Introduction

After introducing aluminum as a parameter in our XRF mineral profile, we investigated its presence in forages and complete feeds used in dairy cattle nutrition. The data highlight its relevance as an indicator of soil contamination, alongside ash content, and even more so than iron and/or silicon.

Some Considerations

The natural physiological content of aluminum in the vegetal tissue of hay is generally very low, between 10 and 50 mg/kg of dry matter (even higher in the root system). In forage plants, this element does not perform essential biological functions and generally we do not find it above the indicated values (but in acidic soils, with a pH < 5.5, the roots absorb it naturally, accumulating it primarily in the roots and to a lesser extent in the stem*); there are some plants called as “accumulators," such as tea, which can contain over 1,000 mg/kg.

However, aluminum levels detected in hay samples are often much higher: our investigations of 7,208 animal feeds (see Table 2) show that only 1% or less of the samples exhibit physiological concentrations. This is due to accidental contamination by dust and soil during haymaking or ensiling.

Ash, Iron and Silicon are often used as indicators of the presence of soil:

Ash has an endogenous origin, specific to the tissue, and an exogenous one due to the presence of soil (or any mineral supplementation in unifeeds). It is therefore an important indicator of dust and soil load if it exceeds physiological levels. However, ash data, at concentrations close to physiological levels, is affected by a significant analytical error with NIR spectroscopy, making it sometimes unsuitable for indicating the presence of soil in the feed, especially at intermediate levels (see last page).

The natural physiological **Iron** content of hay varies between 50 and 200 mg per kg of dry matter and plays a key role in biological functions (chlorophyll synthesis, photosynthesis, and nitrogen fixation). Iron can be absorbed by the forage plant if the soil pH is slightly acidic, and this type of soil is not as uncommon as soil with a pH < 5.5. Even if high iron levels can explain the high soil content in the forage.

Silicon is a physiological component of plants, particularly grasses, as a structural support. Its composition varies greatly in tissues and soils, and it is often abundant but less bioavailable to the plant. Therefore, if we find excess silicon, we assume that it is due to soil contamination.

In this article we evaluate the **distribution of Aluminum** in the main forages/zootechnical feeds typical of bovine nutrition.

** This phenomenon should be considered for crops grown on acidic, loose, gravelly soils. Considering the entire agricultural Po Valley, soils with a pH <5.5 are rare and are found almost **exclusively in the high plains, near the Alpine margin**, where the soils are ancient, decarbonated, and subject to strong leaching. In the mid- and lowland plains, however, neutral or alkaline pHs prevail.*

Data

We collected data obtained with the XRF technique (X-ray fluorescence with Puma - Bruker energy-dispersive XRF instrumentation) on samples received in the period from February 2025 to May 2026, considering the years of forage harvesting and production starting from 2024 (unifeed excluded).

From these data we calculated the mean, the % coefficient of variation, the median and also inserted the total ash as indicators of the total quantity of mineral present in the feed.

In table 1: The detected data of Aluminium ("Al") in the various types of feed

Tab 1	N° of Samples	Mean - **Al** mg/kg	Sr[a] +/- **Al**	CV % **Al**	Median[b] **Al**	Ash %	+/- Sr Ash
Legume haylages (mostly alfalfa)	88	**801**	**942**	**118%**	**455**	**11,0**	**3,2**
Grass Haylages with moisture <65% (52.1%)	454	**653**	**747**	**115%**	**424**	**9,0**	**2,3**
Grass Haylages with moisture >65% (72,1%)	647	**572**	**583**	**102%**	**364**	**9,0**	**2,2**
Dry Unifeeds	1356	**443**	**343**	**77%**	**348**	**8,9**	**1,3**
Lactation Unifeeds	1347	**327**	**210**	**64%**	**275**	**8,9**	**1,0**
Legume hays (mostly alfalfa)	371	**426**	**476**	**112%**	**246**	**9,4**	**1,4**
Grass Hays	2293	**394**	**554**	**141%**	**240**	**7,9**	**1,8**
Corn Silages	586	**119**	**77**	**64%**	**104**	**4,4**	**0,8**
Corn Ears	66	**29**	**39**	**133%**	**10**	**1,8**	**0,3**

[a] Sr: Standard deviation. [b] The median is indicated due to the significant variation in aluminum content: this average is less affected by extremely high or low values. All data is in mg/kg of dry matter, ash is in g/100g of dry matter.

Except for legume haylages, we have a significant amount of data available: we note that the standard deviation and its correlated CV% are very large, indicating the enormous variability in aluminum content. However, it is halved in unifeeds and corn silage because the former is affected by dilution, while the latter is influenced by the specific mowing/harvesting technique. Corn ears were included here purely for comparison purposes: the number of samples is small, but the production technique of this feed is crucial, and in practice, the values found are realistically the physiological values of plant tissue.

The median of all categories (excluding corn) is equal to **336 mg/kg** of Aluminum, providing a rough indication of the most common, realistic average value in these foods.

Specifically, each feed had the following percentage of aluminum distribution:

Tab 2

	Percentage of samples with increasing Aluminum (dry matter in mg/kg)							
	< 50	**from 50 to 300**	**from 300 to 500**	**from 500 to 700**	**from 700 to 1000**	**from 1000 to 2000**	**from 2000 to 5000**	**from 5000 to 15000**
Grass Hays and Straws**	**0,1%**	**62,0%**	**17,8%**	**8,8%**	**4,8%**	**4,7%**	**1,7%**	**0,2%**
Legume Hays	**0,8%**	**58,0%**	**14,8%**	**10,0%**	**7,3%**	**7,3%**	**1,9%**	**0,0%**
Lactation Unifeeds	**0,0%**	**55,6%**	**30,7%**	**8,8%**	**3,6%**	**1,1%**	**0,2%**	**0,0%**
Dry Unifeeds	**0,0%**	**38,4%**	**33,8%**	**14,7%**	**7,2%**	**5,1%**	**0,7%**	**0,0%**
Grass Haylages with moisture >65% (72,1%)	**0,2%**	**41,0%**	**22,6%**	**11,9%**	**10,7%**	**9,7%**	**4,0%**	**0,0%**
Grass Haylages with moisture <65% (52.1%)	**0,2%**	**30,8%**	**24,9%**	**14,5%**	**14,5%**	**10,1%**	**4,4%**	**0,4%**
Grass Haylages	**0,0%**	**30,7%**	**26,1%**	**9,1%**	**11,4%**	**13,6%**	**8,0%**	**1,1%**
Corn Silages	**14,5%**	**82,6%**	**2,6%**	**0,3%**	**0,0%**	**0,0%**	**0,0%**	**0,0%**
Corn Ears	**81,8%**	**18,2%**	**0,0%**	**0,0%**	**0,0%**	**0,0%**	**0,0%**	**0,0%**

**: Wheat straws were differentiated from the grass group but no significant variations were observed between the groups.

Considering that the overall **median** (excluding corn) is approximately **336 mg/kg and that 56-86% of the samples have values < 500 mg/kg**, we frame the same data from the previous table according to the following classification, the meaning of which we have already identified:

Hays	**Background detectable level:** from **0** to **500** mg/kg	**Marginal contamination:** from **500** to **1000** mg/kg	**Significant presence of soil:** from **1000** to **15000** mg/kg
Grass Hays and Straws**	**80%**	**14%**	**6%**
Legume Hays	**73%**	**17%**	**9%**

Hay: With little difference between the two families, 7-8 out of 10 samples are considered to be at "Detectable Background Level," while 1-2 are "Marginal Contamination," and less than 1 out of 10 are "Significant Presence of Soil." Legumes are on average more contaminated by Al than grasses.

Unifeeds	Background detectable level: from **0** to **500** mg/kg	Marginal contamination: from **500** to **1000** mg/kg	Significant presence of soil: from **1000** to **15000** mg/kg
Lactation Unifeeds	**86%**	**12%**	**1%**
Dry and Prepartum Unifeeds	**72%**	**22%**	**6%**

Unifeeds: Lactations show that 90% of the samples have "background" values, i.e., normal, and the remainder are in the "marginal" zone, which is suspect. However, dry ones present more critical issues, with 2 out of 10 samples in the pre-alarm zone and 6% of the samples showing a marked presence of soil.

Various haylages (not corn)	Background detectable level: from **0** to **500** mg/kg	Marginal contamination: from **500** to **1000** mg/kg	Significant presence of soil: from **1000** to **15000** mg/kg
Grass Haylages with moisture >65% (72,1%)	**64%**	**23%**	**14%**
Grass Haylages with moisture <65% (52.1%)	**56%**	**29%**	**15%**
Legume Haylages	**57%**	**20%**	**23%**

Various Haylages, not corn: this type of preservation shows the greatest critical issues (compared to other feeds): legume haylages are poorly represented here (88 samples), but almost a fifth of the samples can be classified as "Significant presence of soil." Among the Gramineae, pre-wilted grains (with dry matter greater than 35%) are the most exposed to the presence of aluminum and therefore soil; here, a third of the samples are in "Marginal Contamination" and between 1 and 2 samples out of 10 show high aluminum levels. The moister haylages seem slightly better, as they are chopped and ensiled differently, like corn silages.

Corn Silages	Background detectable level: from **0** to **500** mg/kg	Marginal contamination: from **500** to **1000** mg/kg	Significant presence of soil: from **1000** to **15000** mg/kg
Corn Silages	**99,7%**	**0,3%**	**0%**
Corn Ears	**100%**	**0%**	**0%**

Corn silage: 3 out of 1,000 samples showed moderate contamination, presumably in the basal portion of the stalk. No significant findings.

Conclusions

We observed that aluminum is present at significant levels in various livestock feeds, with a predominance in **silage feeds** (excluding corn silage) and particularly in legume-based forages. In TMRs (Total Mixed Rations), the ingredients used in dry-cow and close-up diets contribute higher levels of soil contamination, whereas among hays, fewer than 10% of samples show significant soil content. The presence of aluminum is associated with soil contamination in the feed rather than with its natural physiological composition.

In our opinion, **aluminum is the most sensitive and robust indicator of soil contamination** (together with ash content) compared with iron and silicon. Although the latter two remain relevant indicators, they exhibit a higher background level and should be considered mainly when present at high concentrations and when aluminum levels are correspondingly elevated.

Furthermore, **aluminum is a more sensitive and robust indicator of soil contamination than NIR ash values** at intermediate contamination levels (500–1000 mg/kg).

To demonstrate this, we simultaneously **correlated ash content and aluminum concentration** in 2,080 hay and silage samples using the Pearson correlation coefficient (r), dividing the samples into aluminum concentration ranges as follows:

Range of Al	% Ash +/-Sr	ppm Al +/-Sr	N° of samples	Correlation r
from **0** to **500** mg/kg:	**7,7 +/-1,4**	**232 +/-106**	**1567**	**0,28**
from **500** to **1000** mg/kg:	**8,9 +/-1,7**	**684 +/-135**	**325**	**0,17**
above **1000** mg/kg:	**11,7 +/-3,4**	**2081 +/-1407**	**188**	**0,80**

We observe that the highest correlation occurs at aluminum concentrations above 1,000 ppm. Therefore, NIR ash values can be considered reliable (robust) when they are high (above 10.5–11%), whereas their reliability decreases substantially and their practical usefulness becomes limited within the intermediate range (ash values between 9% and 10.5%). In the range below 500 ppm of aluminum, although no significant correlation is observed, ash values are generally low and already indicate the absence of soil contamination. Aluminum occurs naturally at low physiological levels in forages and is only rarely influenced by the plant's physiological interaction with the soil, except through the physical incorporation of soil particles. Furthermore, aluminum is not intentionally added to animal diets.

We therefore suggest the following indicative reference ranges for aluminum as an indicator of soil contamination:

Classification of Aluminum Concentrations in Forages (Dry Matter Basis)	
from **0** to **500** mg/kg:	**Background detectable level.**
from **500** to **1000** mg/kg:	**Marginal contamination: pre-alert levels.**
above **1000** mg/kg:	**Significant soil presence.**

Note: *The Laboratorio Analisi Zootecniche does not carry out monitoring activities but performs feed analyses on a commissioned basis. Consequently, the samples submitted can be divided into two categories, which are often unknown to us: the first consists of samples already suspected of soil contamination (which may introduce a bias in the statistics); the second includes samples analyzed for preventive or exploratory purposes (monitoring-like statistics). Therefore, our dataset provides aggregated results, which nonetheless remain meaningful. The indications provided are based on our own observations and are therefore subject to revision and discussio****n.***

Gonzaga, June 8, 2026 Marco Mancinelli