were also higher in leaves although no significant differences were found in all the dates.

IV. DISCUSSION

The literature on the mineral content of the Maralfalfa cultivation is very limited; however Mcdowell and Valle (2000), Correa (2006) and Correa et al. (2008) mentioned that P, K and Ca contents in forage decreased as the plants grew old, as occurred with our experimental data for Maralfalfa. Kitaba et al. (2007) also obtained that P content in pastures decreased as the plant grew old. The absorption of this element depends on the amount and availability of P in the soil (Palacios-Diaz et al., 2009). Ours results coincided with Idota et al. (2005), who studied manure application in a sandy soil and also found higher available phosphoric acid concentration in soil three months after manure application, but lower after few months due to the maralfalfa absorption. In our study, due to the large P retention capacity of Andosols (which reduces P availability), the observed P increment in soil (Table 1) was lower than obtained by Idota et al. (2005) although their "High manure doses" was similar than that was applied in this study. Despite that, there was a clear response of plant to manure application once P was available.

Gomide et al. (1969) showed significantly higher Ca and Mg values for 140 days in Pennisetum purpureum comparing to 84 days, while P and K decreased by time as for the rest of the authors. This apparent contradiction can be explained analyzing in detail the influence of nutrients assimilability, added by manure or mineral as inputs. Although no references are found about the depletion of K and Ca in soils cultivated with Maralfalfa as results of plant extractions, this fact could explain the lower contents in plant presented in our experimental data from the 3th harvest.

Considering the values presented in Table 3 and the critical levels recognized for nutrition of grazing ruminants (Mcdowell, 1995), all the elements and for all the ages of the plant presented adequate concentration except for the first harvest in which P, Ca and Zn were below the critical level. Regarding soil micronutrients presented in Table 1, only Zn was below the critical level (Lowe et al., 1979 and MARM, 2010) before the manure application so the plant responded to this nutrient addition, although needing time to be available. Despite this, the ratio K/(Ca+Mg) for all the ages of the plant was higher than 2.2, increasing the possibility of induced hypocalcaemia (Dugmore, 1998). Idota et al. (2005) found higher ratio values in sheath than in leaf, as occurred with our experimental data (Table 4).

The Na content in plant showed significant increments as the plants grew old, contrary to what occurred by the rest of the elements. No references are found coinciding with this result in which the concentration varies between 0.11–0.35 % according to plant age. Edmeades and O´connor (2003) defined that adequate concentration in pastures for animals is between 0.07–0.09%; 0.10–0.12% and 0.12% for sheet, cattle and dairy cow respectively. Therefore, Na contents in Maralfalfa are adequate for cutting at any time.

B content in plant was low which can be attributed to the large B retention capacity of allophane (Su and Suarez, 1997). The organic matter supplied by the manure could also have contributed as pointed out by Goldberg et al. 2002 who found that organic carbon content in soil was significantly negatively correlated with leaf B concentration.

The literature on mineral concentration in leaf and sheath of Maralfalfa is scarce. As reported by Heredia and Paladines (2007), P is part of a wide range of molecules, activates different enzymes and metabolic processes control, so their content is higher in leaves than in sheath, which coincides with our result. Ca plays an important role in cell wall. This is the reason that can explain the larger r contents found d in leaves than in sheath. This decrease in Ca concentration corresponds to the lower leaf/sheath ratio found as the plant grows old. This result coincides with Casanova et al. (2006).When comparing plant

Fe values, this element was presented in higher concentration in leaf than sheath, coinciding with cited by Herrera et al. (2008), because the Fe is necessary for the synthesis of chlorophyll.

V. CONCLUSION

All the macro and micro nutrients in Maralfalfa and for all the ages of the plant presented an adequate concentration for ruminant nutrition, except when coincided low content, high retention in soil or no enough time for nutrient to be available after a manure application (Ca, Zn and P respectively in our conditions). In this sense, our results demonstrated an imbalance on K/Ca in Maralfalfa plants. Thus, in order to avoid hypoglycemia problems when using exclusively this specie in ruminant diet, Maralfalfa must be complemented with other fodders species.

Only the Na content in plant showed significant increments as the plants grew old, contrary that occurred by the rest of the elements. Although references about the depletion of K and Ca in soils cultivated with Maralfalfa as a result as plant extractions are scarce, this fact explain the lower contents in plants found in the 3th harvest. Thus, this high yielding crop needs the addition of great quantity of nutrients to avoid soil depletion.

Ca, Mg, B, Fe and Mn contents were higher in leaf than in sheath while for K, Na and Zn were lower in leaf. As the plant grows up, leaf and sheath proportion decrease and, consequently, influences the macro and micro nutrient content. Also, our data demonstrate that soil has a critical influence in plant nutritive value.

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CONFLICT OF INTEREST

Authors declare no conflict of interest

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