Amending Pasture Soils Improves Forage Quality and Economic Return: An Organic Dairy Case Study

C.A.Daley, Ph.D.
California State University, Chico, College of Agriculture, Organic Dairy Program

Introduction

The success of any organic farming system begins with optimal soil fertility. High quality forages that optimize milk production require well-aerated, balanced soils. Getting "there" takes commitment and, in some cases, blind faith that investing in your soils can actually provide a generous return, a return that continues to pay dividends long after the deposit is made into the proverbial soil bank account.

Making that initial investment was an important step in the evolution of the certified organic acreage at the University Farm at Chico State.[1] The investment was considered a pledge to the concept that soil remediation would return value to the operation in some tangible way.

With the help and advice of the Chico State Organic Dairy Advisory Board and Agri-Dynamics (our consulting partner on the study), a long-term soil remediation field trial was conducted to study the effect of a basic soil amendment program on forage quality and yield, with an emphasis on the economic return that would result from added milk production.

Soils on the farm are classified as "Chico Clay Loam. " In the fall of 2008, our initial soil tests revealed a pH of 6.6 and Cation Exchange Capacity (CEC) of 13.8. The initial soil analysis showed significant deficiencies in base saturation for Calcium (Ca) at 55-58%, excessive amounts of Magnesium (33 - 34%) and Iron (32-36 ppm). Sulfur (S) concentrations were far below recommended norms. Such a significant deficiency in Ca and other nutrient had likely compromised nutrient uptake in pasture forages, reducing digestibility and consumption.

Although the initial soil organic matter (SOM) assessment was within the normal range (3.5%), soil penetrometer readings were very high (greater than 75% of readings in excess of 300 psi 2 days post irrigation)[2], indicating "tight" or compacted soils in need of aeration. Soil Ca has a positive impact on soil structure by flocculating clays (forming aggregates), in this way, Ca content works to improve water movement and aeration within the soil profile. The low base saturation for Ca may help to explain (at least in part) the tightness issues in these soils [citation].

Research Methods

The soil remediation research program began in the fall of 2008 and continued through 2010. Ten 5-acre paddocks were randomized to one of two treatments, i.e., amended vs. non-amended. Amended paddocks received a

[1] http://www.csuchico.edu/ag/farm/dairy-unit/index.shtml
[2] Diagnosing Soil Compaction Using a Penetrometer (soil compaction tester). Penn State Extension Agronomy Facts 63. http://extension.psu.edu/cmeg/facts/agronomy-facts-63

combination of soil amendments (see below) designed to remediate the soil over a three-year period to defray these initial costs. All amendments were applied in the fall, with the exception of the spring gypsum application. Amendments were applied each year for three years at a total cost of $289.50 per acre per year (materials and application).

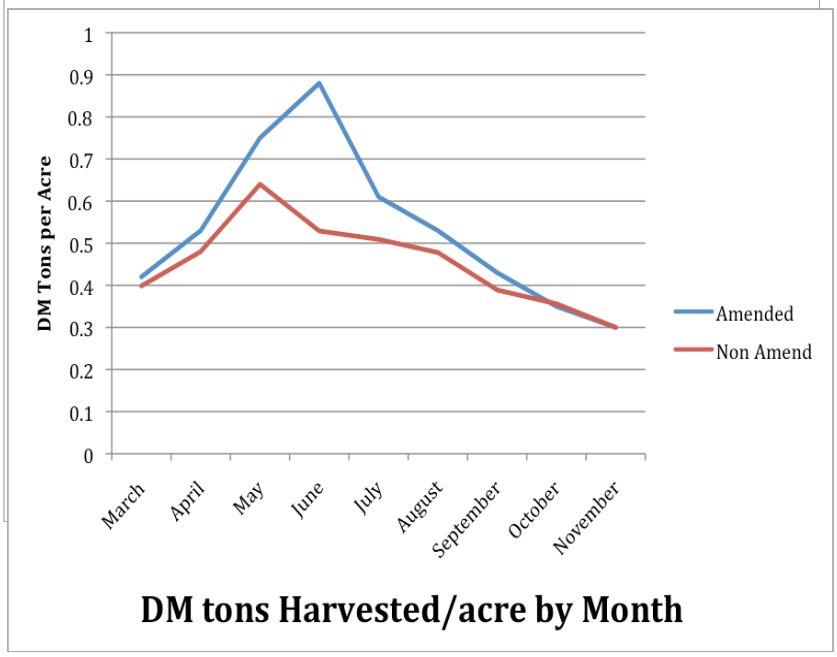
Soil Amendments

All amended or treated paddocks received the following soil amendments annually for three years:

- 2,000 pounds of Gypsum ($53 per ton) applied twice per year (1,000 pounds in the spring and 1,000 pounds in the fall)400 pounds of Hi-Cal lime ($196 per ton)
- 1 pound of Boron ($1.20 per pound) in this case, Granubor® (sodium borate)
- 5 pounds Zinc Sulfate ($1.10 per pound)
- 2 pounds Manganese Sulfate ($0.90 per pound)
- 5 tons of Compost ($35 per ton); (2:1:2 N:P:K)
- Spreading costs of all amendments at $13.80 per acre.

The non-amended paddocks were used as controls (no amendments added other than the nutrients provided by the cows under managed intensive grazing practices).

The grazing season typically begins in March and runs through October with the aid of irrigation, allowing for an average of 8 grazing cycles through 10 paddocks. Pastures were all managed the same across amended and non-amended fields with respect to management intensive grazing (MIG), stocking density varied throughout the season (100 to130 cows per acre). Rest periods also varied throughout the season, for instance during the spring of the year, paddocks were rested between 20 and 25 days; as the summer progressed, the rest periods would take approximately 35-40 days to achieve the 10 to12 inches of re-growth suitable for grazing.



All paddocks were measured for dry matter (DM) yield pre- and post- grazing using a Grass Master brand capacitance probe.[3] Total dry matter yield was calculated by subtracting post-DM values from pre-grazed DM readings. The difference was considered to be DM yield. On average, post-DM values measured approximately 1800 pounds per acre; pre-grazing DM values varied throughout the season. Total DM production per year averaged around 5 tons per acre. (Add forage production data here).

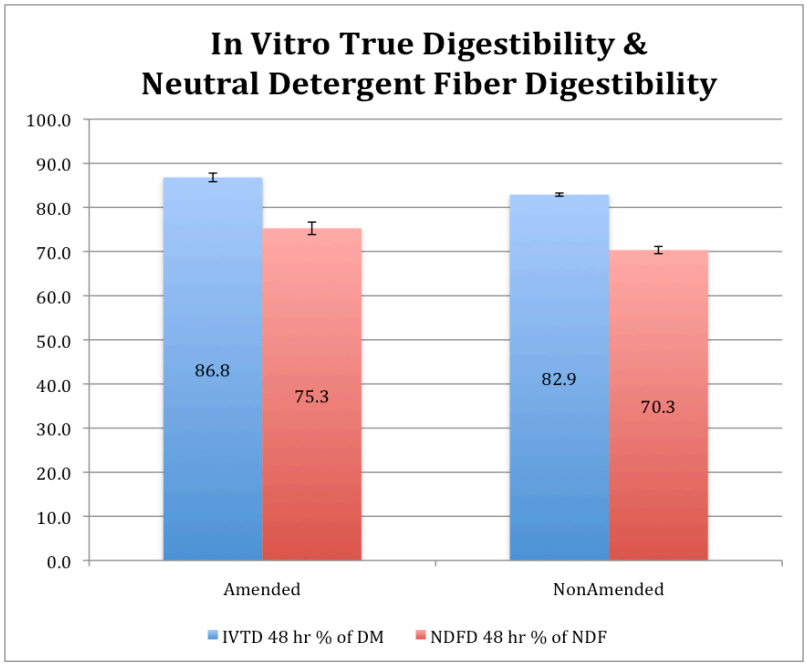
Forages were sampled through replicated composites taken within each paddock along three diagonal transects. Each paddock was sampled three times, each sample represented 10 composite samples that were mixed together with a final representative sample sent for forage compositional analysis by Dairy One Forage Laboratory in Ithaca, New York.[4] Plant species composition included perennial and annual rye, brome/prairie grass, fescue, orchard grass,

[3] Serrano, JM., et al., Calibration of a capacitance probe for measurement and mapping of dry matter yield in Mediterranean pastures. Precision Agriculture December 2011, Vol 12 (6): 860-875.
[4] Dairy One Forage Testing Laboratory. Dairy One, Inc. 730 Warren Road, Ithaca, New York 14850. Phone 607-257-1272.

chicory, plantain, and ladino clovers. No species compositional changes were observed between treatments over the course of the three-year study.

Results

The results for forage quality and yield were averaged over the three growing seasons (2009 to2011). It was not possible to observe any visual differences between treatments even though changes in forage quality and quantity did occur.



Yield

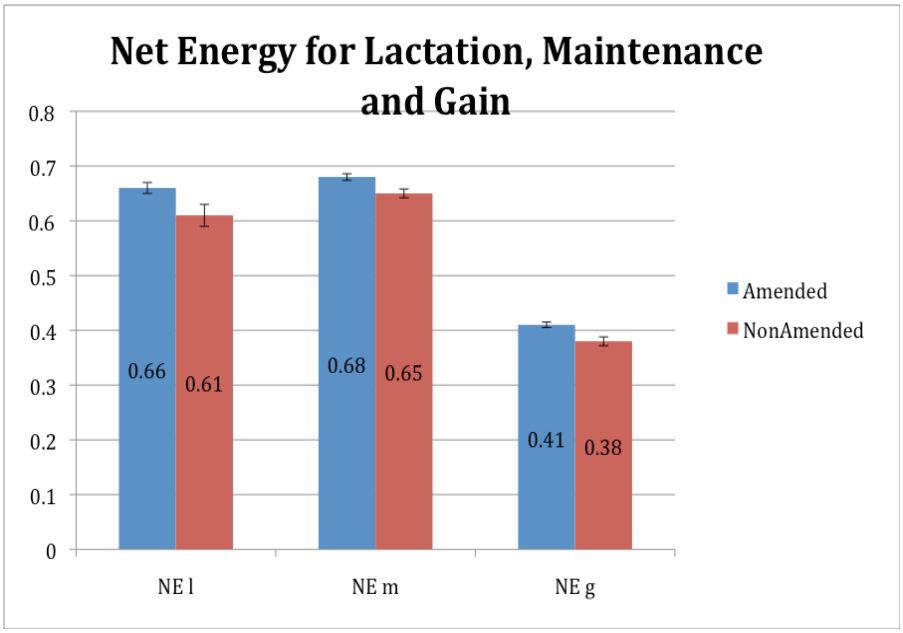
Overall dry matter (DM) production data indicated an additional 180 pounds of dry matter per grazing cycle within the amended paddocks. With eight grazing cycles per season, the additional tonnage per acre was 1,440 pounds of DM.

If we were to calculate the cost of replacing that 1440 lbs of DM with comparable feed, it would cost approximately $253.5/acre to buy $300 hay at 85% DM (2000 lbs* 0.85 DM = 1700 lbs DM/t of hay; $300/1700 lb DM = $0.176/DM lb hay cost). To replace the lost DM production in the non-amended fields (1,440 lbs/ acre) at a feed replacement cost of $0.176/ DM lb = $253.5 per acre (1,440 lb DM/a * $0.176/lb DM = $253.5/a). For the 25 acres of non-mended pasture within our study, $6,336 worth of hay would be needed to compensate for the loss in pasture productivity.

Forage Quality

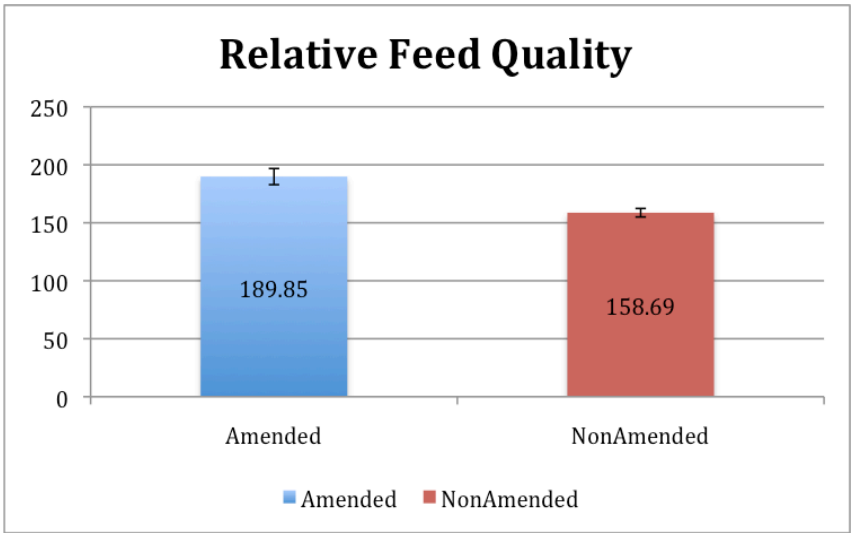
In addition to yield data, there were also significant changes in overall forage quality.

Acid Detergent Fiber (ADF) was significantly improved (34.45% amended versus 36.67% non-amended treatment) indicating an improvement in overall forage digestibility within the amended paddocks. **Neutral Detergent Fiber (NDF)** was also significantly improved by the amendements (52.02% amended versus 58.10% non-amended) which indicates a potential increase in overall dry matter intake due to the **inverse correlation between NDF and dry matter intake (DMI).**[5] As NDF improves (decreases), DMI increases.



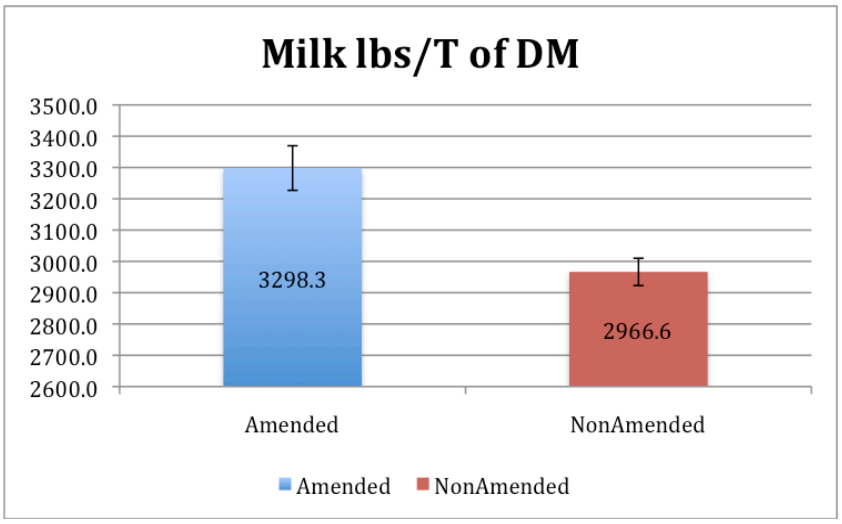
Moreover, the overall digestibilty of the fiber content of the feed improved within the amended paddocks as

[5] Allen, 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83:1598-1624.



reflected in **Neutral Detergent Fiber Digestibility (NDFD) (75.3% amended versus 70.3% non-amended treatment)**. As the fiber content of the feed becomes more digestible, more total nutrients are then available to the cow for milk production and maintenance. In fact, **for each 1% improvement in NDFD, dry matter intake improves by 0.37 pounds, resulting in an increase in 4% fat corrected milk production of 0.55 pounds/day of dry matter consumed.**[6] In Vitro True Digestiblity (IVTD) is a laboratory test designed to simulate digestion as it occurs in the rumen and is therefore an indicator of "true" digestibility of forages. IVTD may be the best measurement of nutrient availability within a feed and is used to calculate NDFD. It is theorectically possible for forages with idential NDF (fiber content) values, to have very different IVTD and TDN bccause of the differences in fiber digestibility. The feed with the most digestible fiber (all other things being constant), will yield more total nutrients and more milk. [7]

The overall energy content of the forage also improved within the amended paddocks (across all energy categories), as reflected in improved **Net Energy for Lactation (NE_L), Net Energy for Maintenance (NE_M) and Net Energy for Gain (NE_G).** NE_L describes the amount of energy in a feed that goes toward milk production and bodily maintenance. Forages harvested within the amended paddocks were on average 0.05 Mega-calories per lb of DM higher in the Net Energy for Lactation as compared to the non-amended forage (0.66 Mcal/lb versus 0.61 Mcal/lb respectively). Amendments significantly improved the energy availability within the forages and, therefore, are more likely to have a positive impact on overall milk production.



The soil amendments also enhanced the total **Non Fiber Carbohydrate (NFC)** content by 3.8%. NFCs include all the non-cell wall carbohydrates consisting of starch, sugar, pectin, and fermentation acids that serve as readily accessible energy sources for the microbes within the rumen.

Relative Forage Quality (RFQ) is an index for ranking forages based on a more comprehensive analysis that includes Crude Protein (CP) content, ADF, NDF, fat, ash, and NDFD calculations. The higher the RFQ, the better the quality. Soil amendments within the treated paddocks improved forage RFQ by 19.6 % (189.85 amended vs. 158.69 non-amended, indicating significantly higher overall forage quality.

[6] Maximizing organic milk production and profitability with quality forages. R. Kersbergen, University of Maine Cooperative Extension.
[7] Forage fiber digestibility: measurement, variability, and impact. H.G. Jung, et al., USDA Agricultural Research Service, St. Paul, MN. Department of Animal Science. University of Minnesota.
http://oca.cce.umn.edu/ltu_portfolio/example/ag/pdfs/jung.pdf

Overall, the soil amendments significantly improved the digestibility and energy content of the forages, resulting in higher **Milk Production per Ton of DM consumed**. This particular statistic is a projection of milk production per ton of dry matter based on the overall digestibility and the energy content of the forage.[8]

Forages from amended paddocks produced 3,298.3 pounds of milk per ton of DM consumed as compared to 2,966.6 pounds of milk per ton for the non-amended treatment. Under the conditions of this study, the amended paddocks produced an additional 331.7 pounds of milk each year - for every ton of DM consumed.

Economic Impact (on a per cow basis)

Using the milk production pounds per ton of DM statistics, as previously stated, cows grazing the amended paddocks produced an additional 331.7 lbs of milk (each year) for every ton of DM consumed. In our grazing system, each cow consumes over 2 tons of DM from pasture-based forages over the course of the grazing season. (see Box 1 for calculations).

Box 1. Calculations for T of DM consumed per cow per season:
The dry matter demand (DMD) per cow is estimated at 40 lbs /day.
We average 50% pasture DMI throughout the season.
Our grazing season is approximately 200 days.
Total Pasture DMI/cow = 2 T DM pasture forage per cow/season

Cows that consume 2 DM tons of the amended forages throughout the season will produce an additional 663.4 pounds of milk over cows grazing non-amended paddocks, which generates an additional $199.02 of income over the course of the grazing season when milk is $30 per hundredweight (CWT) (see Box 2). For our 90-cow herd, that would be an additional $17,911.80 for the year due to improved forage quality.

The additional yield was calculated to be $6,336 per season for the amended paddocks based on the additional yield and the cost of replacing that feed with a similar quality hay (see Box 3 for calculations).

Box 2. Calculations for additional milk production/cow consuming amended forages:
Each cow consumes 2 T DM/year from pasture
Each cow produces 331.7 more lbs of milk/T of DM pasture consumed each year due to improved forage quality
Each cow produces an additional 663.4 lbs of milk/grazing season (2T DM consumed/cow * 331.7 lbs of additional milk per T of DM consumed with the amended forages = 663.4 lbs milk)

Each cow generates an additional $199.02/grazing season at $30/cwt milk (663.4 lbs milk * $0.30/lb of milk = $199.02)

Box 3. Calculations for additional yield produced in amended paddocks:
Amended paddocks produced an additional 1440 DM lbs/ acre/year,

The cost to replace that feed is $0.176 /DM lb (Cost of comparable hay)
Amended paddocks return $253.44 in additional feed at replacement feed prices (1440 DM lbs/acre * $0.176 lb DM replacement feed costs = $253.44/acre)

Amended paddocks saved $6,336 in replacement feed costs each year for the 25 amended acres ($253.44/acre * 25 amended acres = $6,336)

[8] Dairy One Forage Analysis: http://www.dairyone.com/forage/factsheet/forageanalysis.htm

Potential Costs and Returns (on a per acre basis)

The amended paddocks generated more forage of significantly higher quality at a cost of $289.50 per acre per year.

Amended paddocks produced more total forage per acre, saving our program $253.44 per acre in replacement feed costs (this doesn't take into consideration the improved forage quality). For every ton of DM consumed from amended paddocks, cows produced 331.7 more pounds of milk. Our paddocks produced approximately five tons of DM per grazing season, resulting in 1,658.5 more pounds of milk per acre at $0.30 per pound, equivalent to an additional $497.55 in milk income per acre (331/7 lb milk per cow/ton DM * 5 ton DM = 1,658.5 lb milk per cow; 1,658 lb milk per cow * $0.30/lb milk = $497.55 per cow each year).

Quality improvements alone were enough to offset the cost of the amendments in this study. Additional milk income generated $497.55 per acre plus the $253.44 we saved in replacement feed costs, totaling $750.99 per acre of income at a cost of $289.50 per acre per year in amendments. The result was a net increase of $461.49 per acre per /grazing season.

Naturally, the caveat is that this study was conducted on low calcium, high magnesium soils, under irrigation, and managed intensive grazing MIG grazing with a crossbred Jersey herd. Results on other farms would depend on the current soil fertility and costs of remediation which are all site-specific but no less applicable.

There are a number of considerations we did not factor into the economic picture including the reduction in grain costs. As energy values in the forages improve, the need for energy from grain will be reduced, something that would likely have a significant impact on feed costs and net profit per cow.

In addition, we did not calculate the economic impact of improved soil organic matter (SOM) that comes from a more balanced soil. Higher SOM values would likely enhance the water holding capacity of the soil, reducing irrigation costs over time. The NRCS soil quality site states that for every 1% increase in SOM, the water holding capacity of your soil improves by 0.5 inches, making your farm more drought tolerant over time.[9] In addition, the buildup of SOM will enhance the biological activity thereby improving nutrient availability and it will increase the cation exchange capacity (CEC), improving anion retention for important micronutrients like sulfur, boron, and molybdenum.

In summary, achieving balanced soils is essential to improving net profit in a pasture-based organic dairy system predicated on high forage intake and optimal milk production levels. To get to that next level, test your soils and forages, find a good agronomist or soil coach that can help you understand the data, establish some achievable goals, and pull the trigger. Then sit back and watch your soil bank account grow, it will pay long-term dividends and create a legacy for many generations to come.

Acknowledgements

We would like to thank and acknowledge our funding sources including Organic Valley Family of Farms through the Farmers Advocating for Organics (FAFO) and the Applied Agriculture Research Initiative with the State of California. We would also like to thank Jerry Brunetti, with Agri-Dynamics, Martins Creek, PA, for serving as the technical consultant and industry advisor, and Mark Kopecky, Soils Agronomist with Organic Valley CROPP Cooperative, for his extensive review and editorial comments.

[9] http://soils.usda.gov/sqi/concepts/soil_organic_matter/som.html

Soil Analysis	Organic Matter	Nitrogen (ppm)	Phos (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Sulfur (ppm)	Zn (ppm)	Boron (ppm)	K%	Mg %	Ca %	CEC	pH
2011 Amended	4.1	15.8	40.4	394	734	2556	42.2	2.58	0.44	5.14	30.9	62	19.5	7.1
2011 Non Amend	3.8	11.25	24.75	289	800	2412	39.75	1.85	0.3	3.7	33	59.3	18.5	6.9
Difference	0.3	4.6	15.7	105.0	-66.0	144.0	2.5	0.7	0.1	1.4	-2.1	2.7	1.0	0.2
% change	7.9	40.4	63.2	36.3	-8.3	6.0	6.2	39.5	46.7	38.9	-6.4	4.6	5.4	2.9

Table 1. 2011 Soil Analysis Comparisons between Amended and Non Amended Paddocks 3 years after project initiation.