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A Long-Term Data Sequence (1960-2013) to Analyse the Sustainability of Hay Quality in Irrigated Permanent Grasslands Under Climate Change

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Abstract: Face to climate, land and water use changes, sustainability of crop systems and quality of production is in debate. Long term database concerning hay's mineral contents, dry matter and climate dynamics (rainfall and temperature) have been collected and are used here to argue these questions. Such data are scarce, but here were made available, as they were used to obtain and maintain the certification of the crop, specifically Certified Origin Product (COP) hay. Database collected cover 1960-2013 period, in Crau area, South-Eastern France. Permanent grasslands have been established in this plain since the XVIth century and depend on border irrigation. Statistical tests show that a steady state of the total mineral content and dry matter within long-term has been reached. There is no significant correlation between rainfall and mineral content in hay. Additionally, there is no impact of temperature change on dry matter. Furthermore, the total mineral content of hay is systematically the largest in the third cut and the smallest in the first cut. Our findings suggest that irrigation plays a key role for grasslands sustainability. Irrigated grasslands in Crau area appear as a model of intensive agroecology, with COP productions of high value (hay and animal productions), a crop system, created in the XVIth century and that demonstrates its resilience face to the present global changes. It is however presently jeopardized by urban sprawl.

Keywords: Crop Quality, Hay, Crau, Fertilization, Irrigation, Long-Term

1. Introduction

One of the major global challenges today is to increase food and biomass production, while reducing fertilizer and energy uses and improving water use [1]. But two driving forces impact the sustainability of agricultural systems: (i) urban sprawl that extends to agricultural land [3, 4, 5] and becomes a major threat for soil and water resources [6, 7] and (ii) climate changes, which modifies water cycle and technical conditions of crop production [8].

Face to climatic hazards, irrigation and fertilization are the main techniques to increase and regularize crop productions, but intensive crop production usually implies large water, nutrients and energy requirements, and fertile soils. An advantage of forage production is that it grows on marginal soils [39], with limited water and nutrient requirements, is mainly based upon rainfall with sometimes complementary irrigation, little fertilizers supply, and succeeds in maintaining a correct yield to get high quality forage for livestock. But to obtain and to hold relative forage quality

(RFQ), it needs special attention and management such as fertility management and historic nutrients inputs [9, 10, 11], weed control, stage of maturity at harvest, cutting at perfect time, drying it down as soon as possible at the optimum moisture level and storage [12]. Thus quality of forage varies greatly for different farms and different climatic factors [13, 14, 12, 15]. In the last decades, changes of cultivated area allocated to grasslands and of their quality have been observed because of the change in management practices and intensification of land use, which drove to disproportionation in vegetal composition and abandonment of lands in several sites in the world [16, 17, 18, 19, 20, 21, 22].

To assess the impacts of land use and climate change on grasslands quality, time series are of great value. This paper aims to highlight chronicle data of hay quality studying whether recent climate change did actually impact the hay quality in irrigated meadows. For the first time, data of chemical analyses performed on high quality hay of pluri-specific and permanent grasslands (Certified Origin Product) over the period 1960 - 2013 are hereafter published. These data include major nutrients (N, P, K) and many minor or trace elements, for which data are very scarce. Climatic data were collected in the same period. The aim of this paper is thus to assess whether climate change recorded in the last decades resulted in quantitative and qualitative changes in hay production: yield, dry matter content and inorganic composition.

2. Study Area

2.1. Geographical Context

Crau area lies in Provence South-East France forms a triangle of 600 km^2 between Arles, Salon-de-Provence and Fos-sur-Mer (Figure 1a); it was the alluvial fan of Durance River [23]. Climate is semi-arid; rainfall is less than 550 mm/year. The tree cover is quasi non-existent and the Mistral wind blows regularly with a great violence.

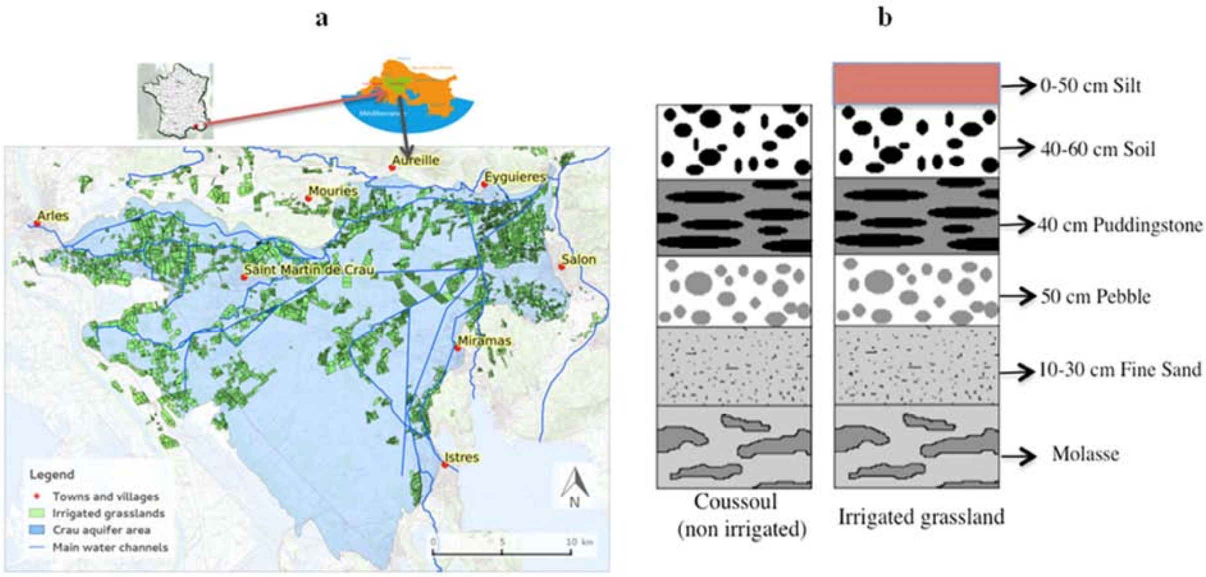

Figure 1. a. Location of the Crau area: irrigated meadow in green, irrigation network in dark blue, aquifer extension in light blue irrigation. b. Soil horizons of Crau plain, note that Coussoul does not have silt horizon that was deposited by irrigation.

In the XVIth century, Adam de Craponne, an engineer of Renaissance, built up a channel bringing water of Durance River to the Crau area. Gradually, secondary channels emerged, which now constitute a dense network of channels, up to 80 km, hence enlarging irrigated area [24]. A part of the Crau area, called “dry Crau”, locally called Coussoul, continues to be occupied by natural steppe (9,200 ha); the remaining “wet Crau” is an irrigated area and occupied mostly by permanent grasslands. Meadow irrigation (15,000 ha), in excess of crop requirements, is responsible for about 70-80% of total recharge of the aquifer (550 km^3) [25, 26, 27]. This groundwater is exploited as a source of drinking water, industries uses and orchards irrigating.

Pebbles deposited by the Durance River were cemented by calcium carbonate to form a petrocalcaric duricrust, i.e. a pedogenetic puddingstone. This latter is cracked, due to present active tectonics. Soils developed on this puddingstone are calcic luvisols [28, 29] with a topsoil of 40-50 cm thick, containing a large content of pebbles [30] (Figure 1b). Due to silt input from the Durance River through irrigation channels, the topsoil was progressively enriched in fine fraction, and an irragric A horizon formed, which is richer in minerals and trace elements, on which grows grassland. The silt input was estimated to be about 1.5 kg/m^3 through irrigation period from April to September [31]. This input minimized after the construction of Serre-Ponçon dam in the 1960s.

2.2. Hay Characteristics in the Crau Area

Hay production is only possible in the Crau by surface irrigation. This area produces high-value hay with a Certified Origin Product (COP) label (in French AOP) that replaces the AOC label at European level since 1997, and this hay is exported all around the world. The COP designation requires chemical quality monitoring and the analytical determination of the main inorganic content for each cut. These analyses, except N, P, K, are not practiced on the hay and literature on mineral contents in other cultures are very rare (*e.g.* [32] or [33] in rice crop) except in the case of study of contamination by metals or metalloids capable of accumulating in parts of the plant intended for animal or human food (*e.g.* [34, 35, 36]…). Diehl and others [37] in 1942 proved, after using several kinds of chemical manure, that the best results to get high quantity and quality of hay were obtained by supplying only P_2O_5 and K_2O. But potassium induces changes in hay floristic composition and yield [31]. Fertilisation is limited to compensating inorganic exportation by crops.

In Crau area, four cuts per year are harvested. In May, the first hay cut, dominated by grasses, is particularly suitable for feeding horses and fattening cattle. In June-July, the second hay cut, balanced by grasses and legumes, is mainly for cows and sheep, because it increases their milk yield. In August-September, the third hay cut, dominated by legumes, gives excellent results on sheep and goats by increasing milk production. In autumn and during the winter, the fourth and last hay cut, less rich in mineral nutrients and with a low value of digestibility, is grazed directly by sheep [38]. Thus the passage of sheep fertilizes grasslands with dung and urine, which represent a bulk mass of about 10.000-15.000 kg/ha [31].

The flora of meadows consists of approximately twenty different species [39, 40]. For instance some species of the Crau flora are grasses (*Arrhenatherum elatius, Dactylis glomerata* L, *Festuca pratensis, Lolium tenue, Holcus lanatus*, *Poa trivialis),* legumes (*Trifolium repens* L, *Trifolium pratense, Lotus corniculatus L, Medicago lupulina, Vicia cracca)* and other various plants like *Leontodon proteiformis, Daucus Carota, Pastanica sativa, Taraxacum officinale, Plantago lanceolata, Galium mollugo, Ranunculus acris.*

2.3. Global Change Analysis

Global change scenarios were analyzed in Crau area for 2025-2035 as a future period [26, 27, 41]. These scenarios were based on recorded and simulated data from the previous IPCC exercise (scenarios A1B, B1 and B2) of the climate, and surveys and simulated data of land use change. Some of key findings are: (i) temperature has increased since 1980 with a rate of 0.5°C each 10 years; this trend continues in the mid-term horizon (*i.e.* 2025-2030); (ii) annual precipitation has not changed significantly since the beginning of the 19^{th} century; (iii) reference evapotranspiration *ETo*, computed using the FAO56-PM method [42] has increased in the recent past and will increase significantly in the near future (around 1.5 – 2 mm/year); (iv) irrigated grassland area will decrease by 6 to 11 % in 2030; because of replacement of irrigated grasslands by other land uses, specially urban areas, which jeopardize the sustainability of groundwater and permanent grassland.

3. Methods

3.1. Data Set of the Hay

The database was constituted by collecting all analytical reports, which were conducted at the request of Committee of Crau's Hay (Comité du foin de Crau) since 1960. Hay analyses were carried out on all kinds of Crau meadow between 1960 and 2013 with various replicates each year (Annex A); 108 points of analysis were collected. The dataset, however, has shortcomings: some years the analysis program was reduced only to dry matter (DM), total nitrogen (TN) and total inorganic contents (TM). Total inorganic content (TM) is the sum of the following elements (P, K, Ca, Mg, Na, Fe, Mn, Cu, Zn); total nitrogen (TN) consists essentially of protein and non-protein (amides, amines). It also shows availability with 2 to 5 replicates by hay cut depending on the year.

Due to a particularly harsh winter that froze the meadows, a special attention was paid to the quality of the first cut of hay in 2012. Thus a set of values for 15 different samples was available in 2012.

3.1.1. Sampling Protocol Used to Performed Hay Chemical Analysis

Every year collection of samples was made by Committee of Crau's Hay. Firstly, the method consisted of collecting hay's samples from 13 producers of hay, covering all municipalities in the Crau area. Hay bales were chosen in the same conditions of harvesting and storage, such as drying in good weather, free of unwanted plants, cutting and storage in the shed up during 4 days maximum and excluding the bales of lower ranks or of the sides outer of the lot. These precautions were taken to get samples as homogeneous as possible and to avoid sampling too oxidized or too wet bales (*i.e.* contact with the ground, too much light). Before drilling, the bale surface was scratched to remove the most oxidized hay. Then the sample was collected from the front face of the bale. Each sample weighs 20 g. These operations were repeated on 10 bales randomly selected for each producer and the collected 10 samples were mixed well in a bucket before putting the final sample in a plastic bag for the laboratory. Air was expelled before closing the bag to limit sample dehydration. The final sample weighed on average 200 g [40].

3.1.2. Laboratory Analysis Methods

Analyses were all conducted in the same laboratory (LANO, Laboratoire des Chambres d'agriculture de l'Interprofession Laitière de Basse Normandie in St Lô, certified by the french Ministry of Agriculture) over the entire period investigated (from 1960 up to now). This has the advantage that, even if the methods of analysis evolved over time, inter-calibrations were made in a normative framework.

DM was determined by the BIPEA EC 77 M 0510 method after drying samples in an oven at 103 °C for 24 hours. TM was established following NF V 18-101 norm.

TN was determined by Kjeldahl method. Ca, Mg, P, K, Na, Cu, Zn, Mn and Fe were analysed before 1980 by spectrometry, and since 1980 by ICP after mineralization by dry way.

3.2. Meteorological Data (1960-2014)

For two climatic stations in the Crau area, daily data of rainfall intensity (mm) and temperature °C (min, max, mean) for the period (1960-2014) were collected from Météo France database and Climatik (INRA Data).

3.3. Statistical Analysis

Statistical analysis was performed for the study period (1960-2013) on all analytical chemistry chronicle data for each hay cut and for climatic data using the R software® and Matlab® code. Test of normality and variance calculations were performed on each set of data. The comparisons of average values of each variable were performed using Tukey test. Correlation tests between variables were performed using Spearman's rank correlation rho. The analysis of time series was performed both by autocorrelation tests, by Wilcoxon rank sum test with continuity correction, and by linear regression to define the trend and the stationary [43]. P <0.05 denoted statistically significant differences.

4. Results

4.1. Climate Data

Rainfall shows low levels in summer (June to August; Figure 2a), and no significant trend with time. Evidence for this is given by computing the moving average for five years (5-yr) of rainfall for the study period (1960-2013) (Figure 2b). The linear regression (*Rainfall* = *a* + *b Year* + *u*) is non significant (NS) at level 0.05. Conversely, the trend of temperature (min, max, mean) is very significant over the study period with p-value < 0.01**, with a positive increase about 1.89°C for the whole period (Figure 2c).

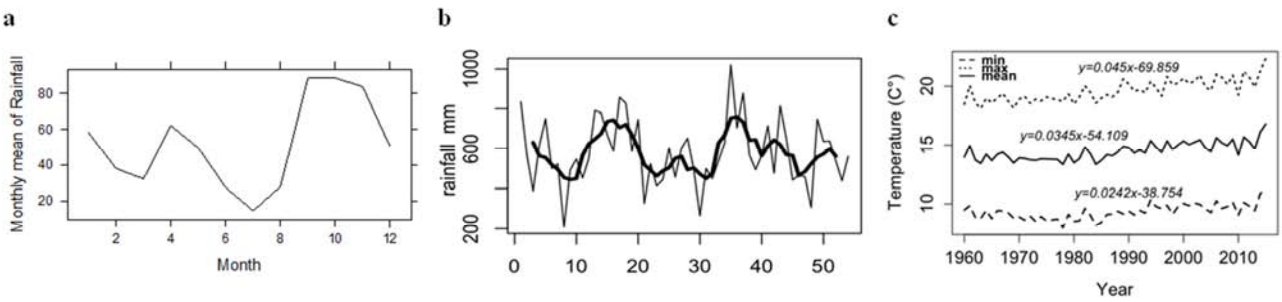

Figure 2. *In Crau area: a. Monthly average of rainfall for (1960-2014); b. Moving average (5-yr) of rainfall for (1960-2014); c. Temporal variation of minimum, maximum and average temperature for (1960-2014).*

4.2. Hay Data

4.2.1. Global Analysis

Average values for the period 1992 to 2003, when the dataset is the most complete are given in Table 1.

Table 1. *Average values (1992-2003) of chemical analyses of hay for each cut.*

	DM	TM	TOM	TN	S	P	Ca	Mg	K	Na	Cu	Zn	Mn	Fe
Cut 1	91.3	8.3	91.7	9.9	1.7	2.6	8.2	2.3	14.1	2134.7	6.6	38.9	61.4	499.2
Cut 2	91.7	10.3	89.7	12.4	2.6	2.9	10.9	3.0	19.7	2379.1	5.8	27.7	39.6	206.6
Cut 3	90.9	10.5	90.3	12.3	2.1	3.1	12.9	3.2	15.5	3190.5	7.9	32.2	47.3	365.7

DM: Dry Matter in g/100g, TM: Total of Mineral content in %DM, TN: Total Nitrogen in %DM, TOM: Total Organic Matter in % DM; P, K, Ca, Mg and S in g/kg of DM; Na, Cu, Zn, Mn and Fe in mg/kg of DM.

Table 2. *Average values of chemical composition and dry matter of Crau hay (1960-2013).*

	DM	TM	TOM	TN	P	K	Ca	Mg	S	Na	Cu	Zn	Mn	Fe
Cut 1 Mean	91.17	8.00	90.50	9.17	2.20	15.55	7.89	2.14	1.68	2228.26	5.37	25.48	49.45	327.61
Sd	3.75	0.88	4.95	3.04	0.35	2.89	2.17	0.45	0.52	722.46	1.88	25.85	16.54	230.08
Cut 2 Mean	91.44	9.50	90.34	12.49	2.79	17.42	10.80	2.79	2.52	2212.22	6.26	23.82	47.84	226.12
Sd	2.18	1.11	1.54	2.04	0.44	3.29	2.43	0.49	0.69	830.95	1.64	4.77	16.66	112.82
Cut 3 Mean	90.94	10.37	90.65	13.37	3.21	15.00	13.24	3.43	2.32	3507.40	8.57	33.20	47.60	394.78
Sd	1.38	0.80	1.83	1.90	0.53	3.08	1.95	0.38	0.63	806.65	1.30	4.73	12.71	165.60

Cut 1: first cut, Cut 2: second cut, Cut 3: third cut, DM: Dry Matter in g/100g, TM: Total of Mineral content in %DM, TN: Total Nitrogen in %DM, TOM: Total Organic Matter in % DM; P, K, Ca, Mg and S in g/kg of DM; Na, Cu, Zn, Mn and Fe in mg/kg of DM.
Sd = Standard Deviation.

For this period elements can be divided into three groups according to their change from first to second and third cuts:

- N content increases from Cut 1 to Cut 2, and stays constant from Cut 2 to Cut 3;
- P, Ca, Mg and Na contents show a monotonic increase from Cut 1 to Cut 3;
- S and K contents increase from Cut 1 to Cut 2 and then decrease from Cut 2 to Cut 3;
- TOM, Fe, Mn, Zn and Cu content decrease from Cut 1 to Cut 2 and then increase from Cut 2 to Cut 3.

Table 2 presents averages and standard deviation (Sd) of all values over 1960 - 2013 period.

4.2.2. Dry Matter Change

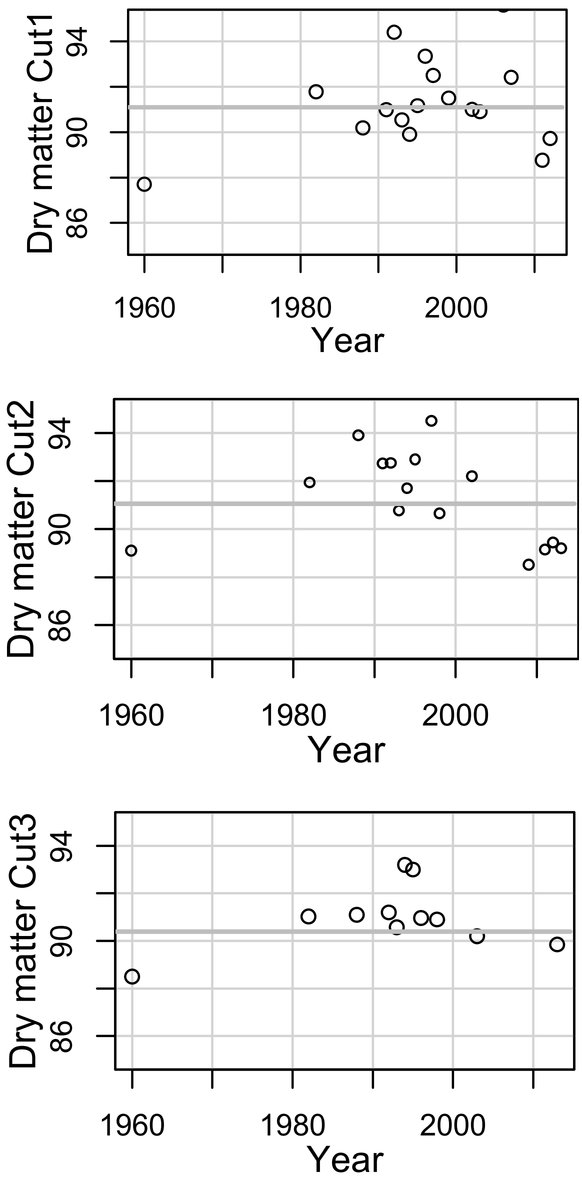

Figure 3. *For three cuts, distribution of annual values of dry matter (g/100g) around the average of all years between 1960 and 2013; note that homogeneity distribution of dry matter over years. In third cut dry matter is smaller than first and second cuts, whose floristic composition consists of more grasses and less legumes.*

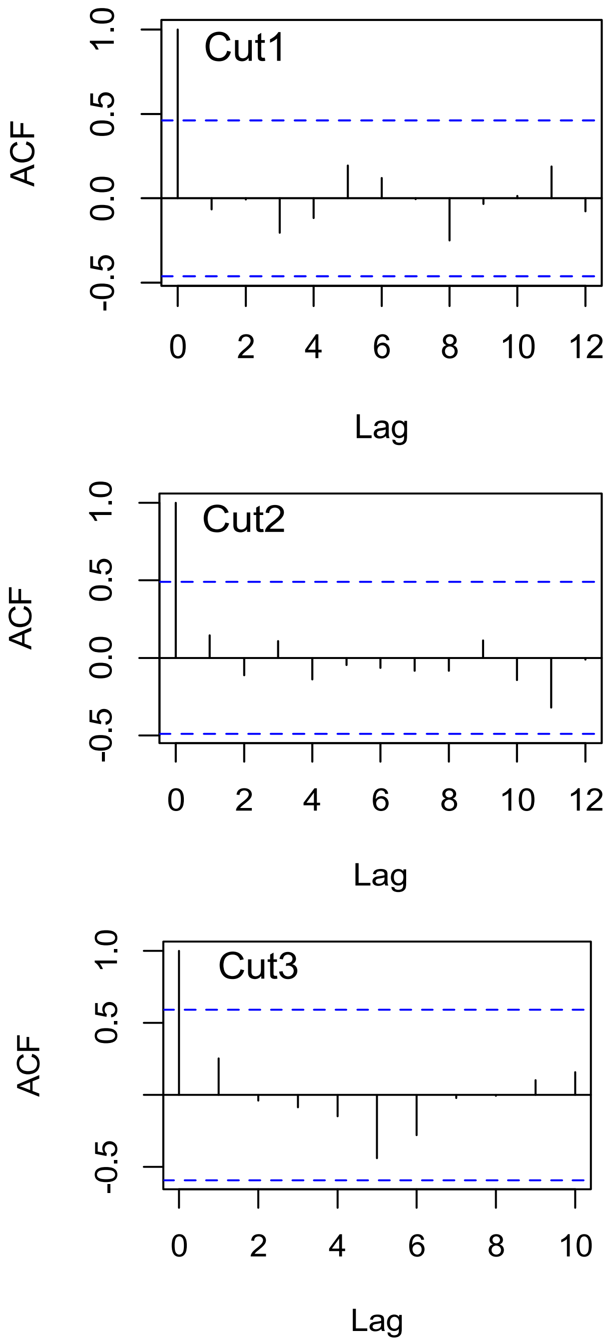

Figure 4. *Autocorrelation of dry matter for three cuts through 1960 to 2013. The two dashed lines are the limits of the confidence interval (P=0.05) of autocorrelation function (ACF) test; note that DM content is independent from a year to year.*

The dataset of dry matter (DM) from 1960 to 2013 was treated as a time series (Figures 3 and 4). DM of the third cut is significantly smaller than DM of first and second cuts (Figure 3), which can be ascribed to its different floristic composition: it consists of less grasses relatively to legumes, and water content of legumes is larger [39]. For each cut, DM changes over time are not significant (NS) and DM remained constant from 1960 to 2013. Evidence for this is the fact that no autocorrelation from year to year was observed when considering all values of DM included in the considered interval in (Figure 4): DM for every year is independent of the previous one. Finally, the trend and the stability of DM was tested by Wilcoxon rank sum test with continuity correction and by linear regression, for all cuts p-value > 0.05 indicating no definite tendency.

4.2.3. Special Case of Year 2012

Nevertheless, according to the Committee of Crau's Hay, 2012 was not a good year for hay Crau, especially for the first and third cut. There were several reasons for low levels in production, such as unfavorable weather conditions during winter and grasslands have been flooded and have not received water for four months straight, which led to the floristic balance change in the first cut. This bad weather took away some legumes grassland, particularly due to freezing of February. Producers have suffered a significant loss of yield: in 1st cut, they harvested 20 to 30% less than a normal year [38], and the main reason belongs to the change in the species composition with the disappearance of legumes. For second cut the mineral contents (mainly calcium and phosphorus) were higher.

4.2.4. Total Mineral Contents

TM of hay increases as: Cut 3 > Cut 2 > Cut 1 with significant differences. According to Shapiro-Wilk normality test, TM values are not significantly different from values normally distributed. In addition, according to Bartlett test of homogeneity, variances of the three cuts are not significantly different. Thereby averages of TM of three cuts were compared using primarily plot of averages: differences are significant (Figure 5) and demonstrated by Tukey test (Figure 6), as the value 0.5 is out of the confidence intervals. For each of three cuts, TM was constant from 1960 to 2013. Temporal variation of TM from 1960 to 2013 period was tested by Wilcoxon Test. All p-values are larger than 0.05: 1, 0.50, 0.22 respectively for Cut1, Cut 2 and Cut3, so the null hypothesis (H_0) is accepted, TM does not significantly change over time.

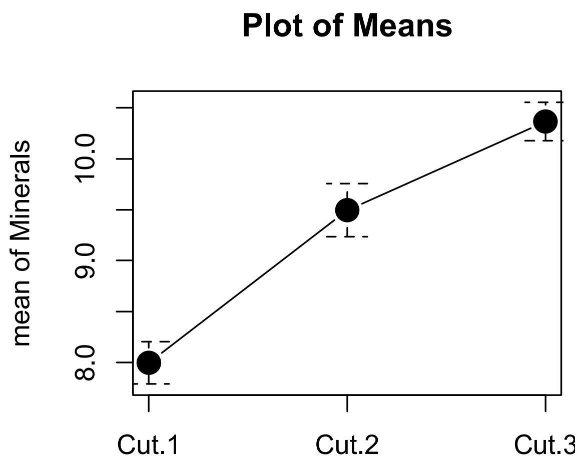

Figure 5. *Plot of means and standard deviation of total mineral contents (TM) in Crau hay. TM (in g/100g of DM) follows the sequence Cut 1 < Cut 2 < Cut 3.*

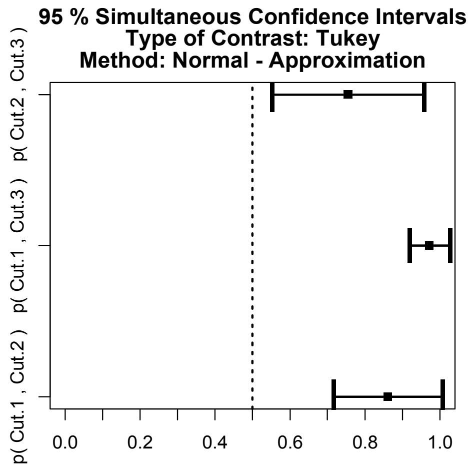

Figure 6. *Tukey plot of the total mineral contents in Crau's hay; TM = total mineral content in g/100g of DM. This plot shows the significance of multiple comparisons of three cuts.*

4.2.5. Nitrogen, Phosphorus, Potassium (NPK) and Other Elements

N and P follow the sequence Cut 1 < Cut 2 < Cut 3, while K the sequence Cut 1 < Cut 2 > Cut 3 (Figure 7).

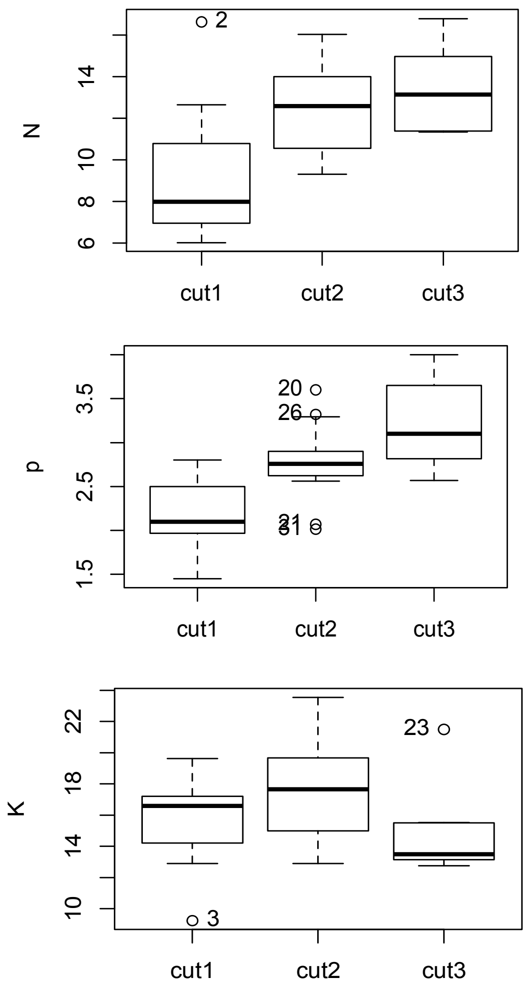

Figure 7. *Box Plot of N, P, K values for thee cuts of Crau's hay; N: total nitrogen in g/100g of DM; P, K in g/kg of DM.*

For each cut, no significant change in N, P, K contents with time was observed. Evidence for this is given by autocorrelation test and Wilcoxon rank sum test, with p-values > 0.05 for all data. Medians of three cuts were compared using Boxplot (Figure 8).

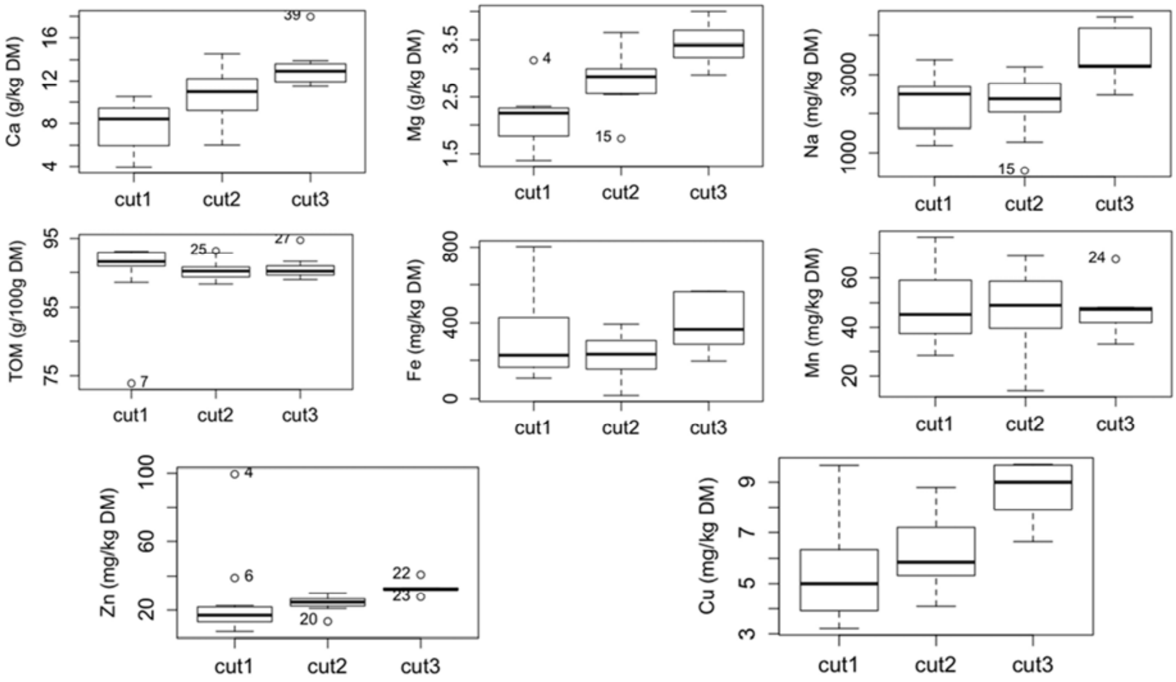

Figure 8. Boxplot of Ca, Mg, Na, TOM, Fe, Mn, Zn and Cu values for three cuts during (1960-2013). TOM: Total Organic Matter in g/100 g of DM; Ca, Mg, K in g/kg of DM; Na, Cu, Zn, Mn and Fe in mg/kg of DM.

According to Tukey test the averages of Ca and Mg of three cuts were significantly different and follow the sequence Cut 1 <Cut 2 < Cut 3. For Na and Cu concentrations were significantly larger in the third cut : Cut 1 = Cut 2 < Cut 3. Other averages of three cuts for TOM (Total Organic Matter), Fe, Mn and Zn were not significantly different. Elements that show the same behaviour between three cuts can be gathered into four groups:

- N, P, Ca, Mg;
- Na, Fe;
- Zn, Cu, Mn;
- K.

The stability of all elements over (1960-2013) period was calculated by Wilcoxon rank sum test (Table 3). Thereby Zn* changes significantly in three cuts over time, for Ca**, Mg* and Na* the change is only in the second cut, for TOM** in the first and third cut. As floristic composition changes between three cuts and as climatic conditions can influence element allocation among plant organs, by changing concentrations of elements associated with plant metabolism or by affecting vegetation species composition [44, 45, 46], correlation coefficients between elements were computed. Significant correlations (r > 0.8) are not observed for the whole population, but are observed when considering separately each cut: between Mg and Na for all cuts, between Mg and Zn for Cut 1. For Cut 3, significant positive correlations are much more numerous: between Cu and Ca, Cu and Mg, Ca and Mg, Ca and Zn; significant negative correlations are observed between Ca and Fe, Zn and Fe.

***Table 3.** Wilcoxon rank sum test for trend of Ca, Mg, Na, TOM, Fe, Mn, Zn and Cu, model P-value.*

	Fe	Cu	Mn	Zn	Ca	Mg	Na	TOM
Cut 1	0.530	0.764	0.764	0.013*	0.053	0.059	0.380	0.004**
Cut 2	0.380	0.380	0.764	0.021*	0.004**	0.028*	0.038*	0.425
Cut 3	0.173	0.173	0.173	0.012*	0.234	1.000	0.173	0.004**

*Denotes Wilcoxon test is significant (P < 0.05). ** Denotes Wilcoxon test is very significant (P < 0.05) and (P < 0.01), respectively.

4.3. Relation Between Total Mineral Contents (TM) and Rainfall, Test of Correlation

Rainfall is abundant within first cut of hay and it decreases within second and third cut, so hay growth depends significantly on irrigation water for the last two cuts. This led us to investigate the correlation between hay mineral content and rainfall amount according to three months of accumulated rainfall before each cut and to yearly rainfall over years. Spearman's rank correlation test showed that the rainfall and total mineral are weakly positively correlated for the first cut (rh0 = 0.3893, p-value = 0.15), weakly negatively for the second (rh0 = -0.41099, p-value = 0.14) and the third (rh0 = -0.2833, p-value = 0.46). Comparison with the Spearman's rank table leads to conclude that the correlation is not significant. As a result, rainfall has a negligible impact on hay quality.

5. Discussion

5.1. Global Changes Impact on the Hay Crop

Climate changes observed from 1960 to present, despite a temperature increase as high as 1.89 °C have no impact on the hay crop. Our results are in line with some previous findings of no change in production under warming in a temperate steppe in northern China [47] or where no significant interactions between warming, altered precipitation and clipping were observed [48] but differ because decreases of the yield were observed [48, 49]. Both dry matter content and hay quality in Crau area were stable through time, at least as an average on all species present in hay. Therefore, the Crau system is resilient face to climatic change. This can be ascribed to crop system based upon water control by irrigation and fertilization.

5.2. Steady State of Dry Matter and Chemical Composition of Hay Through Long-Term

Annual values of dry matter content are evenly distributed through all years, and constantly ordered (Cut 1 > Cut 2 > Cut 3), despite significant changes in temperature from 1960 to 2003. However, increasing of drought and potential evapotranspiration may depreciate forage quality and production [50], but the steady state observed in Crau area can be ascribed to irrigation. Water stress is prevented by irrigation [51] and water supply by irrigation contributes to increase the resilience of the crop system and locally mitigates climate variations in the meadows by buffering air and soil temperatures and moisture variations.

Good management strategies, practices and techniques in permanent grassland maintain the sustainability of production over years and floristic biodiversity. Production and biodiversity are linked, as any alteration in floristic composition would lead immediately to change in production [52]. There are about 20 species in Crau area, the three cuts divide the year in four growth periods and prevent large changes in floristic composition from year to year. More specifically, floristic composition is strongly influenced by nitrogen inputs and by water stress [53]. In the crop system of Crau's grasslands, both N and water inputs are controlled. Fertility management with an annual supplement of mineral fertilizers (P, K), organic manure brought by sheep grazing and prohibition or drastic limitation of nitrogen fertilizer supply prevent loss of diversity.

Optimal levels of practices in Crau have interestingly a role in the resilience of grassland's capability to supplying continuous high value hay in long-term through technical arrangements that are constrained by professional regulations and quality label (COP).

5.3. Irrigation Contributes to Get High Mineral Content of Crau Hay

Total mineral contents of Cuts 1 to 3 show a steady state since 1960, with a constant hierarchy Cut1 < Cut2 < Cut 3. Hay Crau is very rich in mineral components for all cuts. These results converge with earlier studies [37, 31], who analysed the floristic composition and mineral contents for the three cuts in Crau area and showed that chemical content of hay follows as well the sequence: Cut 1 < Cut 2 < Cut 3. The increase of mineral content from the first to the third cut can be explained by the increasing influence of irrigation water with respect to rainwater. Growth of the first cut starts in March based on rainfall, thus there is no significant quantity of irrigation added. Growth of the second cut is in May, a period based on rainfall and irrigation at same time. Growth of the third cut in July depends entirely on irrigation.

Irrigation water has an initial chemical composition directly derived from Durance river [31, 25], then it is concentrated by evaporation, it equilibrates with the soil atmosphere, while dissolving some calcite, which explains the composition of soil solution [25]. Next, the soil solution dissolves mineral fertilizers and supplies more nutrients to plants. Consequently the amount of nutrients provided by irrigation water is the largest in the third cut. This means that the largest content of mineral in the third cut comes from the effect of the quality of irrigation water; another factor is the larger percentage of legumes, which contain more inorganic elements than grasses [54, 55].

6. Conclusion

Till now, there was no impact of climate change in permanent grassland, neither quantitatively, nor qualitatively, at least when considering the average composition of hay. No interannual evolution is observed for dry matter and for most chemical elements. There is no relationship between rainfall and chemical content of hay. Irrigation waters play a key role in hay quality. The stability of yield, of composition of the three cuts, and of the constant hierarchy of mineral content of the three cuts (Cut 1 < Cut 2 < Cut 3) can be ascribed: i) to the control of fertilization (P, K inputs as fertilizers, manure input by sheep grazing and input by irrigation water), and the limitation of N input; ii) to the prevention of water stress by irrigation. Both controls maintain the floristic composition of hay.

Ultimately, the resilience of the agro-system despite a climate change with a temperature increase as high as 1.89°C can be ascribed to the skill of the farmers and to the technical regulations embodied in the Crau's hay quality label (COP). The next step will be now to analyze separately the different species of hay to check if these general conclusions apply differently to the floristic components.

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Annex A

Table A1. *Chemical analyses of hay in Crau area (1960-2013) for Cut 1.*

	Dry matter	TOM	TN	S	P	Ca	Mg	K	Na	Cu	Zn	Mn	Fe
Year	g/100g	% of DM	% of DM	g/kg DM	g/kg DM	g/kg DM	g/kg DM	g/kg DM	mg/kg DM	mg/kg DM	mg/kg DM	mg/kg DM	mg/kg DM
1960	87.7				2.0	7.4							
1982	91.0	90.9	10.6		2.8	10.5	2.2						
1982	91.8	90.9	10.6	2.2	2.8	10.5	2.2	18.3	2500.0	6.0	19.4	56.6	358.0
1991	89.2		5.7		1.4	6.5							
1991	92.1		5.4		1.5	3.3							
1991	91.7	88.6	6.9										
1992	95.2	93.7	7.2	0.9	1.5	4.8	1.8	9.2	1260.5	4.2	12.6	76.7	327.7
1992	93.6	92.3	6.9		2.4	4.5							
1993	90.7	92.5	10.1		2.7	8.8							
1993	89.7	91.0	13.5		2.8	9.5							
1993	91.3	89.7	9.2		2.3	8.7							
1994	89.9	90.2	9.8										
1995	91.1	92.3	8.6										
1995	91.2	93.5	6.9										
1996	94.4	57.1	1.8										
1996	92.3	90.8	10.4	2.2	2.6	10.5	2.3	16.9	2707.7	9.6	22.6	40.7	226.6
1999	91.5	91.5	12.6	2.4	2.5	10.4	3.2	12.9	3382.5	6.7	99.5	53.6	639.3
2003	90.9	93.0	7.7	1.4	2.1	5.5	1.8	17.3	1188.1	5.9	21.1	74.8	803.1
2006	94.6	92.6	6.1	1.6	1.2	6.4	2.1	17.2	931.1	3.8	13.9	20.5	94.6
2006	96.2	92.5	8.4	2.0	2.3	14.3	3.0	12.4	4334.1	4.5	15.3	28.4	134.1
2006	96.0	93.7	6.0	1.5	2.5	6.4	1.9	13.7	2634.9	2.7	11.2	36.2	187.5
2007	92.4	93.1	6.1	1.2	2.4	3.9	1.4	19.6	1340.0	3.2	7.5	31.7	105.8
2009	96.9	91.4	12.7		2.4	9.4							
2011	70.1		9.2		2.4	10.2	2.4	14.3					
2011	88.8		8.3		2.0	8.6	2.1	15.1	2680.0	5.0	17.0	38.0	188.0
2012	88.8		8.3		2.0	8.6	2.1	15.1	2680.0	5.0	17.0	38.0	188.0
2012	88.2		5.9		1.8	8.0	2.0	14.3	3270.0	3.0	13.0	26.0	180.0
2012	88.8		8.7		1.8	7.5	1.7	18.7	1430.0	4.0	14.0	32.0	125.0
2012	91.7		5.6		2.0	5.8	1.6	17.6	910.0	3.0	10.0	34.0	190.0
2012	88.3		11.4		2.4	10.1	2.4	17.8	3140.0	5.0	14.0	43.0	166.0
2012	92.2		6.4		2.3	7.5	1.9	16.2	2730.0	3.6	12.0	38.0	385.0
2012	91.8		6.9		2.4	8.0	2.4	17.2	2390.0	10.7	16.0	32.0	202.0
2012	90.0		8.3		2.4	11.0	3.1	20.0	2330.0	5.0	22.0	42.0	149.0
2012	88.9		7.9		2.1	11.5	2.5	15.5	4220.0	4.1	16.0	48.0	313.0
2012	88.9		10.1		1.3	9.3	2.4	18.8	3260.0	5.7	21.0	48.0	107.0
2012	87.8		8.2		2.7	7.9	2.1	17.7	3240.0	3.6	14.0	35.0	67.0
2012	90.9		9.4		1.6	7.6	2.2	17.0	2420.0	4.2	17.0	32.0	104.0
2012	91.2		7.6		2.2	9.3	2.3	15.6	2390.0	3.7	17.0	34.0	445.0
2012	88.0		7.9		2.2	9.9	2.0	20.2	4290.0	3.5	15.0	35.0	181.0
2012	90.3		7.2		2.1	8.1	2.0	14.8	2910.0	3.4	13.0	37.0	254.0
2013		93.2			1.7	5.3	1.9	17.2	1640.0	3.7	12.3	44.6	92.0
2013		92.6			1.9	7.6	1.7	16.0	2180.0	3.5	13.4	45.9	135.0

TOM= Total Organic Matter, TN=Total Nitrogen content.

Table A2. *Chemical analyses of hay in Crau area (1960-2013) for Cut 2.*

	Dry matter	TOM	TN	S	P	Ca	Mg	K	Na	Cu	Zn	Mn	Fe
Year	**g/100g**	**% of DM**	**% of DM**	**g/kg DM**	**g/kg DM**	**g/kg DM**	**g/kg DM**	**g/kg DM**	**mg/kg DM**	**mg/kg DM**	**mg/kg DM**	**mg/kg DM**	**mg/kg DM**
1960	89.1				2.7	11.0							
1982	91.0	88.9	13.2		2.8	10.9	2.6						
1982	91.9	89.0	13.2	2.3	2.8	10.9	2.6	12.9	2800.0	8.2	24.7	65.6	394.0
1991	92.7		9.3		8.6	8.1							
1992	93.8	89.8	9.4		2.9	11.0							
1992	91.7	90.6	9.9		1.2	13.7							
1993	89.1	94.6	14.2										
1993	92.1	89.8	10.9										
1993	91.5	82.4	15.1										
1993	90.4	89.2	14.0										
1995	92.9	90.4	10.6		2.9	11.3							
1997	94.6	89.6	13.0	2.8	2.2	7.9	2.9	17.6	2431.3	5.3	24.1	59.7	139.5
1997	94.4	89.7	15.1	2.3	3.2	7.0	2.8	18.6	2224.6	6.0	25.3	26.4	167.9
1998	90.7	88.3	14.4	2.1	3.3	14.6	2.8	23.6	2774.4	4.3	26.7	14.3	17.7
2002	92.2	92.8	16.0	3.6	2.7	6.0	1.8	19.7	538.0	8.8	29.9	38.0	232.1
2006	96.0	90.8	11.6	3.4	3.6	16.8	4.8	14.3	2979.7	6.8	30.7	42.2	205.3
2006	95.9	92.4	8.6	2.4	3.0	10.8	2.8	13.1	2841.5	3.6	16.3	39.8	167.9
2006	96.3	90.3	10.4	3.1	3.3	15.7	3.3	16.0	3783.8	5.5	24.7	65.0	539.1
2009	88.5	90.4	12.2										
2011	89.2		12.8		2.6	12.2	3.1	15.0	2040.0	7.0	21.0	69.0	242.0
2012	89.0		11.4		3.5	9.7	2.8	19.4	2540.0	6.0	23.0	65.0	146.0
2012	89.2		12.8		2.6	12.2	3.1	19.4	2040.0	7.0	21.0	69.0	242.0
2012	89.5		11.5		2.5	14.3	3.5	13.6	3520.0	10.0	23.0	89.0	741.0
2012	90.3		10.7		2.3	11.2	2.5	20.0	2240.0	7.0	24.0	34.0	185.0
2012	89.2		11.9		2.3	12.0	2.4	16.0	2530.0	6.0	21.0	36.0	368.0
2013		93.7			1.3	5.0	1.7	15.3	1180.0	3.8	12.4	60.3	134.0
2013		92.7			1.6	6.6	1.8	16.7	1370.0	4.3	14.3	46.5	163.0
2013	89.2	93.1	14.8		3.1	16.2	4.1	15.2					

TOM= Total Organic Matter, TN=Total Nitrogen content.

Table A3. *Chemical analyses of hay in Crau area (1960-2013) for Cut 3.*

	Dry matter	TOM	TN	S	P	Ca	Mg	K	Na	Cu	Zn	Mn	Fe
Year	**g/100g**	**% of DM**	**% of DM**	**g/kg DM**	**g/kg DM**	**g/kg DM**	**g/kg DM**	**g/kg DM**	**mg/kg DM**	**mg/kg DM**	**mg/kg DM**	**mg/kg DM**	**mg/kg DM**
1960	88.5				2.7	12.2							
1982	91.0	88.9	13.8		4.0	13.3	3.3						
1982	91.0	89.0	13.9	2.3	4.0	13.3	3.3	13.1	4180.0	9.0	32.0	33.0	565.0
1992	91.2	94.7	15.4										
1993	91.5	87.9	14.1										
1993	90.0	95.8	10.9										
1993	91.1	88.1	10.0										
1993	89.7	89.1	10.6										
1994	93.2	91.6	11.4										
1995	93.0	89.4	12.7	2.9	4.0	11.9	3.5	21.5	3225.8	9.7	40.9	41.9	195.7
1996	90.9	88.3	11.5	2.2			3.0	17.2	2984.6	7.5	29.5	54.2	632.6
1996	90.5				3.7	16.1							
1996	91.5	91.4	11.1	2.6	2.2	11.2	2.8	9.2	1972.2	5.8	26.3	42.0	492.7
2003	90.2	90.1	13.6	2.9	2.6	13.9	3.7	15.5	4462.3	9.7	33.0	67.6	284.9
2013	89.2		12.4		2.9	12.2	3.5	14.5	3440.0	7.0	19.0	46.0	253.0
2013	90.5		17.5		2.3	23.7	4.5	11.0					

TOM= Total Organic Matter, TN=Total Nitrogen content.

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