Supplement 1

Avslutande utvärdering av ett unikt långliggande jämförande odlingssystemsförsök med ekologisk och konventionell odling i Önnestad
omfattande resultat från odlingssystemförsöken både i Bollerup och Önnestad

Long-term field trials in Scania, Southern Sweden.

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Introduction

The question of different forms of cropping has occupied agronomists for a number of decades and during the 1980's it reached a wider audience. A major drive was therefore initiated in 1987 in what was then the county of Kristianstad, and three long-term cropping trials were set up at the county's agricultural colleges, Bollerup, Önnestad and Östra Ljungby.

After an experimental period running over almost 30 years, the last trial site still running at Önnestad was terminated in 2017. During the course of the trials the objectives and systems compared changed, with the main point shifting from comparing the development of the respective systems over time, to improving each of the according to its own conditions. The results from the all study years between 1987-2012 are available in databases at www.odlingssystem.se.

Literature Review

The field trials in Scania have been subjected to extensive reporting, often concomitant with the completion of crop rotation cycles and acting as an evaluation of these. Ivarsson et al (2001) released a first report evaluating the results of the trials' first 12 years of running in 2001, primarily comparing the conventional and the organic systems. These results showed consistently lower yields from the organic systems over all crops bar ley where the groups were equal (Ivarsson et al 2001; 156), with differences ranging from 41-15 % depending on crop and year. Further significant differences were found when comparing the systems within the conventional/organic groups, where the non- livestock keeping organic system generally exhibiting lower yields than its livestock-keeping counterparts. In addition, farm nutrient balances showed a general surplus or break even of nitrogen in all systems, along with an overall decrease of phosphorus and potassium that differed between the groups of conventional (lower depletion rates) and organic (higher depletion rates). Correspondingly, soil analyses showed an overall sharp decrease in easily soluble Potassium (K-AL) over the period of 1987-1998, with depletion rates ranging from 0.2-0.8 mg K per 100g and year between all systems. In addition, easily accessible phosphorus (P-AL) was also decreasing rapidly at Bollerup, particularly in the organic/biodynamic systems. At Önnestad, P-AL trends showed signs of more moderate depletion rates.

A second report edited by Gissén & Larsson (2008) evaluated the third crop rotation cycle running between 2000-2005. At this point, the field trials in Scania had undergone and were undergoing major adjustments, which entailed a shift in the overall aim of the trials. By now, the main objective of the trials was no longer to compare different management practices, but rather to ‘develop each system according to its inherent philosophy’ (Gissén & Larsson 2008; 11). Nevertheless, Gissén & Larsson in their report confirmed the previous conclusions of lower crop yields in the organic systems compared with the conventional systems, with mean organic crop yields reaching 55 % of conventional yields. This id not confirmed in other evaluations locking on the different systems. An exception to this conclusion was sugarbeet crops, which tended to give equal or slightly higher yields in the organic systems. The report further stressed how farm nutrient balances exhibited depletion rates of P and K for all systems and pointed to N as a limiting nutrient in the organic systems. No conspicuous differences were found in terms of soil organic content at any site.

A report from the fourth crop rotation cycle was released in 2016 (Modig 2016), in which focus was oriented toward each system’s and crop’s relative economic performance, along with some further comparisons of yields between livestock- and non-livestock keeping practices. Results of these confirmed the previous reports’ range of differences in yield, but also noting that pests struck the systems unevenly, thus probably contributing to the conventional systems higher yields (Modig 2016; 4).

Apart from the reports mentioned above, data from the field trials were included in two papers looking at long-term K-dynamics (Andrist-Rangel et al 2007), and K-budgeting (Andrist-Rangel et al 2006). Results from these showed a long-term decline of both readily exchangeable K as well as of available reserves. Furthermore, the K deficit was strongly linked to the fertility and the K delivery capacity of the soils, meaning that the most productive soils (in terms of biomass yields) also exhibited the highest K deficits (Andrist-Rangel et al 2007).

In addition to the reports and papers mentioned above, the field trials in Scania have been the subject of a number of completed and ongoing studies. A full list of these studies can be found in appendix IV.

Background

The field trials in Scania

The experiment sites were set up in the municipality of Kristianstad, in Scania, Southern Sweden in 1987, and ran in six-year crop cycles until 2005 (Östra Ljungby), 2012 (Bollerup) and 2015 (Önnestad). Only results from the latter two are concerned for the purpose of this report. The site characteristics of Bollerup and Önnestad are outlined in Table 1 below.

The trials encompassed five mixed-cropping systems (A-E):

- A Conventional cropping, crop production without animals
- B Conventional cropping with ley and manure (with animals)
- C Organic-biodynamic cropping with ley and manure (with animals)
- D Organic-non-biodynamic cropping with ley and manure (with animals)
- E Organic cropping, crop production without animals

A more detailed description of each respective system is found below.

Table 1 Site characteristics of the trial sites at Bollerup and Önnestad.

Site	Bollerup	Önnestad
Position	55°N 14° E	56°N L 14° E
Mean Annual Precipitation (1961-1990)[a]	654 mm	562 mm
Mean Annual Temperature (1961-1990)[a]	7,6 °C	7,2 °C
Elevation (m.a.s.l.)	45	10
Type and thickness (m) of Quaternary deposit [b]	Clayey till, 8	Post glacial sand, 16
Bedrock[b]	Ordovician clay slate	Cretaceous limestone
Soil texture (subsoil)[b]	Loam	Sandy loam
Earlier land use[c]	Crop rotation with ley. Manure applied. Prior to 1975 crop rotation without ley.	Crop rotation with ley. Manure applied regularly 1960-1986.
Soil-moisture regime	Udic	Udic
Soil Taxonomy (WRB)[b]	Orthoeutric Cambisol	Hypereutric Regosol

[a] As according to the Swedish Meteorological and Hydrological Institute's (SMHI) latest 30-years standard normal period of measurement.
[b] Site information from *Andrist Rangel* et al 2006.
[c] Site information from *Gissén & Larsson* 2008.

Aim of the trials

The initial aim of the trials has been expressed as a means to 'quantify differences and follow the development in the different management practices on three different soils' (Ivarsson et al 2001), or to 'quantify biological and economic differences between organic and conventional cropping systems, as applied to three different sites with varying conditions' (Ivarsson et al 2001). For this reason, the set of management practices (here interchangeably used with *systems*) was equal for all three trial sites. However, the systems would not remain static, but rather be gradually adjusted so as to optimize each practice's performance according to 'its own inherent philosophy and the surrounding conditions' (Gissén & Larsson 2008). Further, all systems were managed through six-year crop rotation cycles, and adjustments made to a system would normally be introduced after the completion of a crop rotation cycle.

After the completion of the second crop rotation cycle in 1998, the overall aim of the trials was shifted so as no longer to strive for the original aim of intersystem comparisons, but rather to 'develop each system toward increasing sustainability' (Modig 2016; 2). Yet further adjustments to this aim was made in relation to the onset of the fourth crop rotation cycle in 2006, where the systems were modified so as to encompass the at that time current market trends of demands for energy crops and organic grassland seed.

System specification and crop rotation cycles

A note on system designations

Due to the history of nomenclature surrounding the trials in Scania where most reports and literature use the capital letter designation A-E to distinguish between the systems, we will for the purpose of this report refer to the systems both with these original designations, as well as with the more elaborate designations of Conventional (Conv.), Organic (Org.) and Biodynamic (Biod.), along with an additional (+A) for livestock keeping systems and an (-A) for non- livestock keeping systems. The system designations will hereafter be used interchangeably.

Crop rotation cycles

The field trials in Bollerup and Önnestad started in 1987 and ran in six-year crop rotation cycles. During the first two crop rotation cycles (1987-1998), the aim was to gather extensive data so as to allow for comparisons between the different systems' performance over time and at differing conditions. More specifically, two conventional systems (A and B) were juxtaposed with two organic systems (D and E) and one biodynamic system (C). One of the conventional and one of the organic systems were simulated as containing livestock (+A), as opposed to non-livestock keeping systems (-A). The biodynamic system also encompassed livestock.

The shift of the overall aim of the trials that ensued the completion of the second crop rotation cycle in 1998, entailed minor changes in the crop rotation schedules at both sites. One such change was that after the 'transition year' of 1999 all fresh manure applied to the systems was replaced by the use of liquid manure. An exception to this was the biodynamic system, which in accordance with guidelines for biodynamic agriculture continued to apply composted manure. A full account of the fertilization strategies for each system and crop rotation cycle can be found below.

With the onset of the fourth crop rotation cycle in 2006, one of the three original trial sites (Östra Ljungby) was scrapped. The remaining trials at Bollerup and Önnestad were readjusted and aligned to the trends of growing energy crops and organic grassland seed. At Önnestad, the biodynamic system was changed in favour of a non-livestock keeping organic system in which ley would be used for the production of biogas and where the digested remnants would then be re-applied to the system as manure. Moreover, growing of vegetables supplemented the traditional crop production. At Bollerup, the organic livestock-keeping system (D) was changed into a similar biogas production-oriented system as with the biodynamic system in Önnestad described above, i.e. without livestock and where digested remnants of biogas production were applied as fertilizers, replacing manure.

Figure 1 Bollerup site, July 2011

Table 2 Characteristics of the four crop rotation cycles between 1987-2012 at Bollerup and Önnestad.

System	Crop rotation cycles 1-3 1987-2005 Both sites	Crop rotation cycle 4 2006-2012 Bollerup	Crop rotation cycle 4 2006-2012 Önnestad
A (Con -A)	Conventional Crop production Without livestock. Mineral fertilizers	Conventional Crop production Without livestock Energy crop production	Conventional Crop/vegetable production Without livestock
B (Con +A)	Conventional Crop production with ley Livestock Fresh/liquid manure	Conventional Crop production with ley Livestock Liquid manure	Conventional Crop production with ley Livestock Liquid manure
C (Biod +A)[a]	Biodynamic Crop production with ley Livestock Composted manure	Biodynamic Crop production with ley Livestock Composted manure	Organic Crop/vegetable production Without livestock Digested remnants
D (Org +A)[b]	Organic Livestock Crop production with ley Fresh/liquid manure	Organic Without livestock Crop production with ley Digested remnants	Organic Livestock Crop production with ley Liquid manure
E (Org -A)	Organic Crop production Without livestock Organic manures.	Organic Crop production Without livestock Organic manures.	Organic Crop/vegetable production Without livestock Organic manures.

[a] At Önnestad, the Biod +A system was changed for a stockless organic (Org –A) system with the onset of the fourth crop rotation cycle in 2006.

[b] At Bollerup, the Org +A system was changed for a stockless organic (Org –A) system with the onset of the fourth crop rotation cycle in 2006.

Crop and soil evenness prior to the commencement of the trials

In the year preceding the commencement of the trials, soil and yield evenness of the sites in relation to the experimental design established was evaluated, with results found in Table 3 and Table 4. The pre-trial evaluations consisted of a) the planting of barley over the full trial sites. The sites were subsequently subdivided into 30 parcels, and harvested accordingly, and b) soil analyses on Soil Organic Content (SOC), clay content, pH, P (P-AL, referred to as P_{ex} in the tables below), K (K-AL, referred to as K_{ex} in the table below, K-HCl), Mg, Cu, B, and soil texture.

The results revealed that the sites were comparable in terms of yield, with 48.3 and 51.3 dt/ha for Bollerup and Önnestad respectively, but with considerably less variation between the parcels at the Bollerup site. Furthermore, the harvest at Önnestad exhibited signs of drought damages at the peripheral parts of the trial site. To compensate for this, the parcel size was diminished from the original 24 x 15m, to the 12 x 15m of the final design. At Bollerup, the original parcel size remained unaltered. In terms of soil analysis, however, significant differences were found between the systems at Bollerup in organic C, P and pH. This observation was later confirmed by Ehrnebo (2003), demonstrating a gradient in the soil at Bollerup, through which the conventional systems A and B exhibited higher soil fertility compared with the other systems.

Table 3 Soil characteristics and yield figures from the tests of evenness before the trials' commencement in 1986, Bollerup.

System	Clay (g/kg)	Organic C (g/kg)	P_{ex} (mg/100g)	K_{ex} (mg/100g)	pH (H_2O)
A (Con -A)	202	28^{c}	7.55^{a}	13.1	6.3^{a}
B (Con +A)	173	27^{bc}	7.55^{a}	11.6	6.4^{b}
C (Biod +A)	170	24^{ab}	9.60^{b}	12.3	6.4^{ab}
D (Org +A)	198	26^{ac}	11.38^{c}	13.5	6.5^{b}
E (Org -A)	203	23^{a}	9.23^{b}	11.3	6.4^{ab}
Yield 1986 (dt ha^{-1}), ± SD			48.3, 3.15		
Parcel size (m)			24 x 15		

Values with the same letter within a column are not significantly different ($p < 0.05$).

Table 4 Soil characteristics and yield ¨figures from the tests of evenness before the trials' commencement in 1986, Önnestad.

System	Clay (g/kg)	Organic C (g/kg)	P_{ex} (mg/100g)	K_{ex} (mg/100g)	pH (H_2O)
A (Con -A)	67	61	21.4	18.4	6.7
B (Con +A)	78	59	18.6	14.9	7.2
C (Org -A)	75	62	21.1	14.1	7.3
D (Org +A)	60	70	14.4	13.3	6.9
E (Org -A)	53	63	16.1	13.7	6.7
Yield 1986 (dt ha^{-1}), ±					
SD			51.3, 15		
Parcel size (m)			12 x 15		

Values with the same letter within a column are not significantly different ($p < 0.05$).

Livestock simulation

Livestock in the livestock-keeping systems was simulated on the basis of yields and quality of ley and fodder crops of each system. At Bollerup, this entailed a livestock intensity of 1 animal unit (AU *) ha^{-1} of lactating cow (LC) and young bovine simulated for the conventional systems (Conv +A), whereas the corresponding numbers for the Organic and Biodynamic systems (Org +A, Biod +A) were 0.8 AU/ha. For Önnestad, the livestock intensity was kept at 0.8 AU/ha whereas the organic and biodynamic systems were kept at 0.7 Unit/ha. Additional information on the livestock simulation process is found in Table 5 below.

- 1 AU correspond to 1 LC, 3 yung cows, 6 calvs acording Swedish Standard for manure production (Swdish bord of Agriculture 2018 www.jordbruksverket.se/swedishboardofagriculture)

Table 5 Livestock simulation characteristics at Bollerup and Önnestad.

	Bollerup			Önnestad		
	Con +A	Biod +A	Org +A	Con +A	Biod +A	Org +A
Cows (AU ha^{-1})	1	0.8	0.8	0.8	0.7	0.7
Stall period LC day year	240	240	240	240	240	240
Feed LC^{-1} (kg/ DM/ day)	20-23	20-23	20-23	20-23	20-23	20-23
Milk yield^{-1} AU (kg year^{-1})	8000	7500	7500	8000	7500	7500

Fertilization strategy

Table 6a Fertilizer input over the four crop rotation cycles at Bollerup, expressed as N/K/P kg ha^{-1}

System	Rotation Cycle	Org. N (kg ha^{-1})	Min. N (kg ha^{-1})	N-Fix (kg ha^{-1})	Org. K (kg ha^{-1})	Min. K (kg ha^{-1})	Org. P (kg ha^{-1})	Min. P (kg ha^{-1})
Con –A	1	-	123	-	-	45.2	-	21.6
	2	-	123	-	-	36.4	-	22.2
	3	-	124	-	-	38.4	-	18.4
	4	-	104	-	-	51.9	-	21.6
Con +A	1	62	98	27	44.1	37.9	4.4	16.3
	2	100	87	20	67.4	35.8	10.8	15.2
	3	141	79	62	64.6	36.1	14.9	4.9
	4	190	89	73	93	59.5	18.9	6.7
	1	44	-	71	47.2	-	8.3	-
Biod +A	2	56	-	42	47.6	-	7.5	-
	3[a]	56	-	42	47.6	-	7.5	-
	3[b]	104	-	98	98.4	-	16.5	-
	4	124	-	132	103.1	4.2	15.6	-
	1	60	-	71	42.5	-	9	-
Org +A	2	83	-	40	53	-	10.5	-
	3	120	1	118	60.7	9.5	11.2	0.5
	4	95	9	74	9.5	27.4	5	8.5
	1	-	-	96	-	-	-	-
Org -A	2	-	-	96	-	-	-	-
	3	-	8	96	-	-	-	3.4
	4	48	8	96	9.9	41	3.2	8.7

[a] 2000
[b] 2001-2005

Table 6b Fertilizer input over the four crop rotation cycles at Önnestad, expressed as N/K/P kg ha-1

System	Rotation cycle	Org. N (kg ha-1)	Min. N (kg ha-1)	N-Fix (kg ha-1)	Org. K (kg ha-1)	Min. K (kg ha-1)	Org. P (kg ha-1)	Min. P (kg ha-1)
Con - A	1	-	62	-		110	-	17
	2	-	44	-		91	-	7
	3	-	83	-		74	-	10
	4	-	165	-	50	81	-	22
Con +A	1	57	91	20	86	51	11	14
	2	84	70	29	110	26	13	0
	3	178	76	60	130	81	21	0
	4	181	82	44	48	83	20	1
Biod +A	1	43	0	51	69	0	12	0
	2	60	0	90	116	0	13	0
	3	3 a 113	0	69	53	0	13	0
	4	98	3	95	59	49	8	4
Org +A	1	66		53	69		15	-
	2	70		80	94		11	
	3	149		63	104		16	
	4	138	0	86	0	12	15	
Org -A	1	0	0	96	0	0	0	
	2	0	0	96	14	0	0	
	3	21	0	96	48	5	2	
	4	44	2	96	9.9	4	4	

Table 21a. Fertilizer input in type and quantity along with the crop it was applied to.Bollerup 1987 – 2012.

System	Rotation period	Fresh manure[g] (tonnes)	Fertilized crops	Liqid manure NH_4-N (kg ha^{-1})	Urine NH_4-N (kg ha^{-1})	Urine Fertilized crops
Con +A	1	35	SB		25, 25	Ley I, Ley II
	2	35, 24	SB, WW		60, 60	Ley I, Ley II
	3[a]		SB, WW, B, Ley I, Ley II	45, 85, 65, 45, 85		
	3[b]		WW, Ley II, B, Ley I, SB	85,45,65, 45, 85,		
	4[c]		WW, Ley II, B, ley I, SB, O	85, 45, 65, 45,85,65		
	4[d]		WW, Ley II, B, Ley I, SB	65, 50, 55, 50, 65, 55		
	4[e]		WW, Ley II, B, Ley I, SB, O	65, 65, 55, 65, 65, 55		
Biod +A	1	35	SB		25, 50	B, WW,
	2	48	SB		55, 55, 50, 50	B, WW, Ley I, Ley II
	3[a]	57	SB		80, 45, 45	P, WW, Ley I
	3[b]	57	SB		80, 45, 45, 80, 60	WW Ley II, GF RW, RW
	4[c]	46	SB		60, 55, 50, 60, 50	RW, Ley II, GF, L/O, Ley
	4[d]	34	SB		55, 45, 50, 40	RW, Ley II, GF, L/O
	4[e]	45	SB		70, 45, 50, 40, 45	RW, Ley II, GF, L/O, Ley 1
	4[f]	42	SB		65, 40, 45, 35, 40	RW, Ley II, GF, L/O, Ley I
Org +A	1	35	SB, WW		50, 50	B, WW
	2	35	SB, WW		55, 55, 50	B, WW, Ley I
	3[a]		O/P, O/P, WW, ley II	85, 45, 85 85		

3[b]	WW, Ley II, GF, SB RW, RW	85, 45, 85, 85, 85, 85
4[c]	SW (3), Hemp, SB (3)	15, 25, 40
4[d]	SP, SB, O	50, 50, 50
4[e]	SW, SB, O	50, 50, 50
4[f]	SW, SB, O, BlLup	50, 50, 50, 50

Table 7. Fertilizer input in type and quantity along with the crop it was applied to.Önnestad 1987 – 2012.

System	Rotation period	Fresh manure[g] (tonnes)	Fertilized crops	Liqid manure NH_4-N (kg ha^{-1})	Urine NH_4-N (kg ha^{-1})	Urine Fertilized crops
Con +A	1	30	Pt		25, 25	Ley I, Ley II
	2	37	Pt		60, 60	Ley I, Ley II
	3[a]		O, B, Pot, Ley II, SB	45, 45, 75, 45, 75		
	3[b]		SW, Ley II, SB, O, Pt	60,50,80, 50, 75,		
	4[c]		SW, Ley II, SB, O, Pt Ley I,	45, 50, 65, 45, 65, 50		
	4[d]		B, Ley II, RB, O, Pt Ley I,	45, 65, 65, 45, 65, 65		.
	4[ef]		Ley II, RB, Pt, Ley I, SB	65, 65, 65		.
Biod *+A	1	35	Pt		25, 25, 50	B, WW, R
	2	48	Pt		40, 40, 35, 35	B, R, Ley I, Ley II
	3[ab]	39	Pt		40, 40, 40, 75	O/P, B; Ley II, SB
	4[c]		PL, SW, C, B		60, 40, 35, 25	
	4[d]		PL, C, SW, Ley		60, 40, 45	
	4[e]		PL, C, SW, Ley SB		40, 68, 70	
	4[f]		PL, C, SW, Ley		60, 60, 65	
Org +A	1	30	Pt		50, 50	B, WW
	2	30	Pt		40, 35, 35	B, WW, Ley I
	3[a]		O, B, Pt, SB	45, 45, 75 75	40 40 35	Ley II Ley II Ley II
	3[b]		Pt, B, SB, O Pt, B, SB, O	75, 45, 75, 45 75, 50, 80, 45	20, 20	Ley I, Ley II
	4[c]		Pt, B, SB, O	75, 50, 75, 45		
	4[d]		Pt, B, RB, O/P,	75, 60, 75, 55		
	4[e]		Pt, B, SB, O	75, 50, 75, 45 / 75, 60, 75, 45		
	4[f]					

[a] 2000	B = barley	Pt = potatoes
	C= Carrots	PL = plant leak
		RB = read beats
		RW = rye wheat
[b] 2001-2005	GF = green fodder	SB = sugar beet
[c] 2007-2009	O = oat	SW = spelt wheat
[d] 2010	O/P = oat/peas	WW = winter wheat
[e] 2011	P = peas	

[f] 2012

[g] For the Biod +A system this was composted manure.

*) Biodynamic -until 2005

Land use prior to the commencement of the trials
From the mid-1970's the site at Bollerup was managed through a 6-year crop rotation cycle including ley. In the decade preceding the trials' commencement, fresh manure from cattle was added on a regular basis. Prior to 1975, the site was managed in a crop rotation cycle without livestock, and thus probably also excluding ley from the crop rotations, although this is not verified. The site at Önnestad was included as a part of the local agronomy school since 1960. Also here the field was running on a crop rotation schedule, in which ley was included and to which fresh manure was added on a frequent basis.

Organic and Biodynamic regulations and practices
Guidelines from the Swedish standard certifying organ for organic production (KRAV) were adopted in the organic systems. According to these standards, no freely soluble mineral fertilizers or chemical pesticides are allowed (KRAV 2002). In addition, all systems were adapted so as to reflect plausible farming practices of the 5-10 % most 'environmentally conscious' farmers in Sweden (Modig 2016; 2).

The biodynamic systems were managed in accordance with guidelines established by the Swedish standard certifying organ for biodynamic production (DEMETER Sweden). In addition to the application of composted manure, the field preparations BD-500 and BD-501 were used. BD-500 was sprayed early springtime on exposed soil, whereas BD-501 was applied to grains and oat/peas at the time of stem elongation, as well as to potato tubers and sugar beets at early growth stages.

Irrigation
The following crops in Önnestad (all systems) were irrigated: onion, carrot, potato, and beetroot. No other crops were irrigated. At Bollerup, no irrigation was applied.

Tillage
At Bollerup, the soil was ploughed in the autumn, after harvest in all systems and parcels. The parcels containing catch crops or green manure were tilled as late as was permitted by the weather conditions. At Önnestad, the soil was ploughed at spring concomitant with spring sowing.

Liming
At both trial sites liming in the form of CaO was supplied on a yearly basis to compensate for Ca removal with crops and leaching. At Bollerup, with pH-figures typically around 6.3, an average of 190 kg CaO ha^{-1} year^{-1} was supplied. Corresponding figures for Önnestad, with pH-figure varying more between the systems but typically in the range of 6.7-7.2, an average of 127 kg CaO ha^{-1} year^{-1} was supplied.

Termination of the trials
The Bollerup trials were terminated after the completion of the fourth crop rotation cycle in 2012. At Önnestad, a fifth crop rotation cycle was instigated, and subsequently terminated after three years in 2015 due to insufficient funding. In

order to facilitate a final evaluation of the trials, a single crop was planted and harvested over the whole trial fields in the two years ensuing the termination of the trials. Consequently, in 2013-2014, oat and subsequently winter wheat was grown over the whole site at Bollerup. Similarly, in 2016, oat was grown over the whole experimental field at Önnestad, followed by rye in 2017.

For the purpose of this report, the ‘experimental period’ will hereafter refer to the period between 1987-2012 (Bollerup) and 1987-2015 (Önnestad), respectively. The two single-crop years terminating the trials will be referred to as ‘the terminal years’.

Materials and methods

This study used the full set of data available from the Bollerup (1987-2014) and Önnestad (1987-2017) trials. The data for a range of variables for the experimental period between 1987-2012 are available on the trials' official website at www.odlingssystem.se. In Table 22 below, measurement methods with their respective references are listed.

Experimental design

Of the original three trial sites established in 1987 (Önnestad, Bollerup and Östra Ljungby), the two latter were set up as non-randomized five-system parcel designs, whereas at Önnestad, a Completely Randomized Design (CRD) was used. The parcel size along with the results of pre-commencement values of soil indicators and yields of Bollerup and Önnestad are found in Table 8 and Table 9 above, whereas a detailed map of the field designs with allocated individual plots and their system designation are found in appendix V.

The logic behind the non-randomized design at Bollerup was, according to Gissén & Larsson (2008; 26) to facilitate the practical aspects of each management system and field demonstrations. It should be acknowledged, however, that by nature of statistics, the non-randomized field design poses severe challenges to meet requirements of data independence (Gomez & Gomez 1984). In this regard, all results of intersystem comparisons from Bollerup have traditionally been cautiously interpreted (Ivarsson et al 2001, Gissén & Larsson 2008, Modig 2016) and will continue to be so in this study.

By means of evaluation, the method most commonly used in the literature surrounding the trials is a single-factor analysis of variance, where any given variable (e.g. yield) is tested against the treatment factor (c.f. Ivarsson et al 2001, Gissén & Larsson 2008), but also simple linear and non-linear methods when investigating changes over time (c.f. Ivarsson et al 2001, Andrist-Rangel et al 2007).

Soil sampling

Topsoil (0-20 cm) was sampled annually after the final crop had been harvested in the autumn. During the two first crop rotation cycles 1986-1998 (excepting 1987), individual samples from all parcels were analysed at both sites, whereas composite samples containing pooled sub-samples from all system parcels were used from the onset of the third crop rotation cycle and onwards. Exceptions here are 2009, 2012 and the concluding year of each trial site, where all parcels were sampled.

Exchangeable K and P

Throughout the experimental period, yearly measurements of the level of plant easily accessible K and P were conducted through ammonium lactate extraction (K-AL, P-AL). The accessible K and P extracted through this method are hereafter referred to as exchangeable K and exchangeable P, abbreviated K_{ex} and P_{ex}.

Data on K_{ex} and P_{ex} were available from the field trials' database over the whole experimental period for respective site with the exception of the transition year 1999 at Bollerup. This data was subsequently supplemented with data for the terminal years.

Acid extractable K and P

As an estimate of the proportion of harder-bound K and P in the soil that is not readily accessible for plant uptake, acid extractable K and P (here abbreviated K-HCl and P-HCl) were extracted with HCl from the mineralogical pool, and the extracts analysed by flame emission spectroscopy. Although far from rendering exhaustive figures, K-HCl and P-HCl give a useful indication of the amount of mineral bound K and P in feldspars and mica (Andrist-Rangel et al 2007).

The dataset of K-HCl reaches from 1986-2012 (Bollerup), with the exception of the transition year 1999, and from 1986-2017 (Önnestad). Data from the years 1990-1991 were absent at both sites. The dataset of PHCl is limited to the period between 2001-2012 at Bollerup and 2001-2017 at Önnestad.

In the KHCl series, the data point for 1995 at Önnestad was removed as it was an outlier, something also pointed out by Andrist-Rangel et al (2007), and Ivarson et al (2001).

Soil Organic Carbon (SOC)

Samples of topsoil (0-20 cm) were sent to an accredited lab (Eurofins Agro Testing Sweden) for soil organic carbon using the loss on ignition (LOI) method with a clay-content correction factor.

Data on organic carbon consisted of parcel measurements for the years 1986, 2009 and 2014, along with composite measurements in 2012 at Bollerup. At Önnestad, the above data was complemented with parcel measurements from the final year of the second crop rotation cycle in 1998. Two measurement points from the 1986 data for Önnestad were excluded from the analysis as they were found to be outliers and fell outside analytical acceptability. The measurement points excluded adhered to the Con –A, and the Biod +A systems.

Table 8 Analyses and references of methods used.

Variable of Analysis	Method	Reference	Margin of Error	Range of Measurement
Exchangeable P, K, Ca, Mg	Suspension in Ammonium Lactate (AL) Optical Emission Spectroscopy (ICP-OES)	S028310 S028310T1 SS-EN ISO 11885	<20%	
Acid extractable P, K, Cu	Suspension in Hydyrochloric acid (HCl) Optical Emission Spectroscopy (ICP-OES)	KLK 1965:1	<10%	
pH	Deionized water suspension (pH(H2O))	SS-ISO 10 390	0.3 pH-units	1-14
Soil Organic Carbon	Loss on Ignition (LOI)	MK-3001	5 %	

Statistical methods

Outliers

All datasets were initially checked for normality of distribution according to the Shapiro-Wilk test (Royston 1982, $p < 0.05$). When present, outliers were tested and excluded on the basis of Grubb's test (Grubbs 1969, $p < 0.05$). All tests for outliers were conducted with the 'outliers' package for R (Komsta 2011).

Tests of pre-commencement evenness

The soil analysis data collected prior to the trials' commencement were tested for differences between systems using one-way Analysis of Variance (ANOVA) with soil variables (e.g. pH) treated as response variable with six replicates, and system treated as independent variable. In case of significant differences ($p <$

0.05) between systems, Tukey's Honest Significant Differences test (Hothorn et al 2008) was applied to discern what systems differed.

Statistical analysis of long-term data
Simple linear regression techniques with groups (*System*) were used to fit models to soil data variables using the Multcomp package of R (3.3.2) (Hothorn et al 2008). The fitted slopes were then tested for differences using Tukey's Honest Significant Differences test ($p = 0.05$).

Test of differences between systems in the terminal year
Testing for differences in the soil organic content of all systems at both trial sites was done in the terminal year at of 2015 and 2017 in Bollerup and Önnestad respectively. For this analysis a one-way Analysis of Variance (ANOVA) was used with organic carbon as response variable with six replicates. In case of significant differences ($p < 0.05$) between systems, Tukey's Honest Significant Differences test was applied to discern what systems differed.

Field balances
All field balance data was gathered from the trials' official site www.odlingssystem.se, and concern the period between 1987-2012. Field balances were calculated through adding inputs consisting of mineral fertilizer (Fmin) and organic fertilizer (Forg) and subtracting outputs in the form of crop off-take including harvest and removed crop residues (Eq. 1). Contributions in the form of atmospheric deposition, seeds and other input flows, as well as output flows in the form of runoff and leaching are not included in this report.

(1) $$Balance = F_{min} + F_{org} - H$$

Field balances for K and P were calculated for every crop rotation cycle between 1987-2012, excluding the interim year of 1999 where data was incomplete.

Results

Field balances P and K

Both K- and P field balances (Table 24 and Table 25) showed that crop offtake markedly exceeded the inputs, resulting in negative balances for all systems on both sites bar the K balances for system A (Con -A), and P balances for the Conv – A system at Bollerup. On average over all four crop rotation cycles 1987-2012, the K deficit at Bollerup varies between 6 kg ha^{-1} $year^{-1}$ (Con -A), to -60 kg ha^{-1} $year^{-1}$ (Org +A). Correspondingly, figures for K deficits at Önnestad range between 5.9 kg ha^{-1} $year^{-1}$ (Con -A), to -51.8 kg ha^{-1} $year^{-1}$ (Biod +A).

The generally negative K- and P field balances largely result in total deficits over the whole experimental period of 25 years Table 9, with the exception of net surplus values of K registered in the Con –A system at both sites. The range of deficits of K ranges from -578 kg ha^{-1} in the Org –A system at Bollerup, to deficit values of -1620 kg ha^{-1} for the Org +A, also Bollerup.

Similarly, P field balances at Bollerup range between 4 kg ha^{-1} $year^{-1}$ (Con -A) and -11 kg ha^{-1} $year^{-1}$ (Biod +A), with corresponding figures for Önnestad ranging between -4.6 kg ha^{-1} $year^{-1}$ (Con -A) and -9.8 kg ha^{-1} $year^{-1}$ (Biod +A). Also, here total deficits are recorded over the whole experimental period, with the exception of the Con –A system at Bollerup.

Table 9 Total surplus and deficits of K and P over the experimental period, defined as the accumulated field balances (kg ha^{-1} 26 $year^{-1}$) in all systems .

K, P (kg ha^{-1} 26 $year^{-1}$)	Con -A	Con +A	Biod +A	Org +A	Org -A
K (Önnestad)	803	-733	-1028	-1014	-434
K (Bollerup)	156	-988	-1352	-1560	-572
P (Önnestad	-120	-159	-255	-156	-242
P (Bollerup)	104	-78	-286	-234	-182

Table 10a Mean annual K field balances (kg ha^{-1} $year^{-1}$) for the four crop rotations cycles (1987-1992, 1993-1998, 2000-2005, 2006-2012), and estimated mean annual field balance for the whole experimental period (1987-2012).

		Önnestad					Bollerup				
K kg ha^{-1} $year^{-1}$		**Con -A**	**Con +A**	**Biod +A**	**Org +A**	**Org -A**	**Con -A**	**Con +A**	**Biod +A**	**Org +A**	**Org -A**
Balance	2006-2012	21	12.4	-26,9	-23	4.3	6.4	-13.5	-55.9	-56.8	-19.3
Balance	1999-2005	10.3	-23.7	-23.7	-38.2	47.6	10	-24.8	-41.1	-57.4	-19.6
Balance	1993-1998	30.5	-44.9	-61.1	-51.6	58.1	0.5	-42.1	-49.7	-54.6	-24.3
Balance	1987-1992	61.7	-57.2	-46.5	-43	-6.2	8.2	-70.5	-60.1	-69.7	-24.8
Balance	1987-2012	30.9	-28.2	-39,5	-39	-16.7	6	-38	-52	-60	-22

Table 10b Mean annual P field balances (kg ha-1 year-1) for the four crop rotations cycles (1987-1992, 1993-1998, 2000-2005, 2006-2012), and estimated mean annual field balance for the whole experimental period (1987-2012).

		Önnestad					Bollerup				
P kg ha^{-1} $year^{-1}$		**Con -A**	**Con +A**	**Biod +A**	**Org +A**	**Org -A**	**Con -A**	**Con +A**	**Biod +A**	**Org +A**	**Org -A**
Balance	2006-2012	-0.2	-5.5	-15.7	-5.8	-8.1	8	-3.5	-11.7	-4.5	-2.8
Balance	1999-2005	-7.6	-10.3	-11.8	-7.4	-8.2	1.3	-6.4	-7.4	-12.7	-5.2
Balance	1993-1998	-12.5	-11.8	-8.7	-10.1	-11.2	3.2	0.9	-15.2	-9.6	-10.7
Balance	1987-1992	1.8	3.2	-3.1	-0.5	-9.6	3.9	-3.7	-11.3	-10.2	-9.8
Balance	1987-2012	-4.6	-6.1	-9.8	-6	-9.3	4	-3	-11	-9	-7

Soil organic carbon development

Soil organic matter (SOM) in the topsoil (0-20cm) increased for all systems at Bollerup over the whole experimental period when the two terminal years of whole field crops 2013-2014 are excluded (Table 10, Figure 2) In contrast, when these are instead included in the series, the trends instead generally point to decreasing SOM over time (data not shown). Similarly, the organic matter (M) found in 2014 consistently point to lower values then the pre-commencement values in 1986 which further cements the notion of a general 'humus drainage' of the soil during the trials' terminal years of whole-field single crop strategy.

When making intersystem comparisons of the long-term SOC-development, the highest and lowest trend increases were found in the Biod +A and the Org +A systems respectively. Additional significant differences between the systems are letter-indicated in Table 26 below. These results should nevertheless be interpreted cautiously considering the absence of reliable year-to-year measurements at both sites. In addition, the soil gradient at Bollerup, along with the non-randomized field design means that the data at that site does not satisfy requirements of independence.

When comparing with the long-term trends of SOM-development at Önnestad, however, results indicate a decrease in all systems in the period between 1986-2012 (Table 10, Figure 3). Here, the inclusion of the 'starvation years' only serve to further emphasize the decrease in SOM over the whole experiment period, and this is further vindicated when comparing the final SOM values of 2017 with the pre-commencement values of 1986 (Table 10). In contrast to Bollerup, there were no significant differences between the SOC of the respective systems at Önnestad.

Table 10 Long-term trends in SOM as expressed by the slope of regression lines in the period 1986-2012, and SOM values in g/kg for the terminal year of the experimental period at
Bollerup (2014) and Önnestad (2017).

	Bollerup		Önnestad	
	Slope	Organic M (g/kg)	Slope	Organic M (g/kg)
Year(s)	1986-2012	2014	1986-2012	2017
Con -A	0.01252[a]	25[a]	-0.02052	50
Con +A	0.01792[ab]	25[a]	-0.00647	58
Biod +A	0.02849[b]	22[ab]	-0.01142	58
Org +A	0.00508[a]	21[b]	-0.03023	62
Org –A	0.01621[a]	21[b]	-0.01926	56

n = 6 replicates for both regression lines and terminal year values. Values with the same letter within a column are not significantly different ($p < 0.05$).

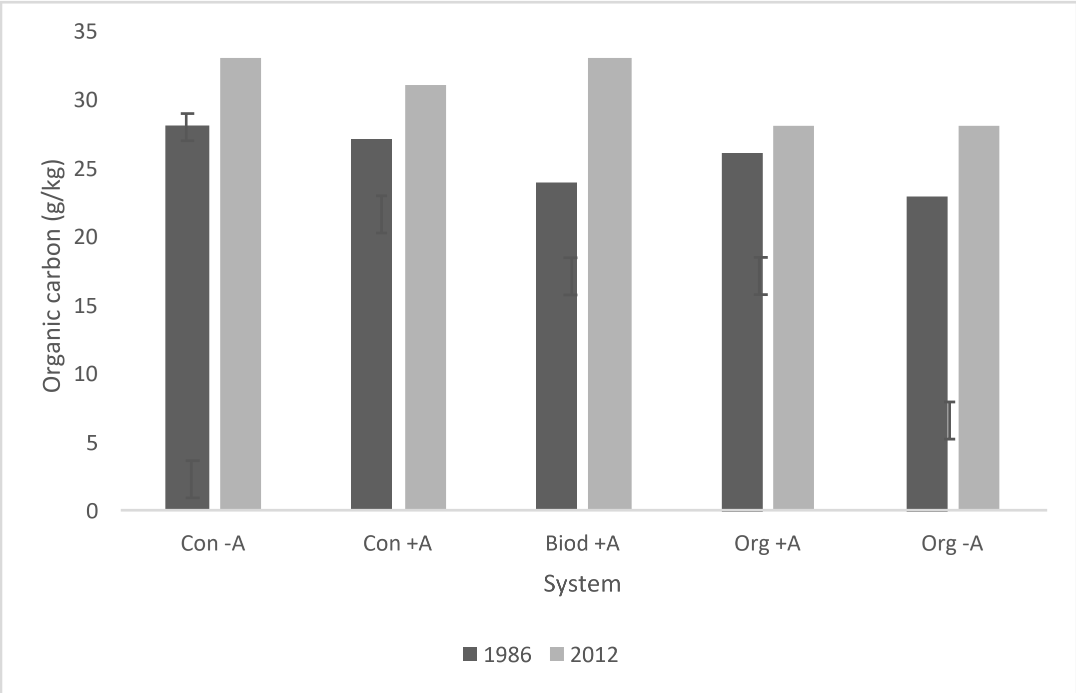

Figure 2 Soil organic matter (g/kg, ± SD) at Bollerup in the first and final year of the experimental period 1986 and 2012.

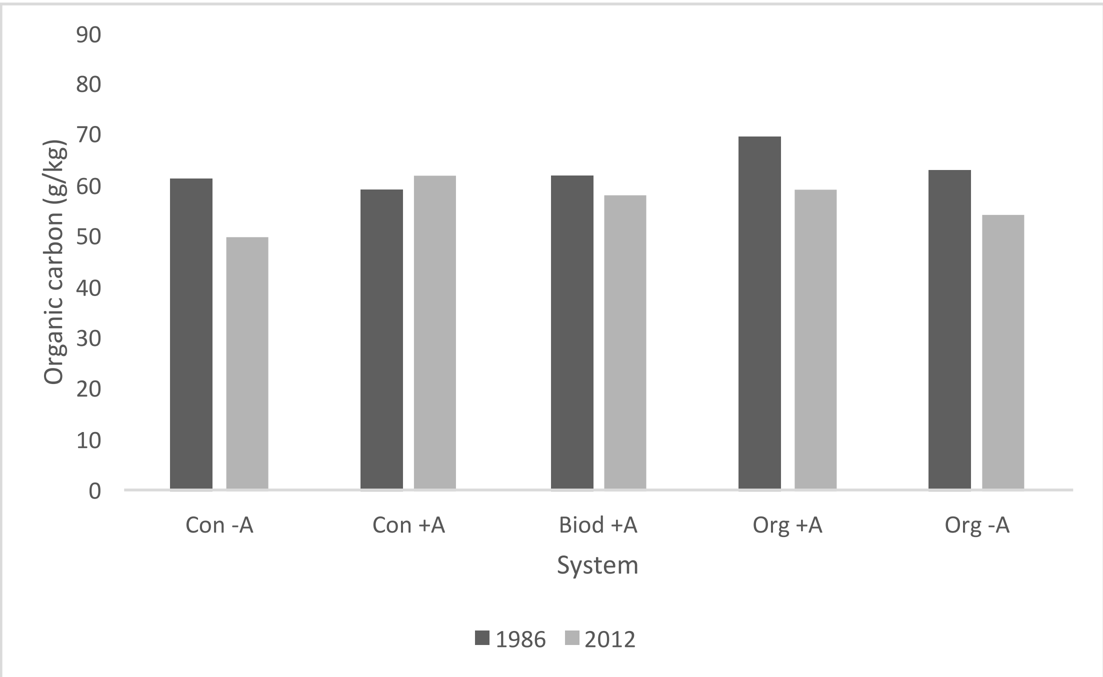

Figure 3 Soil organic matter (g/kg, ± SD) at Önnestad in the first year and final stages of the experimental period 1986 and 2012.

Exchangeable K

The trends of K_{ex} at both sites indicated similar patterns of rapid depletion during the first crop rotation cycle and subsequent stabilization during the following rotation cycles (Figure 22 and Figure 23). During the last crop rotation cycle, a slight trend of increasing K_{ex} could be seen at both sites, rendering the overall trends a polynomial shape (all systems). The Con –A system at Bollerup is a notable exception to the above pattern, with levels exhibiting a long-term stable trend fluctuating between 11–16 mg K $100g^{-1}$. Most of the minimum concentrations occurred between 2000 - 2007 (Bollerup), and 2004 – 2009 (Önnestad), and varied between 6.4 and 11 mg K $100g^{-1}$, and 3.3 and 6.2 mg K $100g^{-1}$ respectively.

Since K_{ex} data was thus unfit for linear regression analysis, they are exempt from Table 27 below comparing regressions slopes between the systems. The results are instead displayed in Figure 24 and Figure 25, showing the trials' pre-commencement values, along with the terminal year values of 2014 and 2017 for Bollerup and Önnestad respectively.

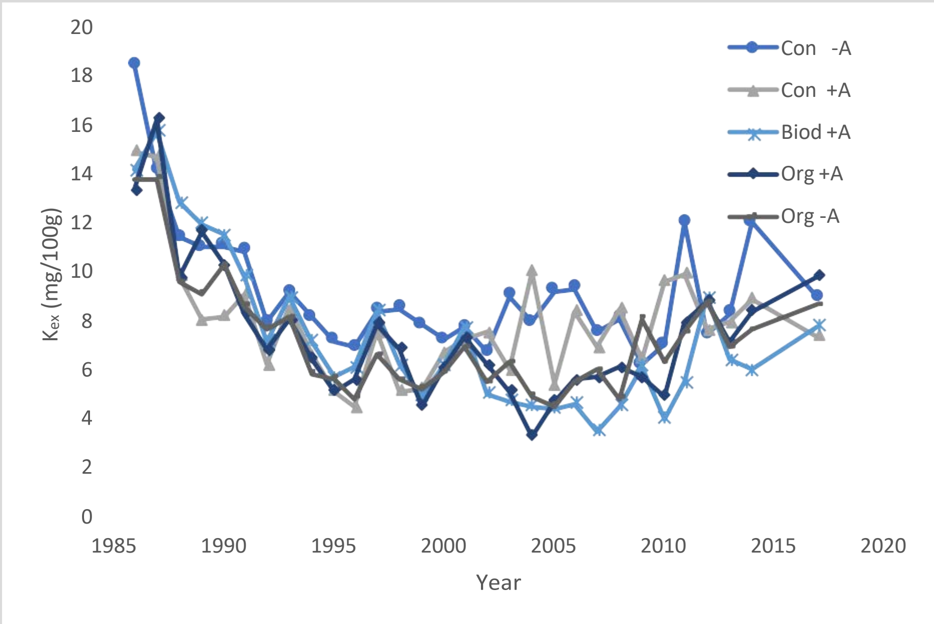

Figure 4 Exchangeable K (K_{ex}) of the five management systems in Önnestad over the whole experimental period (1986-2017).

The depletion rates of K_{ex} between the first and terminal year of the trials were higher at Önnestad, which also had comparatively higher levels of K_{ex} before the trials' commencement in 1986 (Figure 4). The rate of depletion also appears to be uniform among the systems, although this is not verified statistically. At Bollerup, the two –A systems point to a long-term increase of K_{ex}, whereas the +A systems all exhibit varying rates of depletion. Additionally, significant differences were found between the systems at the terminal year (2014), confirming higher levels of K_{ex} in the –A systems (Figure 24) in line with the results found by Andrist-Rangel (2007).

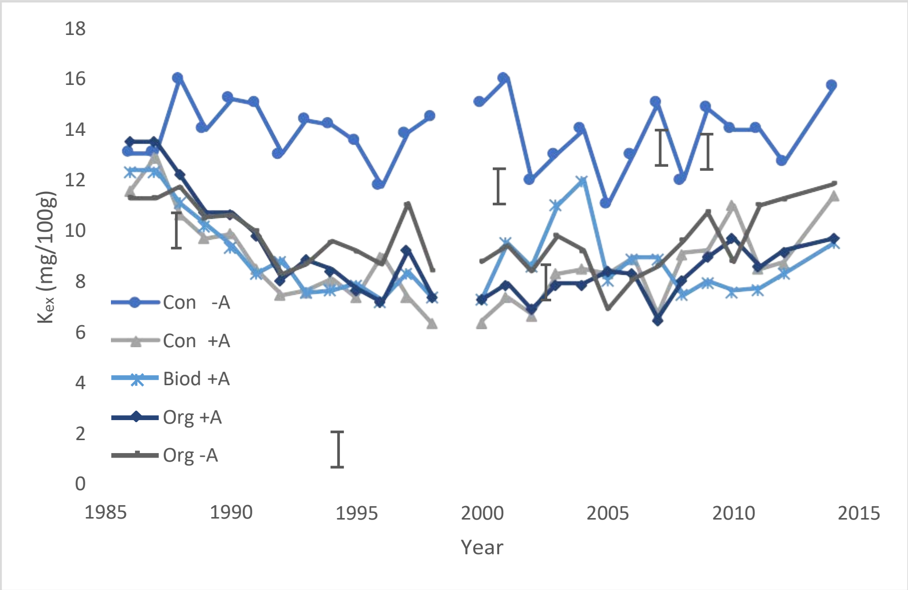

Figure 5 Exchangeable K (K_{ex}) of the five management systems in Bollerup over the whole experimental period (1986-2014). No measurements were done in 1999.

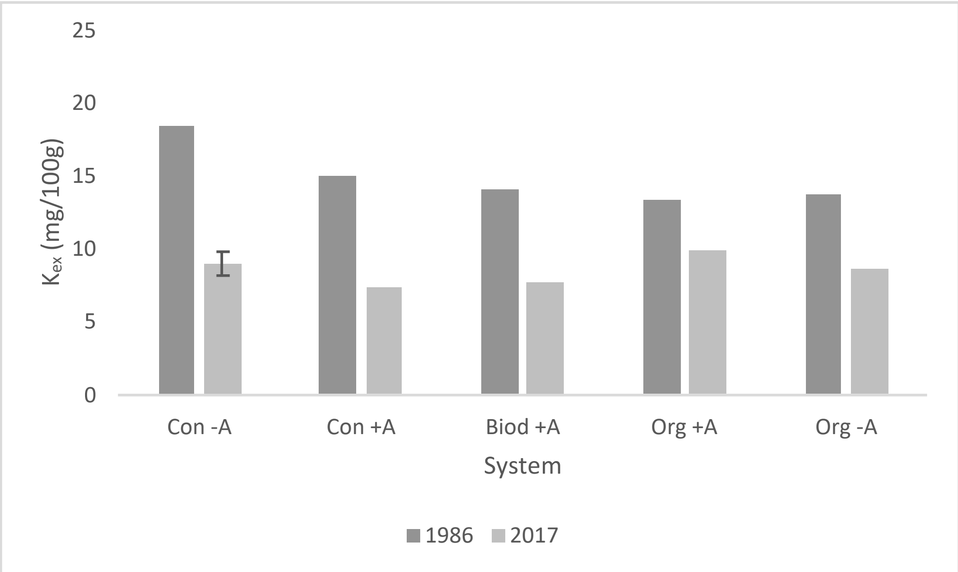

Figure 6 Exchangeable K (K_{ex}) at Önnestad in the year preceding the trials' commencement in 1986, along with values after the terminal year in 2017. Error bars indicate SD; n = 6 replicates.

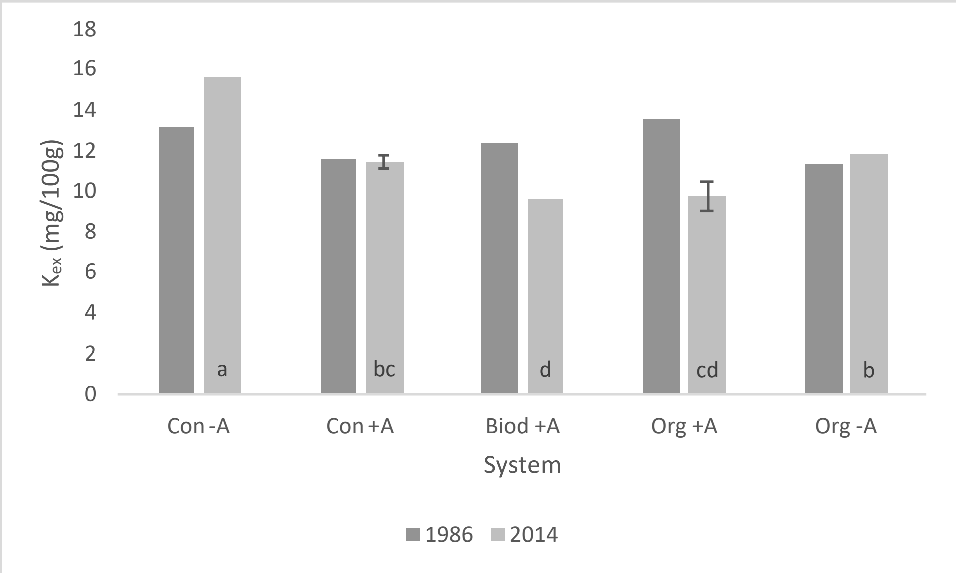

Figure 7 Exchangeable K (K_{ex}) at Bollerup in the year preceding the trials' commencement (1986), along with values after the terminal year in 2014. Error bars indicate SD; n = 6 replicates. Columns with the same letter are not significantly different ($p < 0.05$).

Acid extractable K

Contrary to the easily accessible K_{ex}, the proportion of soil K that could be extracted with HCl show trends of long-term increase at both sites. At Bollerup (Figure 7, Table 11), the results indicate a steep increase in K_{HCl} roughly coinciding with the third crop rotation cycle between 2000-2005, which is both preceded and subsequently followed by relatively stable levels. Minimum concentrations therefore occur relatively early in the experimental period and range between 82 – 88 mg K $100g^{-1}$.

When examining the long-term trends of the individual systems, these roughly share the same development with the exception of a significantly higher increase rate in the Con –A system (Table 11).

Table 11 Long-term trends in exchangeable and HCl-extractable P along with HCl-extractable K as expressed by the slope of regression lines over the whole experimental period including the terminal years 1986-2014 (Bollerup) and 1986-2017 (Önnestad).

	Bollerup			Önnestad		
	P_{ex}	P_{HCl}	K_{HCl}	P_{ex}	P_{HCl}	K_{HCl}
A (Con -A)	-0.0673^{b}	0.7424^{ab}	2.3410^{b}	-0.2649^{ab}	0.8493	0.0242
B (Con +A)	-0.07840^{ab}	1.1101^{b}	1.9665^{a}	-0.2265^{ab}	1.0437	0.0575
C (Biod +A)	-0.1156^{a}	0.4371^{a}	1.9513^{a}	-0.3046^{a}	0.9541	0.1295
D (Org +A)	-0.1218^{a}	0.9627^{ab}	1.8822^{a}	-0.1574^{a}	0.8459	0.1845
E (Org -A)	-0.0823^{ab}	0.6766^{ab}	1.8466^{a}	-0.1287^{b}	0.6071	0.2743

Values with the same letter within a column are not significantly different ($p < 0.05$).

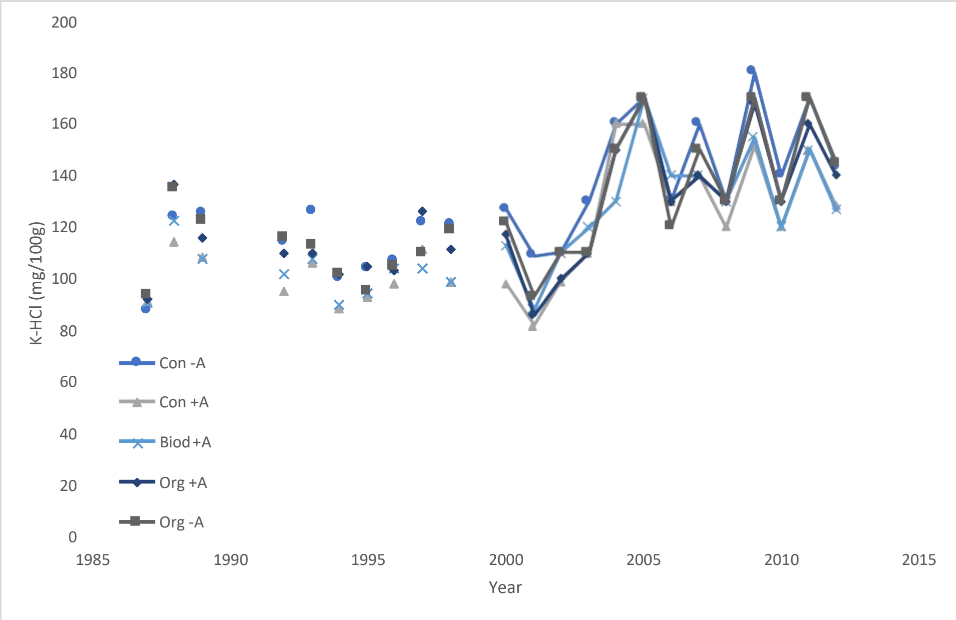

Figure 8 Acid-extractable K (K_{HCl}) of the five management systems in Bollerup over the whole experimental period (1986-2014). No measurements of K_{HCl} were conducted in 1990-1991 and 1999.

Önnestad show overall K_{HCl} levels averaging one third of the levels at Bollerup, but here the long-term trend is slightly polynomial with an initial depletion followed by a trend of linearly increasing levels instigated roughly around the commencement of the third crop rotation cycle in 2000 (Figure 8). At Önnestad, no significant differences could be discerned between the systems' K_{HCl}-trends over time.

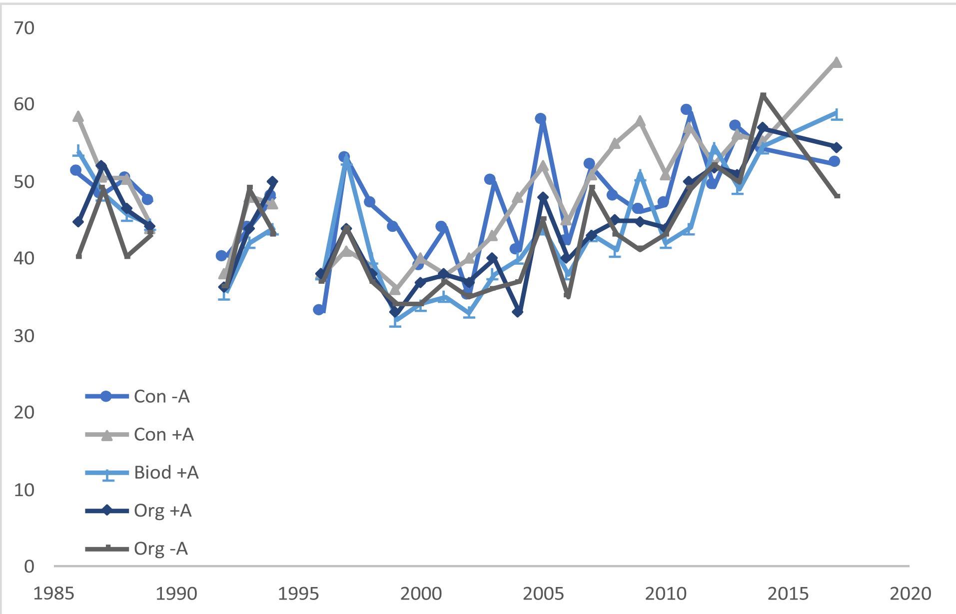

Figure 9 Acid-extractable K (K_{HCl}) of the five management systems in Önnestad over the whole experimental period (1986-2017). No measurements of K_{HCl} were conducted in 1990-1991; the 1995 value is discarded as it is an outlier.

Exchangeable and acid extractable P

Over the whole experimental period P_{ex} was declining linearly at both sites, with both initial and final values, as well as depletion rates higher at Önnestad. Contrary to the easily accessible K fractions, no system was exempt from the long-term P_{ex} decline, albeit significant differences were found between the rates of depletion (Table 11). More specifically, the Org –A system showed significantly lower depletion rate than the organic (+A) and biodynamic systems at Önnestad, whereas the Con –A system showed similar lower depletion rates compared to the organic (+A) and biodynamic systems at Bollerup.

Initial pre-commencement levels were roughly two times higher at Önnestad compared with the initial levels at Bollerup, with values ranging between 14.4 to 21.4 mg P $100g^{-1}$ and 7.6 to 11.4 mg P $100g^{-1}$ respectively. This balance was somewhat tilted during the course of the experimental period due to the slightly higher depletion rates at Önnestad.

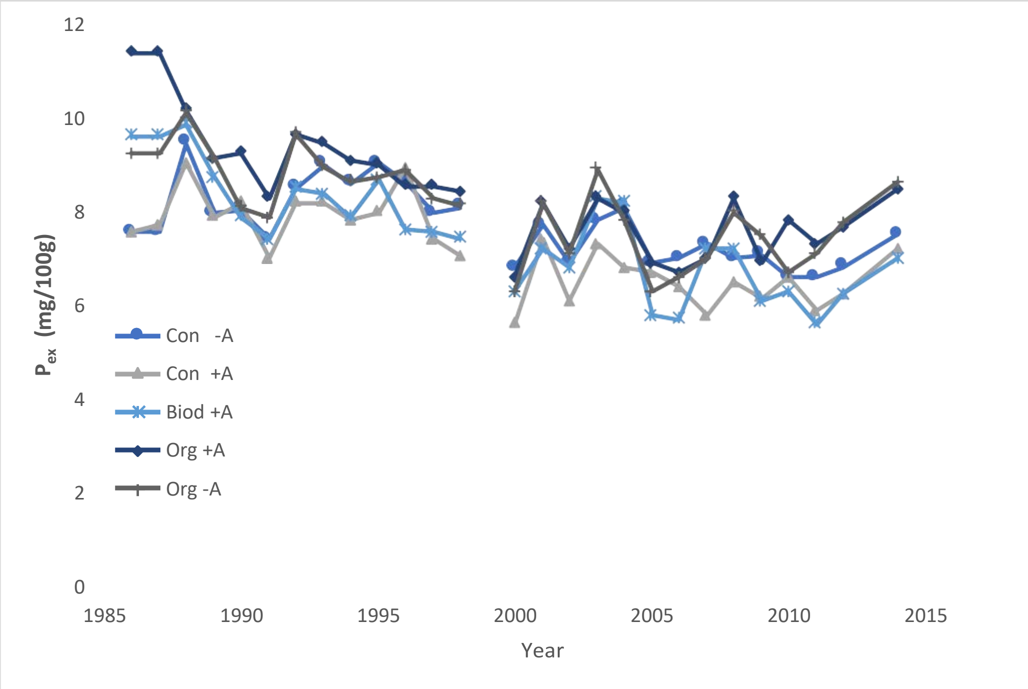

Figure 10 Exchangeable P (P_{ex}) of the five management systems in Bollerup over the whole experimental period (1986-2014). No measurements were done in 1999.

For the acid extractable P, measurements commenced by the end of the third crop rotation cycle in 2001 and continued until the termination of the trials. The results (Figure 10, Table 11) show slightly increasing trends at both sites, with significant differences between the Con +A (higher increase) and the Biod +A (lower increase) systems at Bollerup. A period of relatively strong fluctuation of P_{HCl} levels at Bollerup (all systems) can be associated with the termination of the third crop rotation cycle and the onset of the fourth, but it is not clear if these changes reflect any broader management restructurings or if they should be ascribed to climatic conditions. The corresponding P_{HCl} levels at Önnestad show no conforming fluctuation patterns.

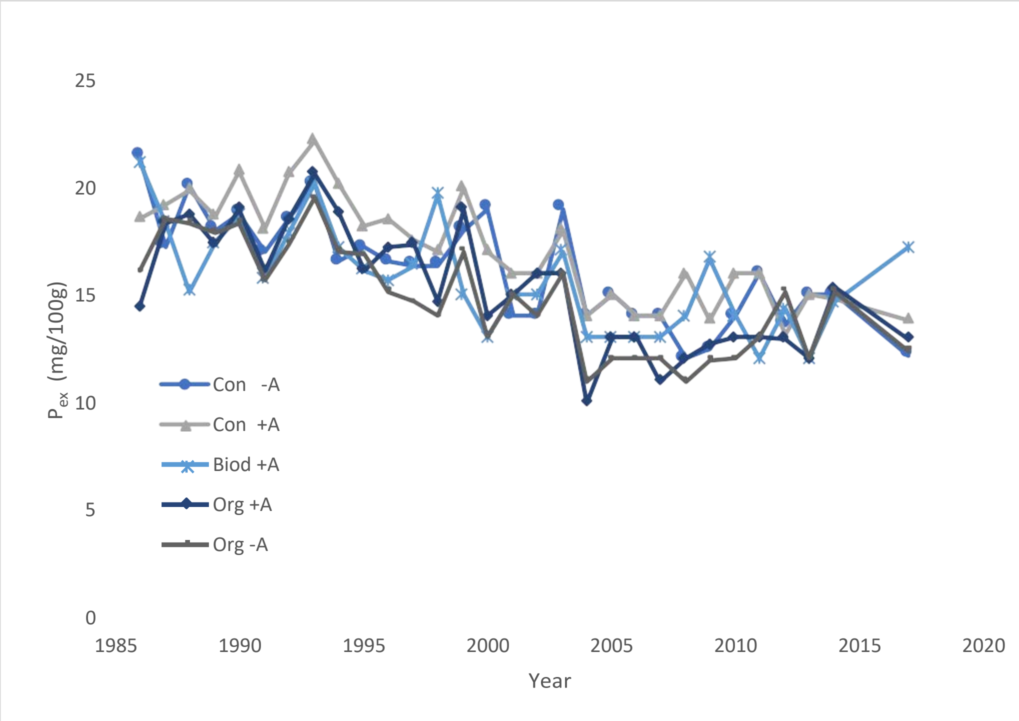

Figure 11 Exchangeable P P$_{ex}$) of the five management systems in Önnestad over the whole experimental period (1986-2017).

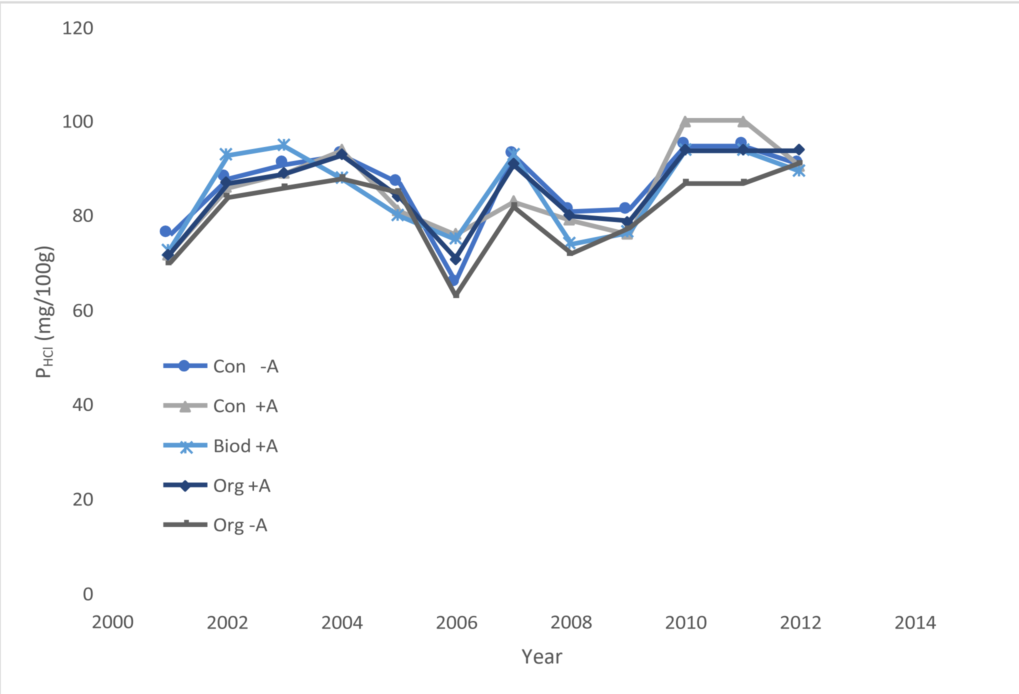

Figure 12 Acid-extractable P (P_{HCl}) of the five management systems in Bollerup over the whole experimental period (1986-2014).

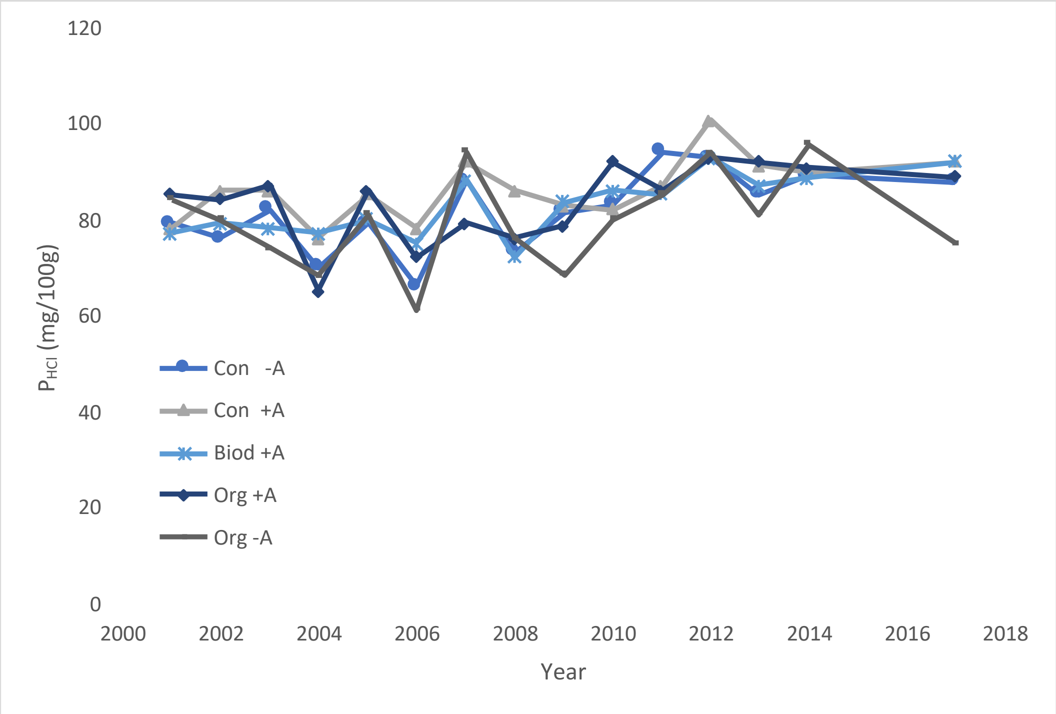

Figure 13 Acid-extractable P (P_{HCl}) of the five management systems in Önnestad over the whole experimental period (1986-2017).

Long-term trends of pH and exchangeable Ca

Changes in pH remained relatively stable over the whole experimental period at both sites, with differences between the first and the last year of measurement limited to decimal pH-units. In terms of intersystem comparisons, significant differences were found between the pH-trends over the whole experimental period at Önnestad (Table 12), where the –A systems exhibiting slight positive trends compared to the negative slopes of the +A systems. The relative stability of pH over time at Bollerup can be juxtaposed with similar stability of the Ca_{ex} levels over time, in which small but significant differences were found between the Con –A, and the Org +A systems. Conversely, all systems at Önnestad exhibited declining Ca_{ex} values that during the first 13-15 years, before the levels tended to stabilize at around 200-300 mg $100g^{-1}$(Figure 13). Here, reflecting the long-term pH-trends, the decline of Ca_{ex} was significantly lower in the –A systems than in the Biod +A system, indicating that the differing fertilization strategies may have contributed to the soil exchangeable Ca, in addition to the equal liming supplied to all systems.

Table 12 Long-term trends of pH, Mg, Ca, Cu and B as expressed by the slope of regression lines over the whole experimental period including the terminal years 1986-2017 at Önnestad.

Önnestad	pH	Mg	Ca_{ex}	Cu	B
A (Con -A)	0.0052^{bc}	0.0355	-1.4511^{b}	-0.2072	-0.0036^{ab}
B (Con +A)	-0.0076^{ab}	0.055	-4.4950^{ab}	-0.2045	-0.0047^{ab}
C (Biod +A)	-0.0121^{a}	0.0545	-5.6512^{a}	-0.2258	-0.00798^{a}

D (Org +A)	-0.0021[ac]	0.0729	-4.5826[ab]	-0.2215	-0.0035[ab]
E (Org -A)	0.0071[c]	0.0962	-2.2583[b]	-0.1886	0.0011[b]

Values with the same letter within a column are not significantly different ($p < 0.05$).

Table 13 Long-term trends of pH, Mg, Ca, Cu and B as expressed by the slope of regression lines over the whole experimental period including the terminal years 1986-2014 at Bollerup.

Bollerup	pH	Mg	Ca_{ex}	Cu	B
A (Con -A)	0.0106	0.2902[a]	-0.1088[b]	-0.0290	-0.0106
B (Con +A)	0.0082	0.3553[ab]	-0.3498[ab]	-0.0619	-0.0103
C (Biod +A)	0.0082	0.3624[b]	-0.5168[ab]	-0.0686	-0.0139
D (Org +A)	0.0075	0.3157[ab]	-0.6773[a]	-0.0225	-0.0111
E (Org -A)	0.0099	0.3120[ab]	-0.5141[ab]	-0.0726	-0.0125

Values with the same letter within a column are not significantly different ($p < 0.05$).

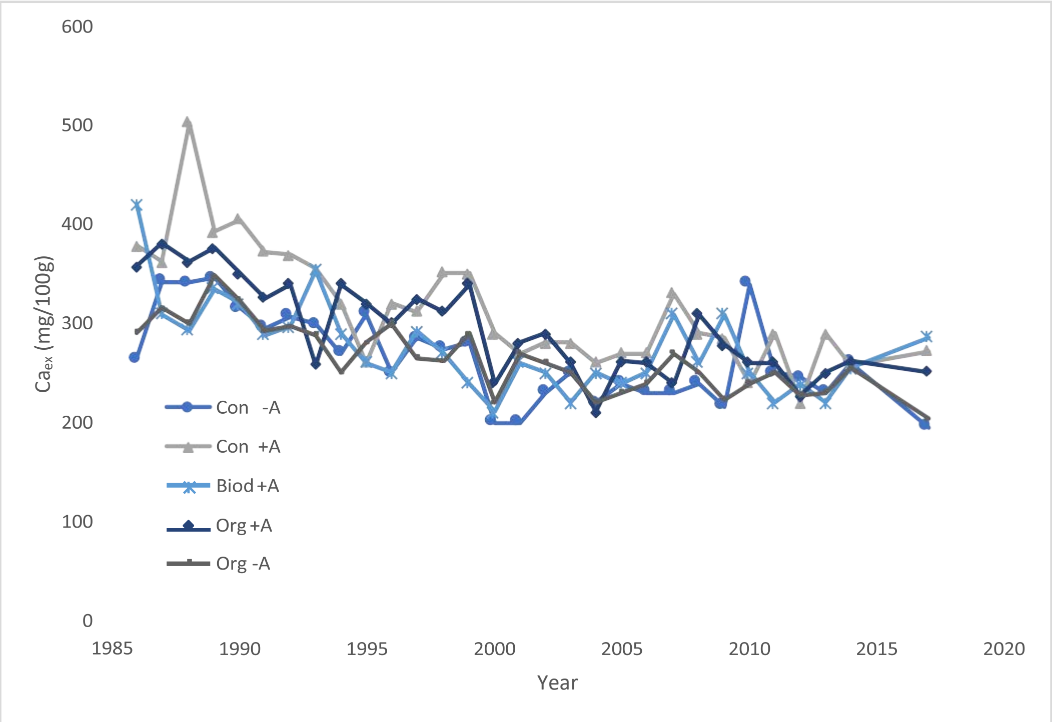

Figure 14 Exchangeable Ca (Caex) of the five management systems in Önnestad over the whole experimental period (1986-2017).

Long-term trends of Mg, Cu and B

The soil magnesium content increased over time at both sites, but at a far higher rate at Bollerup. Here, intersystem comparisons point to overall higher increases in the +A systems compared with the –A systems, with significant differences between the Biod +A and the Con –A systems (Table 12). Over the whole experimental period, soil available Mg at Bollerup roughly tripled, from 4-5 mg $100g^{-1}$ in 1986 to 12-13 mg $100g^{-1}$ at the last measurement in 2014. At Önnestad, this trend was less pronounced with only marginal differences between the measurements in 1986 and 2017 and no significant differences between the systems.

In terms of Cu and B, no real trends could be distinguished neither when looking at trends over time, nor when comparing the trials' commencement and final measurement values. When comparing trends of B over time, significant differences were found between the Org – A system, indicating a slight increase over time, and the Biod +A system exhibiting the largest decreasing trend of the systems (Table 13) in Önnestad, but these trends did not result in significant intersystem differences in the terminal year measurements.

Discussion

Soil organic carbon developments

The soil's humus (organic matter/carbon factor1,7 used here) is related to the pools of organic carbon and organic N, and is at large a result of the opposite processes of mineralization of organic substances and the decomposition of organic material (Ottabong et al 1997). As such, the impact of land management changes often entails significant effects on soil carbon (Kätterer et al 2012, 2014), with results often varying depending on the management practices (Ghabbour et al 2017). In the Swedish context, farms with bovine livestock-keeping practices and ley herbage have been shown to generally exhibit higher soil organic contents then their non-livestock keeping counterparts (Carlgren & Mattson 2001). As such, it would have been interesting to closer investigate differences between +A and –A systems, along with further examinations of the biodynamic practice compared with its organic and conventional counterparts. However, due to the varying nature of the systems over the course of the experimental period, along with the scarce quality data available on SOC, these possibilities have not been pursued here. Instead, we are restricted to general observations of long-term trends.

When thus juxtaposing the two trial sites, the contrasting levels of pre-commencement SOC is likely to be a mix of the differing soil characteristics of the respective sites, and the management practices prior to the trials' commencement. The higher levels of SOM at Önnestad may thus be at least partly associated to the crop rotation schedule (including ley) and livestock-keeping management kept from the 1960's and until the trials' commencement, whereas Bollerup was managed without livestock and ley herbage until the decade preceding the trials. However, no immediate intersystem differences are apparent at the Önnestad site where the randomized experimental design best permits such comparisons. At Bollerup, the Biod +A, which was remained intact until the termination of the trials there in 2012, shows the highest relative increase of SOC when comparing final year with pre-commencement values (Figure 2). Such results are in line with Fließbach et al's (2007) findings of SOC levels after 21 years in the DOK-trial, where the increase of soil organic carbon was highest in the biodynamic system compared with conventional and organic management. Here, however, the lack of similar trends in the other livestock-keeping systems with ley herbage included in the crop rotation puts a question mark to a similar conclusion. In addition, the soil gradient discovered at Bollerup (Ehrnebo 2003), in combination with the non-randomized field design resulting in higher pre-commencement levels of SOC in the conventional systems introduces further confounding elements.

Potassium and phosphorus field balances

The large accumulated K deficits in all systems, bar the conventional non-livestock keeping, at both sites point to an apparent under-fertilization, particularly of the +A systems (Con, Biod and Org) that also included ley herbage in the crop rotations (Table 23). This in spite of the trials following the recommended application rates of both P and K set by the Swedish Department of Agriculture [Jordbruksverket]. While previous studies (c.f. Watson et al 2002) have pointed to K deficits commonly occurring in organic agriculture with ley herbage, the problem here also encompasses the Con +A system at both sites, where fresh and subsequently liquid manure (from 1999 and onwards) was supplemented by mineral K fertilization. A plausible explanation for this apparent under-fertilization might thus be ascribed to the trials' aim of reflecting the putative farming practices of the most environmentally conscious farmers in Sweden (Modig 2016; 2), with a concomitant restraint of fresh manure and PK-fertilizer applications out of fear of aggravating the already substantial eutrophication problems in the adjacent Baltic Sea Region associated to the leaching of nutrients from agriculture (Stålnacke et al 2014). Out of the two sites here investigated, Bollerup exhibited the larger overall K deficits, with the differences again particularly pronounced in the +A systems. In addition to differing fertilizer strategies, it is possible that this discrepancy is also connected to the different texture classes of the respective sites' soils, and their concomitant capacity of supplying easily accessible K (Askegaard & Eriksen 2002, Andrist-Rangel et al 2006).

Regardless of the causes of long-term K depletion, no significant differences were found between the K-levels in winter wheat kernels of the respective systems at both sites after the third crop rotation cycle (Gissén & Larsson 2008; 45-46), and K does not seem to be the limiting nutrient of yield at either site (Andrist-Rangel et al 2007).

The phosphorus field balances point to similar overall accumulated deficits at both sites, with the exception of the Con –A system at Bollerup. Here, a similar conclusion of deliberate under-fertilization as noted in the above case of K deficits lies easy at hands, although also here fertilization rates were in line with the Swedish Department of Agriculture's recommendations (Gissén & Larsson 2008). In spite of negative field balances ranging between 4.6 kg P ha^{-1} year^{-1} to 9.8 kg P ha^{-1} year^{-1} at Önnestad, and a surplus of 3 kg P ha^{-1} year^{-1} to a deficit of 11 kg P ha^{-1} year^{-1} at Bollerup, overall soil P availability nevertheless still falls in the IV-V (Önnestad) and III-IV (Bollerup) classes in the , which following current recommendations entail restricted P fertilization (Jordbruksverket 2017). Consequently, the P accumulated deficits of phosphorus do not appear to be of a sufficient magnitude for increased fertilization rates.

On a system level, this under-fertilization is clearest discernible when it comes to the application of fresh manure in the Biod +A system upheld over the whole experimental period at Bollerup, and until 2005 at Önnestad. In line with previous results of P field balances on organic and biodynamic farms in Sweden (Granstedt 2000), the +A systems with extensive P removals in the forms of ley and milk exhibit larger deficits than the Con –A system, which is only partly recuperated through fertilization. The Org –A systems here represent somewhat of an anomaly since they during the first two crop rotation cycles (1987-1992, 1993-1998) were deliberately under-fertilized (Ivarsson et al 2001).

Long-term trends of exchangeable and acid extractable potassium and phosphorus

The rapid K_{ex} losses at both sites during the first crop rotation cycle indicate that plants initially relied to a high degree on the soil's easily accessible pool for K uptake. This is further corroborated by the field balance for the same period exhibiting the overall largest deficits when compared with ensuing crop rotations (Table 23). Andrist-Rangel et al (2007; 424) suggest that the plateau in K_{ex} levels subsequently reached at both sites further indicate a strong buffering capacity in which K is released from the non-exchangeable pool to the pool of easily accessible K. This is however not backed by a concomitant lowering in the K_{HCl} levels associated with the former pool . On the contrary, K_{HCl} levels exhibit trends of linear increase at both sites.

Conclusion

In the Swedish context, farms with bovine livestock-keeping practices and ley herbage generally have higher soil organic carbon than non-livestock keeping counterparts (Carlgren & Mattson 2001). The two long-term farm system studies with four, 6-year crop rotations in Bollerup and Önnestad, Scania are, to a certain degree, representative of changing soil parameters due to dissimilar farm practice backgrounds. Higher levels of SOM at Önnestad may thus, at least partly, be associated with crop rotation (including ley) and livestock- keeping practices held over from the 1960's until trials commenced. Bollerup was managed without livestock and ley herbage until the decade preceding trials. At Bollerup the biodynamic system with ley and cattle manure showed the highest relative increase of SOM when comparing final year with pre-trial values. At Bollerup, soil organic matter increased, while at Önnestad it decreased. These results are in line with Fließbach et al's studies (2007) and the long-term studies in Järna in central Sweden (Granstedt & Kjellenberg 2008 and Granstedt, 2017). Lack of similar trends in the other livestock-keeping systems in Bollerup with ley herbage included in crop rotation makes a comprehensive conclusion uncertain. In addition, further confounding elements are introduced with the soil gradient found at Bollerup (Ehrnebo 2003), which in combination with the non-randomized field design, resulted in higher pre-trial levels of SOM in the conventional systems.

The rapid K_{ex} losses in topsoil at both sites during the first crop rotation cycle indicate that plants initially relied to a high degree on easily accessible pool in soil for K uptake. This is further corroborated by the field balance for the same period exhibiting the overall largest deficits when compared with ensuing crop rotations.

There is a need of further studies to better understand these processes. Specifically, studies of other site conditions, in properly randomised experiments are called for.

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