Phosphorus deficits by long-term organic dairy farming?

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Key words: case study, farm study, P-AL, P budget, perennial ley, soil P

Abstract

Long term studies (1989-) on an organic dairy farm show decreasing topsoil concentrations of extractable phosphorus (P-AL), and a low P surplus on farm level. The average P-AL value, 100 mg kg^{-1} dry soil is still above optimal (70 mg), but has decreased by more than 50% since 1989. Perennial ley yields tend to decline, and variations in soil P concentrations contribute to explain ley yields. This may call for additional P application on fields with low P status. However, for soils with medium (30-70) or low (< 30) P-AL, no relationship was found with yield level. Further, in a field experiment located on this farm, on low P soil with low and high applications of slurry over 5 years, applied P increased P concentrations in plant material rather than in soil. Future farm management should utilise locally available P sources to close the P gap by bringing back P removed in farm products, to avoid long-term P deficiency in soil.

Introduction

Tingvoll experimental farm with 28 ha of cultivated land and 8 ha of grazing fields is part of the Norwegian Centre of Organic Agriculture (NORSØK), established in 1986. Organic milk production was established in 1989, initially with 12 cows, increasing to 22 cows when the tenant family got access to renting nearby land with associated milk quota in 2006. A new farm building and a biogas plant were set up in 2010. Whereas this reduced the everyday workload for the tenant family significantly, milk yields had to be increased to cover higher tenant costs. In common with most other Norwegian dairy farmers, the tenants at Tingvoll farm have replaced local resources (grazing) by purchased inputs (concentrates) to increase the economic output. Organic 3.0 aims to make organic mainstream, but mainstreaming organic agriculture causes trade-offs between productivity and other goals such as diversity and self-sufficiency, as demonstrated by the development at Tingvoll farm.

Phosphorus (P) is an essential macronutrient for plants, and is a restricted resource. Sub-optimal P availability in soil may limit crop yields, and low soil P concentrations are not easy to restore. This paper presents changes in soil P over time, and investigates relationships between soil P and perennial ley yields. A field experiment on low-P soil with different manure applications is presented as a case study within the Tingvoll farm-case. The aim is to discuss the need for closing the P gap in organic agriculture, based on a long-term farm level study.

Material and methods

Tingvoll farm (62°54′N, 8°11′E) is located in NW Norway, along the coast with a humid and cool climate, well suited for milk production form dairy cows. Annual farm-gate P budgets are available for 1994-2012, based on farm accounts and standard P concentrations. On all fields, topsoil (0-20 cm) was analysed for concentrations of ammonium acetate-lactate soluble P (P-AL) in 1989, 1995, 2002, 2009 and 2015. The same plots were used for augering 10-12 soil cores per composite sample at each sampling date (late autumn). For calculations, values below detection limit (20 mg P kg^{-1} dry soil) were computed as 15 mg.

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Crop yields have been measured since 1994, by harvesting 5 representative plots of 10 m^2 on each field directly before the farmer's harvest. Dry matter (DM) content is determined, and since 2008 botanical composition. Perennial leys at Tingvoll farm are usually cut twice a year. Since 2010, fodder is conserved in round bales, the harvest occurs much more rapidly, the first cut is earlier and fields may often be cut three times, or grazed in the autumn. Complete records of all cuts are not available for all fields. 160 records of yields from the first cut are presented here as kg DM ha^{-1}.

An experiment was located on a field with low-P soil in 2010, with P-AL measured in spring 2011, 2013 and 2016. The study (SoilEffects) compared anaerobically digested cow manure slurry with untreated slurry, with low (30 tons ha^{-1} yr^{-1}) or high (60 tons ha^{-1} yr^{-1}) amounts of manure applied on plots of 3 m x 8 m in a block design with four replicates, totally five treatments: Control, Undigested slurry low (USL) and high (USH), Digested slurry low (DSL) and high (DSH). The low level mimics the local organic farming system, whereas the high level is representative for a conventional system in this region. The crop was perennial grass-clover ley established in 2009, re-established with a green fodder cover crop in 2014. In 2014, no manure was applied, but the after-effect of manure applied in 2011-13 was recorded. On average for the whole period, the P concentration in the slurry was 0.41 kg ton^{-1}. The soil organic matter content is 11%, and the average soil bulk density is 1030 kg m3 dry soil which implies that the topsoil dry weight is 2060 ton ha^{-1}. Soil P concentrations were converted to amounts of P in topsoil in kg ha^{-1} by multiplying with this number (Table 1). Soil sampling comprised 6 cores per composite sample from each experimental plot. During 2011-13, P concentration in the harvested plant material was analysed, and the average values were used to estimated amounts of P removed from each treatment over the whole period.

Results and discussion

The average P budget during 1991-2012 was a surplus of 1.6 kg P ha^{-1} yr^{-1}. During 1991-2004, the average annual surplus was only 0.16 kg P ha^{-1}, increasing to 4.1 kg ha^{-1} during 2005-12 when the herd increased (Ebbesvik et al. 2014). Former studies of organic dairy farms aiming at self-sufficiency with nutrients (Løes and Øgaard 1997) found decreasing soil P with farm level P surplus < 8 kg ha^{-1} yr^{-1}. This result was confirmed for Tingvoll farm. On average for 16 sites sampled in all years, the average P-AL value decreased from 203 to 100 mg kg^{-1} soil. The fields at Tingvoll farm had widely different initial P-AL status in 1989, ranging from 387 to 51 mg P kg^{-1} soil. A decline in P-AL concentrations from sampling to sampling has occurred on almost all fields, with more rapid changes for fields high in P.

At the farm, perennial grass-clover leys are re-established each fourth or fifth year with greed fodder, oats or barley as a cover crop. Yield levels vary significantly with time (Figure 1), but the long-term trend is slightly negative (r^2=0.12). One explanation may be that the first cut occurs at earlier developmental stage of the ley since 2010, when round bale harvesting was introduced. However, we cannot exclude that lower soil P concentrations have contributed to this decline. An assessment of crop yield levels in 2014, combining with all available records that could possibly explain ley yields, revealed that soil P concentrations had a significant and positive effect on first cut DM yields, along with the proportion of legumes and precipitation in April + May (Ebbesvik et al. 2014). A negative effect was found of number of years after establishment, proportion of weeds, and precipitation in June. Altogether, these factors explained 49% of the first cut DM yields. However, when splitting yield records in classes dependent on soil P-AL level, no relationship was found between P-AL and yield level for medium (30-70 mg P kg^{-1} soil) or low (< 30) P soil. For P-AL > 70, a positive relationship was found (r^2=0.20). The average yield level was 0.43 ton ha^{-1} with P-AL below 30, 0.42 with P-AL between 30 and 70, and 0.47 for soils with P-AL > 70.

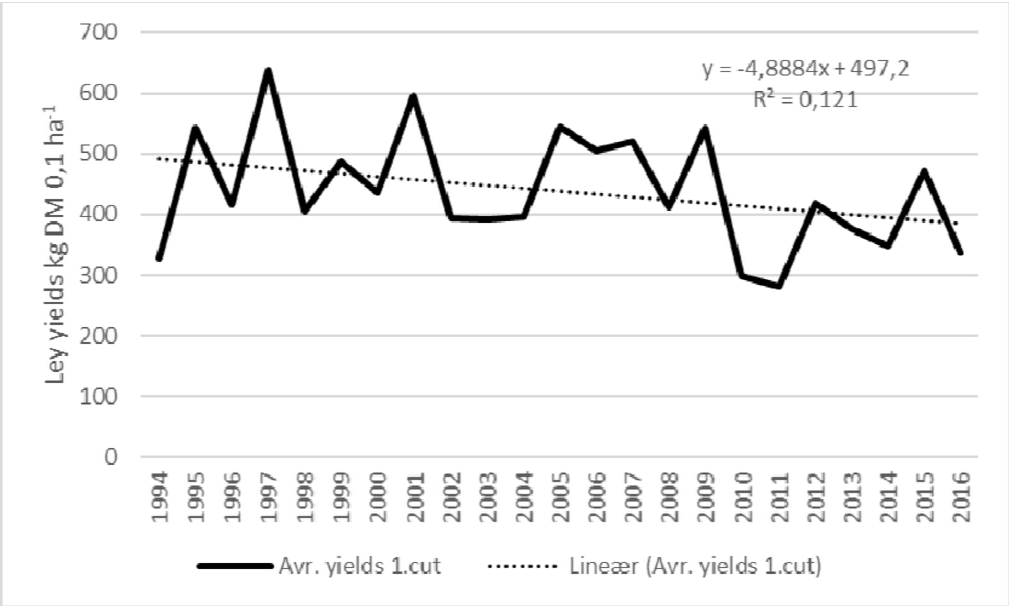

Figure 1. Yield levels of perennial ley, average values for 2-9 fields, on Tingvoll farm 1994-2016, first cut (during June).

Table 1: Changes in topsoil P contents (kg P ha^{-1}, 0-20 cm depth) from 2011 to 2013 and 2013 to 2016 compared with P budget (kg ha^{-1}, P applied in slurry minus P removed in yields) for low (30 t ha^{-1} year^{-1}) and high (60 t) applications of digested or undigested slurry in 2011, 2012, 2013 and 2015.

Period	Soil 2011 vs 2013	P budget 2011-12	Soil 2013 vs. 2016	P budget 2013-2015
Undigested slurry, low	+17.0	-6.8	-15.5	-19.2
Undigested slurry, high	+26.3	6.9	-13.4	-5.5
Digested slurry, low	+12.4	-6.9	-15.9	-20.5
Digested slurry, high	+18.0	7.2	-14.8	-6.7
Control, no slurry	+3.6	-20.5	-22.0	-24.6

In the field experiment, soil P concentrations increased from spring 2011 to 2013, and more with applications of high amounts of slurry (Table 1). From spring 2013 to 2016, the soil P status decreased, also in treatments receiving at least twice the amount of slurry that is available on average for Tingvoll farm. The accumulated P fertilisation during 2011-2015 was 49.2 kg P ha^{-1} with low manure application, and 98.4 with high. The average P content (% of DM) during 2011-13 was 0.17 in the Control treatment, 0.18 with USL and DSL, 0.21 with DSH and 0.22 with USH. During 2011-15, the accumulated yields comprised 26.5 ton DM ha^{-1} in the Control, 40.9 with USL, 42.6 with DSL, 44.1 with USH and 46.6 with DSH. Assuming that P concentrations for 2011-13 are relevant for the whole period, the P removal in yields equals 45.1 kg ha^{-1} in the Control, 75.2 with USL, 76.6 with DSL, 97.0 with USH and 98.0 with DSH. Significantly higher P concentrations with application of high amounts of slurry treatments, and weak effects on soil P-AL from manure application, indicate that the P applied was taken up by the plants, instead of adsorbed to the soil. No manure application in 2014, but removal of yields increased by manure applications in 2011-2013, and ploughing of the field in 2014 with a possible dilution of P-AL by some subsoil with lower P-AL, add to the explanation of reduced of P-AL levels from 2013 to 2016. Subsoil P-AL concentrations in the field surrounding the experiment were < 20 mg kg^{-1} in 2015.

Conclusion and outlook

This study shows that soil P concentrations decrease by long-term organic dairy farming, in spite of a small farm level P surplus. Relationships between soil P-AL levels and yield levels are not clear for soils with P-AL concentrations below the optimal value of 70 mg kg-1 soil. Increasing the fertilisation with P in animal manure may increase plant P concentrations instead of enriching the soil P. Future studies may clarify if this is a result of the crop being a perennial ley. The declining soil P values call for a closing of the P gap, to avoid reduced soil fertility in future. Locally available sources could be horse manure from a nearby riding school, or seaweed. Increasing the production may be required to keep track with social conditions for the farmers, but may reduce diversity and utilisation of local resources.

References

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