AGRICULTURAL AND FOOD SCIENCE

J. Kivelä et al. (2015) 24: 68–83

Effects of meat bone meal as fertilizer on yield and quality of sugar beet and carrot

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Meat and bone meal (MBM) is a by-product of the meat industry and is an important pathway for recycling of N and P. MBM contains about 8% N, 5% P, 1% K and 10% Ca. Field trials compared the effects of MBM and mineral fertilizer on yield and quality of sugar beet (2008-2009) and carrot (2010-2011) in Finland. MBM fertilisation of sugar beet grown on clay loam and sandy clay soil gave 11.4% (2008) and 19.6% (2009) lower yields than mineral fertilizers. The lower root yield in 2008 was compensated by higher extractable sugar content and lower amino-N, K and Na in root but no such compensation in root quality was detected for 2009. Mixing MBM with mineral NPK fertilizers had similar effects as MBM-alone. MBM (80 kg N ha^{-1} 2010 and 60 kg N ha^{-1} 2011) together with K fertilizer (Patentkali®, 180 kg K ha^{-1}) were applied for carrot to a fine sandy till soil in 2010 and sandy loam in 2011. MBM alone gave 14% lower total and marketable root yield than mineral fertilization. The lower yield was compensated by improved quality, lower NO_3^- content in the carrot and good storability. Adding extra fertilizer during growth or separating fertilization applications had no effect on root yield or quality. MBM performed in these cases mainly as an organic N fertilizer. The N supply from MBM is not sufficient for achieving same yields as with mineral fertilizers. The relative N efficiency of total N of MBM was 83% that of mineral fertilizers. MBM should be targeted on soils with low P status. We conclude that MBM is a reasonably competitive alternative to mineral fertilizers, and as a recycled fertilizer it is a good option for organic production.

Key words: nitrogen, phosphorus, organic fertilizer, recycling, sugar beet, carrot

Introduction

Meat and bone meal (MBM) is a by-product of the rendering industry. It contains about 8% Nitrogen (N), 5% Phosphorus (P), 1% Potassium (K) and 10% Calcium (Ca) (Ylivainio et al. 2007, Carcia and Rosentrater 2008), which makes it a valuable source of nutrients for plant production.

MBM was suspected as the carrier of the prion that caused bovine spongiform encephalopathy when it was incorporated into feed for ruminants and the use of MBM in animal feed formulations was banned in the EU in 2000 (Brewer 1999). Since 2002, animal by-products have been divided into three categories from the highest risk category 1 to the lowest category 3 (EC 2002). Since 2006, European Commission's regulation No 181/2006 authorised the use of MBM in category 2 and 3 uses as fertilizer for arable crops (EC 2006a). The fear of traces of MBM still contaminating the food chain remains an obstacle to its full use as an organic fertilizer in vegetable production, however. Lamprecht et al. (2011) discussed the trade-off between P recycling and health protection in Switzerland: bone disposal had a clear impact on Switzerland´s P cycle; a substantial proportion of animal-by-products are exported to other countries as these are not accepted as materials for fertilizers in Switzerland.

In a life cycle assessment (LCA), Spångberg et al. (2011) compared the environmental impacts of meat meal fertilizer with those of inorganic chemically synthesized fertilizers by comparing their impacts on the production and quality of crops. The functional unit they used was one kg of spring wheat produced and 0.59 kg of animal by-products treated. Using animal by-products for recycling as fertilizers instead of incinerating them for combined heat and power (CHP) decreased greenhouse gas and acidifying emissions and it also decreased the use of non-renewable energy. However, the use of animal by-products did increase the total energy used by the system. Therefore the acceptance and use of animal by-products for energy or for nutrient recovery depend on the priorities and laws stipulated by society.

Rock phosphate resources are limited and recycling P within the food system is extremely important for sustainable production (Cordell 2010). A high P content makes MBM an important source for P recycling. In Finland for example, ca. 40 kg of animal by-products per capita (at least 200 million kg) are generated annually (Salminen 2002). The second and third category MBM fertilizer, which are risk free contain 4 – 5 million kg P; if spread evenly on all Finnish arable lands, MBM alone would provide over 2 kg P ha^{-1} annually.

Manuscript received September 2013

A meta-analysis conducted by Valkama et al. (2009) reported an overall significant 11% increase in Finnish cereal yields as a response to P fertilization compared to controls fertilized with nitrogen and potassium only. The response was highest in organic soils, intermediate in coarse-textured soils and lowest in clay soils (Valkama et al. 2009). Although MBM contains much P, the solubility of P is very low as about 0.15% is water soluble and 40% is soluble in ammonium citrate solution (Ylivainio et al. 2007). MBM contains a low level of K and most N in MBM is in organic form, the proportion of ammonium-N was reported to be 2.5% (Ylivainio et al. 2007). Mixing MBM with N and K from inorganic sources could possibly improve the fertilization effect.

The use of MBM as a fertilizer has been tested on spring and winter wheat (Salomonsson et al. 1994, 1995, Lundström and Lindén 2001), cereals and ryegrass (Jeng et al. 2004, 2006), barley and oats (Chen et al. 2011) and maize (Nogalska et al. 2012). In these studies MBM gave similar grain yields and grain protein content as those for corresponding cereals that had been treated by mineral fertilizers. The relative N efficiency of total N in MBM compared to N from mineral fertilizers equalled about 80% (Jeng et al. 2004).

There are no internationally published studies on the use of MBM as fertilizer for root crops to the best of our knowledge. Two important root crops in temperate agriculture that belong to two different plant families are sugar beet (*Beta vulgaris,* Amaranthaceae) and carrot (*Daucus carota,* Apiaceae). The aim of this study was to test the use of MBM as a fertilizer for root crops in Boreal conditions and compare the effects of MBM-alone, with mineral fertilizer and MBM mixed with mineral NK fertilizers: 1) on root yield, sugar content, and nutrient content of sugar beet, and 2) on root yield, storability and nutrient content of carrot.

Material and methods

Sugar beet

Study site and soil analysis

MBM was tested as fertilizer for sugar beet in field experiments over two growing seasons by SjT (Sugar Beet Research Centre Finland) at Tuorla Research Farm in Piikkiö in Southwest Finland. The preceding crop for both experiments was spring wheat. Soil samples for standard Finnish soil fertility analyses were prepared and analyzed according to the methods described by Mäkitie (1958) and Sillanpää (1977) for soil type, pH and nutrient contents at the very start of the experiments. Soil samples were analysed before and after the experiment in both years (Table 1 and 2). Methods of soil analyses are presented in Appendix 1.

Table 1. Soil analysis results before sowing and after harvest of sugar beet in 2008 (mg l^{-1}, except pH) (Finnish soil quality classification terminology: Aaltonen 1997)

	Spring 2008		Autumn 2008	
pH	6.9	High	6.2	Acceptable
Ca	3180	Good	2260	Acceptable
P	36.7	High	24.5	High
K	292	Acceptable	195	Acceptable
Mg	395	Acceptable	248	Acceptable
Na	43	Tolerable	26	Rather low

The soil type in the 2008 trial was clay loam with organic matter 3.0 – 5.9%, pH and acid ammonium acetate extractable -P levels were good (soil quality classification, Aaltonen 1997), but K, Mg and Na were relatively low (Table 1). The soil type in the 2009 trial was sandy clay with organic matter 6.0 – 11.9%. P and K contents were on the margin of acceptability, Na was rather low, but Mg was good and Ca was high (Table 2).

Table 2. Soil analysis results from before sowing and after harvest of sugar beet in 2009 (mg l^{-1}, except pH)

Spring 2009			Autumn 2009											
			HY1		NK1		MBM		MBM+NK1		MBM+HY1		MBM+HY1	
pH	6.4	Good	6.3	Acc.	6.4	Good	6.3	Good	5.8	Acc.	6.3	Good	6.3	Good
Ca	4590	High	4720	High	4985	High	4602	High	4710	High	4640	High	4730	High
P	10.9	Tol.	13.4	Good	12.1	Acc.	11.2	Acc.	10.6	Acc.	13.3	Good	11.5	Acc.
K	269	Tol.	242	Acc.	250	Acc.	245	Acc.	244	Acc.	250	Acc.	252	Acc.
Mg	435	Good	259	Acc.	268	Acc.	274	Acc.	208	Acc.	275	Acc.	279	Acc.
Na	49	R. low	34	R. low	37	R. low	38	R. low	37	R. low	38	R. low	38	R. low

Tol.=Tolerable, Acc.=Acceptable, R.low=Rather low ; Finnish soil quality classification terminology: Aaltonen 1997.

Weather conditions

The weather at the site in 2008 (Table 3) was relatively warm in early May after the sowing of sugar beet, but was then very dry until the middle of June. September and October of 2008 were relatively cool, but had more rain compared to the long-term means of regional rainfall for these two months.

Table 3. Temperature and rainfall in the growing seasons of the field trials (Finnish Meteorological Institute weather station data from Kaarina 60°39'N 22°55'E for sugar beet, and Kauhajoki 62°41'N 22°18'E for carrot)

	Sugar beet trials						Carrot trials					
	Temperature (°C)			Rainfall (mm)			Temperature (°C)			Rainfall (mm)		
Year	2008	2009	1971-2000	2008	2009	1971-2000	2010	2011	1981-2010	2010	2011	1981-2011
April	5.7	4.6	3.4	31	2.5	37	-	7.6	3.7	-	3.7	31
May	10.1	10.5	10.0	12	30.5	35	12.4	9.8	9.1	73.8	34.3	35
June	14.5	13.3	14.7	74	63.3	52	13.3	16.2	13.3	41.5	71.3	53
July	17	16.5	16.9	26	119.3	76	19.9	18.5	16.7	75.4	115.6	52
Aug.	14.5	16.0	15.5	104	84.8	79	15.3	15.3	15.8	84.6	154.5	76
Sep.	9.4	12.7	10.3	62	49.5	68	9.7	11.8	11.4	72.1	110	61
Oct.	7.8	3.4	5.5	160	75.5	74	4.1	6.1	6.9	49.8	31.6	67

In 2009, the soil was relatively moist during the spring sowing time and the rainfall was sufficient during spring and June for the smooth emergence of sugar beet. June of 2009 was relatively cool, but in July the temperature rose to the long-term mean and the temperature accumulation of 2009 matched that of the 2008 sum. No significant dry spells to cause water shortage for the plants occurred, even though the rainfall during April-May and September was fairly low in 2009 compared to the 30-year mean of 1971-2000.

Materials and experimental designs

The varieties of sugar beet grown were "Jesper" in 2008 and "Lincoln" in 2009, their selection was based on subjective assessment for their suitability for the sites by SjT research personnel. NPK nutrient content in 2008 for Viljo Yleislannoite™ MBM was 8-4-3 (8% N, 4% P, 3% K as dry weight %) and in year 2009 for Perus-Viljo 8-5-1 (8% N, 5% P, 1% K as dry weight). Three inorganic fertilizers were used for comparisons: Pellon Hiven Y2™ 18-3-6 (HY2), Hiven Y1™ 23-3-6 (HY1) and Nurmen NK1™ 20-0-7 (NK1), all from Yara Ltd. Low potassium in the MBM fertilizers were supplemented using potassium sulphate (K_2SO_4) by K+S Kali Ltd (Table 4). This K_2SO_4 was mined from natural salt deposits in Europe. The mined K_2SO_4 is suitable for organic farming according to regulations (EC 2007, 2008) due to its natural origin and the minimal processing required by fertiliser factories even though it is a mineral fertilizer. MBM fertilizers and nutrient analyses of MBM were obtained from the rendering plant Honkajoki Ltd and nutrient analyses of mineral fertilizers from Yara Ltd in Finland.

Table 4. Nutrient contents of fertilizers used for sugar beet and carrot

	Fertilizers	N-P-K	Nws	Pws	Ca	S	Mg	Na	B	Mn	Zn	Se
		%							mg kg^{-1}			
Sugar beet	HY1	22-3-6	22	3	0	6	1	0	1	300	100	15
	HY2	18-3-6	18	3	0	4	1	6	800	12000	-	15
	NK1	20-0-7	20	0	0	2.5	1	4	200	-	1500	15
	MBM*	8-4-3	2.5	0.15	11	1.5	0.8	1	25	4	55	0.19
	MBM*	8-5-1	2.5	0.15	11	1.0	0.8		25	4	55	0.19
	K2SO4*	0-0-42				18						
Carrot	PY1	8-5-19	8	5	-	12	2.5	-	500	2500	-	15
	CaS	-	-	-	21	16	-	-	-	-	-	-
	NCa	15.5-0-0	15.5	-	19	-	-	-	-	-	-	-
	KS	0-0-40	-	-	-	17	-	-	-	-	-	-
	NKS	9-0-28	9	0	-	14	-	-	1500	2500	1000	-
	NP	12-23-0	12	23	-	-	-	-	-	-	-	-
	MBM*	8-5-1	2.5	0.15	12	0.5	0.8	0.5	25	4	55	0.19
	KSMg*	0-0-25	-	-	-	17	6	-	-	-	-	-

*= approved according to regulation (EC) 834/2007 and (EC) 889/2008 for use in organic farming systems
ws = water soluble

The experiment conducted in 2008 had a Latin square design with four fertilizer treatments. The plots consisted of 4 x 12 m long rows, which were shortened to 10 m later during the growing season. The net plot area that was harvested for the root crop yield was 10 m per row of the 2 inner rows.

The distances between the adjacent rows was 47.5 cm and between the mono-germ seeds 18 cm. The fertilizer treatments were planned based on the contemporary best practice recommendations given to sugar beet growers in Finland, which was: 140 N, 43 P, 60 K, 80 Na, and 14 Mn kg ha^{-1} (SjT 2014). The four fertilizer treatments used were: HY2 as conventional control, MBM, MBM+NK1, and MBM+HY2 (Table 5). The three treatments that included MBM provided 100%, 77% and 75% of total N for MBM, MBM+NK1, and MBM+HY2, respectively. The application rates at each fertilization spreading were adjusted to achieve 140 kg N ha^{-1}, resulting in systematic differences between the treatments in application rates of other nutrients (Table 5).

Table 5. Rates of fertilizer applications (kg ha^{-1}) and N, P, and K applied for the sugar beet in 2008 and 2009 trials

Year	Fertilizer treatment	N in MBM	Fertilizer	N	Nws	P	Pws	K
		%	kg ha^{-1}					
2008	HY2	0	778	140	140	23	23	46
	MBM*	100	1750	136	44	87	3	53
	MBM+NK1	77	1000+300	140	85	40	2	31
	MBM+HY2	75	1000+333	140	85	40	2	33
2009	HY1	0	595	131	131	17	17	34
	NK1	0	650	130	130	0	0	46
	MBM**	100	1625	130	40	65	2	60
	MBM+NK1	80	1300+130	130	58	52	2	60
	MBM+HY1	80	1300+118	130	58	56	6	60
	MBM+HY1	90	1462+59	130	49	60	4	60

ws = water soluble.
*= MBM Viljo 8-5-3 Yleislannoite™.
**= MBM Viljo 8-5-1 Perus-Viljo™.
In all treatments with MBM in 2009, potassium sulphate for K was added.

The experiment conducted in 2009 was a randomized complete block design with six fertilizer treatments and four blocks as replicates. Instead of 140 (as the general recommendation and in 2008) the targeted N application rate was 130 kg ha^{-1}. The rate was adjusted downwards due to higher organic matter content of the site than in 2008.

Six treatments were HY1 and NK1 as controls; MBM alone; three MBM + mineral fertilizer mixtures: MBM80+NK1, MBM80+HY1, MBM90+HY1 (in which MBM provided 80%, 80% and 90% of total N, respectively). Except in the two controls, K fertilizers (K_2SO_4, 42% K, 18% S) were added according to the calculated needs of sugar beet.

Crop management

The respective sowing and harvesting dates of sugar beet were 5 May and 2 October in 2008, and 11 May and 28 September in 2009. The fertilizers were placed at the time of sowing under the seeds by a monogerm combine-seed-drill. However, because of the bulkiness of MBM, it was impossible to spread MBM at the same time as that of sowing the sugar beet seeds in some plots and consequently about one third of MBM treatment was spread on the field surface prior to sowing. During the growing season, herbicides were applied as needed and to all the plots (two times per growing season). Pesticides were not used.

Measurements and data analyses

Root yield (kg ha^{-1}), sugar content (%) and extractable sugar content (%) were measured in the sugar beet trials. The yield of sugar as kg ha^{-1} was calculated from the sugar content of the root yield of sugar beet per ha^{-1}. The amino-N, Na and K contents in the root of sugar beet were also measured. The samples of sugar beet, which were fertilized only with MBM were sent to EVIRA (Finnish Food Safety Authority) to ascertain that no residual bone meal was found using microscopy. The soil tests were made by AgroAnalyysit Ltd in Salo, following the same procedures as in Viljavuuspalvelu Ltd (Appendix 1). The laboratory is ISO registered and the soil test has been accredited according to ISO/IEC 17025 by FINAS (Finnish Accreditation Service). Analysis of variance (ANOVA) was performed using SPSS® version 20 software GLM univariate procedure. Tukey´s test was used to compare means at a 5% risk.

Carrot
Study site and soil analysis

Two field trials were conducted, in 2010 and in 2011. Carrot varieties that were suitable for mechanised processing and handling were grown on a commercial farm in Teuva, in the province of Southern Ostrobothnia in Finland. Soil samples were analysed before and after the sowing and harvesting of carrots in both years. The previous crop had been oats in both carrot trials.

The soil was fine sandy till (Hunt & Seymour 1985) in the 2010 trial, with organic matter 6.0-11.9% and soil pH was at an optimum level. According to the Finnish soil quality classification terminology (Aaltonen 1997), the P content of the soil was classified as good, soil Ca classed as tolerable, K and Mg only acceptable, and S and B rather low (Table 6).

Table 6. Soil analysis results from before sowing and after harvest in 2010 for the carrot trial (mg l^{-1}, except pH and NO_3^--N kg ha^{-1})

	Before sowing		After harvest					
			Conventional		Supplemented + split		MBM	
pH	6.2	Good	6.2	Good	6.2	Good	6.3	Good
Ca	1100	Tol.	1500	Acc.	1600	Acc.	1700	Acc.
P	15	Good	12	Acc.	13	Acc.	13	Acc.
K	130	Acc.	50	R.low	55	R.low	59	R.low
Mg	150	Acc.	220	Good	230	Good	270	Good
S	4.2	R.low	45.4	Good	70.2	High	57.3	High
B	0.3	R.low	0.6	Acc.	0.7	Acc.	0.6	Acc.
Cu	7.7	Good	5.8	Good	6.5	Good	6.2	Good
Mn	17	Tol.	7.9	R.low	9.7	R.low	7	R.low
Zn	7.63	Good	2.85	Acc.	3.02	Acc.	3.28	Acc.
NO_3^--N	<20		<20		<20		<20	

Tol.=Tolerable, Acc.=Acceptable, R.low=Rather low ; Finnish soil quality classification terminology: Aaltonen 1997.

In the 2011 experiment the soil was sandy loam (organic matter 12.0 – 19.9%), with acceptable pH. Nutrients were on acceptable level, only Mg was low in soil quality category tolerable (Table 7).

Table 7. Soil analysis results prior to sowing and post-harvest in 2011 for the carrot trial (mg l^{-1}, except pH and NO_3^--N kg ha^{-1})

	17.5.2011		13.10.2011					
			Conventional split in two		Conventional split in three		MBM	
pH	5.6	Acc.	5.4	Acc.	5.4	Acc.	5.4	Acc.
Ca	1400	Acc.	750	R.low	1000	Acc.	770	R.low
P	10	Acc.	17	Good	17	Good	20	Good
K	160	Acc.	68	R.low	62	R.low	64	R.low
Mg	110	Tol.	73	R.low	81	Acc.	78	R.low
S	16.7	Good	14.3	Acc.	19.0	Good	13.0	Acc.
B	0.7	Acc.	0.4	R.low	0.6	Acc.	0.5	R.low
Cu	5	Good	3.6	Acc.	5.7	Good	4.7	Acc.
Mn	42	Acc.	29	Good	41	Good	39	Good
Zn	5.16	Acc.	3.39	Good	5.36	Good	4.64	Good
NO_3^--N		<10	<10		<10		<10	

Tol.=Tolerable, Acc.=Acceptable, R.low=Rather low; Finnish soil quality classification terminology: Aaltonen 1997.

Weather conditions

The temperature during the growing season at the site of the carrot trial in 2010 did not differ much from the mean temperature of 1981-2010 period. In 2010, rainfall in May and June was, however, above the long-term mean, in May 73,8 mm as long term mean is 35 mm, and June 75,4 mm as long term mean is 53 mm. In 2011, compared to the long-term means 1981-2010, the temperatures in April and June were much higher, whereas rainfall was less in April and during harvest in October, but higher from June to September (451,4 mm, whereas long-term mean is 242 mm) (Table 3).

Materials and experimental designs

In both trials, conventional mineral fertilizers were compared with MBM (Aito-Viljo™, 8-5-1) supplemented with KSMg (Patentkali, K 25%, Mg 6%, S 17%) (Table 8). The mechanical-handling and processing-tolerant carrot variety “Nigel” was used. Nigel is a variety that is also suitable for long storage. The usual fertilizer regime on the farm for the variety “Nigel” was N 80.5, P 30.0, K 191.5, Ca 80.0, Mg 22.5 and S 165.0 kg ha^{-1}.

The trials conducted in both years had non-randomized complete block on-farm designs with four replicates. In the 2010 experiment, each of three fertilization treatments was allocated to four neighbouring carrot rows running 500 m in length. Hence, the three fertilization treatments required, in all, 12 rows (row spacing 0.8 m, seeding density was 60 seeds per row metre) times 500 m. Sampling of the carrots for each treatment was done systematically from plots made at points that were measured at 15, 140, 265 and 490 m linear distance from the field edge along the rows. At each of the above measurement points, 3 m of two inner rows for each treatment was sampled, which gave 6 row-metres per plot as the sample size. In this arrangement, the treatments within each sampling point (i.e. block) were not randomized. Any possible effects on carrot yield and quality arising from heterogeneity of the field parcel can be expected to be more manifest between the sampling points (125 m apart) than between the treatments. Moreover, each sampling plot had the other two treatments located within 9.6 m across the rows. The sampling scheme and design in 2011 were the same as in 2010 but the field parcel was smaller and only allowed 155 m of row length for the treatments. Sampling was done from points that were measured at 10, 55, 100 and 145 m from the field edge along the rows. For controlling NO_3^- content in carrot, in 2011 each replicate included a control plot without fertilization: the control was not used for any other purpose.

In the 2010 carrot trial MBM was applied at 80 kg N ha^{-1} rate. The conventional fertilization rate used is 48 kg N ha^{-1}, thus supplements of 32 Kg N ha^{-1} was given to make up the experimental application rate of 80 kg N ha^{-1} rate (Table 8). The three treatments were: only basic mineral fertilizer PY1 supplemented with CaS, at the rate of 48 kg N ha^{-1}; basic mineral fertilizer PY1 supplemented with CaS at the application rate of 48 kg N ha^{-1} plus NCa and KS added during growth at the supplementary rate of 32 kg N ha^{-1} to equal an overall treatment of 80 kg N ha^{-1}; MBM and Patenkali™ at an application rate of 80 kg N ha^{-1} (25 kg ha^{-1} of water soluble N). Other nutrients were adjusted in the 2010 study so that their respective application rates were targeted at about P 50, K 190, Ca 120, Mg 43, and S 122 kg ha^{-1}.

Table 8. Rates of fertilizer applications (kg ha^{-1}) and mineral nutrients applied for the carrot in 2010 and 2011 trials

Year	Treatment	Date of app.	Fertilizer	Application rate kg ha^{-1}	N	P	K	Ca	Mg	S
2010	Conventional	19.5	PY1	600	48	30	114	-	15	69
			CaS	380	-	-	-	80	-	61
			Total		48	30	114	80	15	130
	Supplemented and split	19.5	PY1	600	48	30	114	-	15	69
			CaS	380	-	-	-	80	-	61
		21.7	NCa	206	32	-	-	39	-	-
			KS	190	-	-	76	-	-	-
			Total		80	30	190	119	15	130
	MBM	19.5	MBM	1000	80	50	10	120	-	-
			KSMg	720	-	-	180	-	43	122
			Total		80	50	190	120	43	122
2011	Conventional split in two	26.5	PY1	400	32	20	76	-	10	48
			KSMg	250	-	-	63	-	15	43
		19.7	NKS	330	30	0	92	-	-	46
			Total		62	20	231	-	25	137
	Conventional split in three	26.5	NP	60	7	14	0	-	-	-
			KSMg	250	-	-	63	-	15	43
		22.6	NKS	300	27	0	84	- -	42	
		19.7	NKS	300	27	0	84	- -	42	
			Total		61	14	231	- 15	127	
	MBM + KSMg	26.5	MBM	750	60	38	8	90 6	4	
			KSMg	450	-	-	113	- 27	77	
		19.7	KSMg	450	-	-	113	- 27	77	
			Total		60	38	234	90 60	158	

MBM = organic Aito Viljo™.
KSMg = mineral potassium and magnesium fertilizer Patentkali from K + S Kali GmBH.
PY1 = Perunan Y1™ (8-5-19).
NCa = Peltokalkkisalpietari™ (N 15.5%).
KS = Kaliumsulfaatti™ (K 40%).
CaS = Kalsiumravinne™ (Ca 21%, S 16%).
NP = Starttiravinne™ (12-23-0).
NKS = Puutarhan NK2™ (9-0-28).

The N-fertilization rate in the 2011 trial was set at 60 kg N ha^{-1} in all the treatments. This application rate was reduced from the 80 kg ha^{-1} rate used in 2010 because of the higher soil organic matter content in the field parcel used in the 2011 trial. The two conventional mineral treatments were divided into two or three separate applications, and the MBM-alone treatment was split into two applications (Table 8). In one conventional treatment the mineral organic fertilizers PY1 and KSMg were applied before sowing and NKS was applied post-sowing (during growth). In the other conventional treatment the mineral fertilizers NP and KSMg were applied before sowing and NKS was spread twice during the growth phase. MBM and also MBM combined with KSMg were applied before sowing and the KSMg alone was applied during the growth phase. The application rate of potassium was 230 kg ha^{-1}, because of the organic soil type.

Crop management

The sowing and harvesting dates of the carrot crops were 19 May and 7 October in 2010, and 26 May and 11 October in 2011. Herbicides and insecticides were applied evenly over the whole crop by the farmer. Those fertilizers that were applied at sowing were mulched by sowing machine. The fertilizers that were applied during the growing season the timing was determined by the crop developmental stage.

The storage characteristics of the carrots were evaluated for both trial years. In the first year, a 10 kg sample of carrots from each plot was put into a storage room from 5 October 2010 to 21 March 2011 (three samples, one sample for each fertilizer treatment, storage time of 167 days). In the second year, for each treatment two bags of 10 kg carrots were put into storage from 12 October 2011 until 20 April 2012 (in total six samples, two from each treatment, storage time 191 days).

Measurements and data analyses

Total root weight (kg ha^{-1}), total root yield (kg ha^{-1}), marketable root yield (kg ha^{-1}) and number of roots ha^{-1} were measured in the carrot fertilizer trials. Carrots that were not suitable for market included: small (diameter < 2 cm), cracked, diseased, with scab, and pest injured. The mean marketable root weight (g) was calculated as:

Mean marketable root weight (g) = marketable root yield (kg ha $^{-1}$) / marketable root number (1000 ha-^{1})

Root nitrate analyses were made from two samples of marketable carrots from every treatment by Viljavuuspalvelu Ltd (ISO registered), in both years. The soil tests were made by Viljavuuspalvelu Ltd (Appendix 1) and accredited according to ISO/IEC 17025 by FINAS (Finnish Accreditation Service). Analysis of variance (ANOVA) was performed using SPSS® version 20 software GLM univariate procedure. Tukey´s test was used to compare means at a 5% risk.

Results

Sugar beet

Root and sugar yields

The mean root yield of sugar beet in 2008 was 52 t ha^{-1}, which is a fair yield under Finnish growing conditions. The mineral fertilizer HY2 gave a 54 t ha^{-1} yield, which was a significantly (p=0.05) higher yield than the 48 t ha^{-1} yield obtained for MBM (Fig. 1). This was the only significant treatment effect on root yield. MBM mixed with mineral fertilizer gave a similar yield as MBM alone (NS). In 2009 the mean root yield was 48 t ha^{-1}. Again, mineral fertilization gave significantly (p<0,001) higher yields, about 10 t ha^{-1} higher than MBM alone.

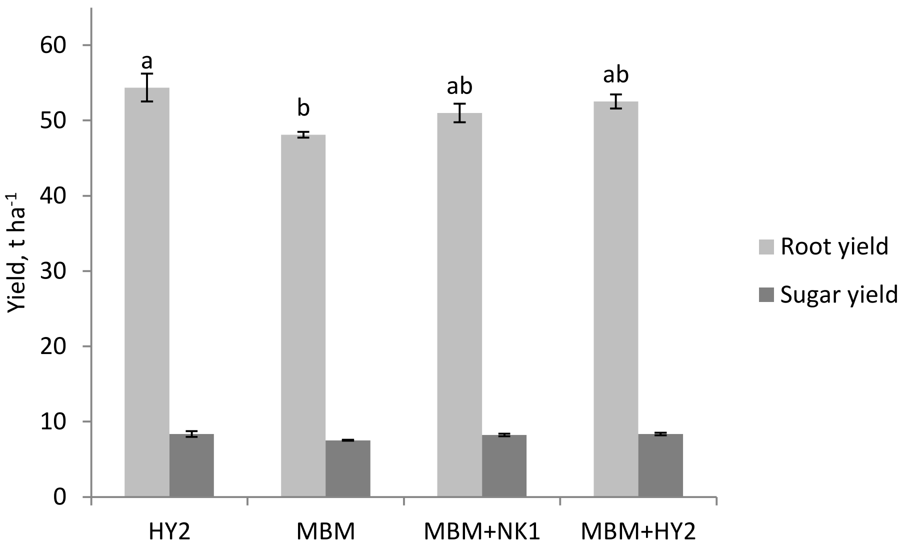

Fig. 1. Root yield and sugar yield of sugar beet by different fertilizations in 2008. (Error bars: ± standard error. Different lowercase letters above columns indicate significant (p=0,05) differences between the means.)

Also yields from the treatments with MBM mixed with mineral fertilizers were significantly lower than with mineral fertilizers alone (Fig. 2). In 2008 there were no significant differences in sugar yield between the treatments. The mean yield was 8.1 t of sugar ha^{-1} (Fig. 1). In 2009 the two mineral fertilizers gave significantly (p<0.01) higher sugar yield, 10.5 t ha^{-1} in 2009, than for MBM alone or MBM mixed with mineral fertilizers, 8.5 t ha^{-1} (Fig. 2).

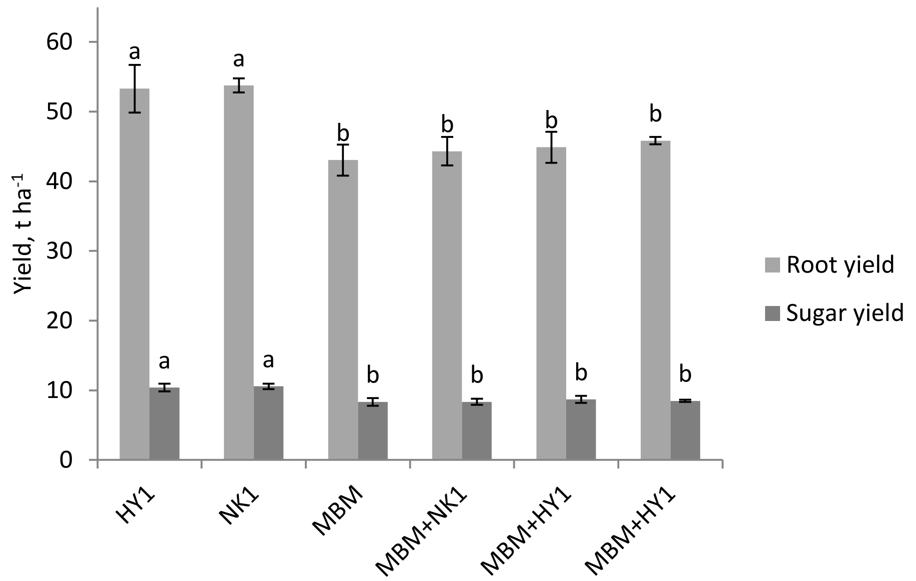

Fig. 2. Root yield and sugar yield in sugar beet by different fertilizations in 2009. (Error bars: ± standard error. Different lowercase letters above columns indicate significant (*p*=0,05) differences between the means.)

The overall mean extractable sugar percentage was 76.0% in 2008. Mineral fertilization gave significantly (*p*=0.04) lower extractable sugar percentage (73.0%) than MBM alone (77.8%) and MBM mixed with mineral fertilizers (Table 9). The mean extractable sugar percentage was 88.8% in 2009 and no significant treatment effects were found (*p*=0.292; Table 9).

Table 9. Sugar content, extractability, amino-N, K and Na concentrations in sugar beet in 2008 and 2009

2008						2009					
Treatment	Sugar	Extr.	amino-N	K	Na	Treatment	Sugar	Extr.	Amino-N	K	Na
	%	%	mg $100g^{-1}$				%	%	mg $100g^{-1}$		
HY2	15.4 a	73.0 a	18.5 b	7.69 b	1.99 b	HY1	19.6	89.8	6.75	3.54	0.14
n.a.	-	-	-	-	-	NK1	19.6	88.6	8.75	4.15	0.17
MBM	15.6 ab	77.8b	13.0 a	6.36 a	1.44 a	MBM	19.3	89.4	5.87	3.70	0.12
MBM+NK1	16.2 b	76.7b	15.8 ab	7.31 b	1.30 a	MBM+NK1	18.8	88.5	6.63	3.96	0.20
MBM+HY2	15.9 ab	76.5b	16.0 ab	7.32 b	1.22 a	MBM+HY1	19.3	89.3	6.63	3.71	0.16
n.a.	-	-	-	-	-	MBM+HY1	18.5	87.5	8.25	4.30	0.21

Statistically significant differences between the fertilizer treatments for *p*<0.05 are denoted by letters a, b.
In 2009, there were no significant differences.

Amino-N, K and Na concentrations

Overall, amino-N, K and Na contents in the roots of sugar beet were higher in 2008 than in 2009. Amino-N (Table 9) in root fertilized with MBM alone was 13 mg $100g^{-1}$ in 2008, which was significantly lower than obtained with mineral fertilizer HY2 (18.5 mg $100g^{-1}$). No significant differences were found in amino-N treated with MBM alone or MBM mixed with mineral fertilizers. The α-amino-N values in sugar beets significantly increased by elevating the levels of nitrogen fertilizer application. The K content was significantly lower in root fertilized by MBM-alone (6.36 mg $100g^{-1}$) than in root fertilized by mineral fertilizers or combinations of MBM with mineral fertilizers (mean 7.44 mg $100g^{-1}$). The Na content in sugar beet treated by HY2 (1.99 mg $100g^{-1}$) was significantly higher than sugar beet fertilized by MBM alone or MBM mixed with the mineral fertilizers (mean 1.32 mg $100g^{-1}$). No significant differences in amino-N, K and Na between the five treatments were found in 2009 (Table 9).

Carrot

Total and marketable root yield

In 2010 the mean total root yield 92 t ha^{-1} of carrot was very high compared to the mean for Finland (42 t ha^{-1}) for the same year (Yearbook of Farm Statistics 2011). In 2011 the mean yield was 67.6 t ha^{-1}. In both years, MBM (supplemented with KSMg) gave significantly lower total root yield than the mineral fertilizations.

The mean for the mineral fertilizers was 96 t ha^{-1}, 14 t more than for MBM (p=0.022) in 2010 (Fig. 3), and 68 t ha^{-1}, 8 t more than for MBM (p=0.002) in 2011 (Fig. 4). Additional mineral N fertilization during growth in both years did not increase root yield of carrot. The relative MBM-N_{tot} effect to mineral N was 2010 85% and 2011 88%.

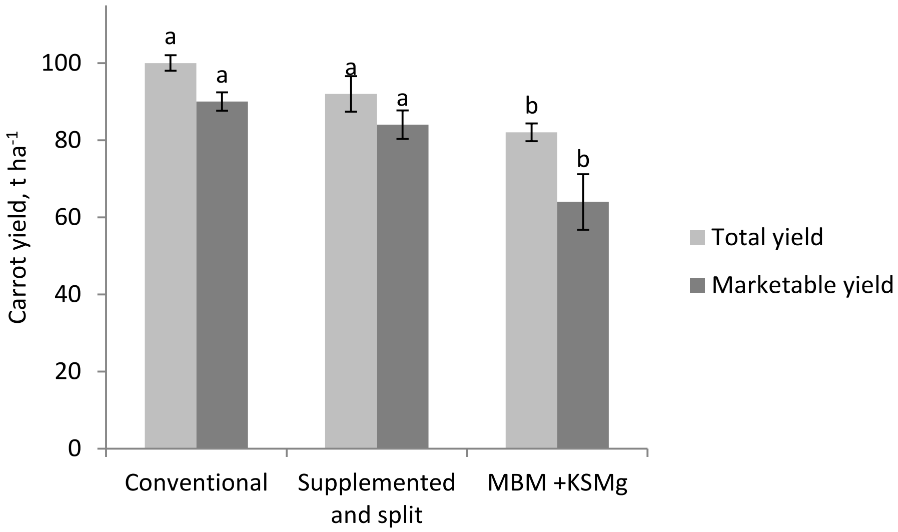

Fig. 3. Total root yield and marketable root yield of carrot by different fertilizations in 2010. (Error bars: ± standard error. Different lowercase letters above columns indicate significant (p=0,05) differences between the means.

The marketable root yield of carrot in 2010 had a similar pattern to that of the total root yield for the respective treatments: the MBM alone treatment gave a significantly (p=0.013) (27%) lower marketable yield (64 t ha^{-1}) than the two mineral fertilizer treatments (mean 88 t ha^{-1}) (Fig.3). The MBM-alone treatment also produced a lower marketable yield ratio (78%) than the two mineral fertilizer treatments (90%) (Table 10). One reason for this was that in 2010 carrots grown on the MBM-alone and combined fertilization treatments had a lot of scab in one plot, which made them unappealing for the market. However, since the carrot was for food processing purposes, the scab did not affect the use or the acceptability of carrot after peeling. Another important quality factor is size of individual carrot. Small sizes (diameter<2cm and weight<50 g) are considered to downgrade the quality. In year 2010 MBM fertilization tended to give more small carrots (2.2 t ha^{-1}) than the inorganic fertilizations (0.8 t ha^{-1} by conventional, 6 t ha^{-1} and supplemented and split fertilization).

Table 10. Percentage of marketable root yield (t ha^{-1}), number of marketable roots (Mkt. no.) and mean marketable root weight of carrot in 2010 and 2011

Treatment	2010			Treatment	2011		
	Mkt. %	No. mkt.	Weight g		Mkt. %	No. mkt.	Weight g
Conventional	92	569	158	Conventional split in two applications	92	462	145
Supplemented and split	89	497	172	Conventional divided in three applications	93	432	152
MBM	78	417	155	MBM+split KSMg	92	366	150

The conventional divided application treatments in 2011 did not differ in terms of marketable root yield (66 t ha^{-1}) (Fig.4). As in the 2010 trial, in 2011 MBM gave significantly (p=0.029) (17%) lower marketable yield (55 t ha^{-1}) than the conventional fertilizers (Fig. 4).The percentage of marketable root yield was the same for all treatments (ca. 92%) (Table 10). MBM alone produced least (1.2) small sized carrots (diameter<2cm and weight<50g) followed by conventional fertilization split in two applications (2.1) and conventional divided into three applications (3.2 t ha^{-1}).

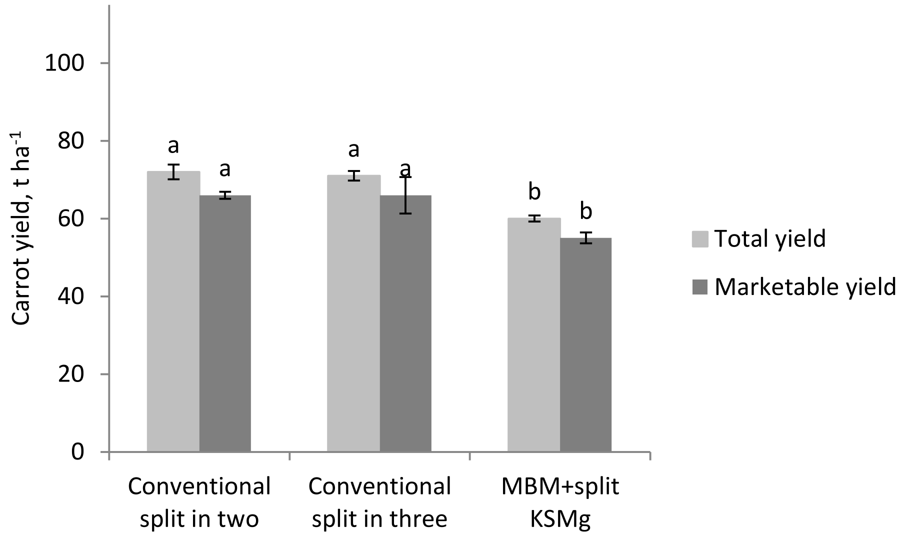

Fig. 4. Total root yield and marketable root yield of carrot by different fertilizations in 2011. (Error bars:± standard error. Different lowercase letters above columns indicate significant (*p*=0,05) differences between the means.)

Mean marketable root weight

The mean marketable root weight of carrot in 2010 was 162 g, which tended to be higher than that obtained in 2011 (149 g). The basic fertilization in 2010 tended to result in higher mean root weights than basic + additional, and MBM alone treatments. The mean root weight in 2011 was about the same for every fertilizer treatment (Table 10).

Nutrient content

The data did not allow for statistical testing of the nutrient concentrations in carrot. The analysis of the samples suggested the lowest NO_3^- content for MBM treatment, 55 and 93 mg kg^{-1} in 2010 and 2011 (Fig. 5), respectively. This was half or less than half of the nitrate contents in the conventionally fertilized treatments. In 2010, the mineral split fertilization at 80 kg N ha^{-1} resulted in as high as 390 mg NO_3^- kg^{-1}. In 2011, the mineral split fertilization at 60 kg N ha^{-1} resulted in content of 210 mg NO_3^- kg^{-1}, while in the unfertilized control the content was 29 mg NO_3^- kg^{-1}.

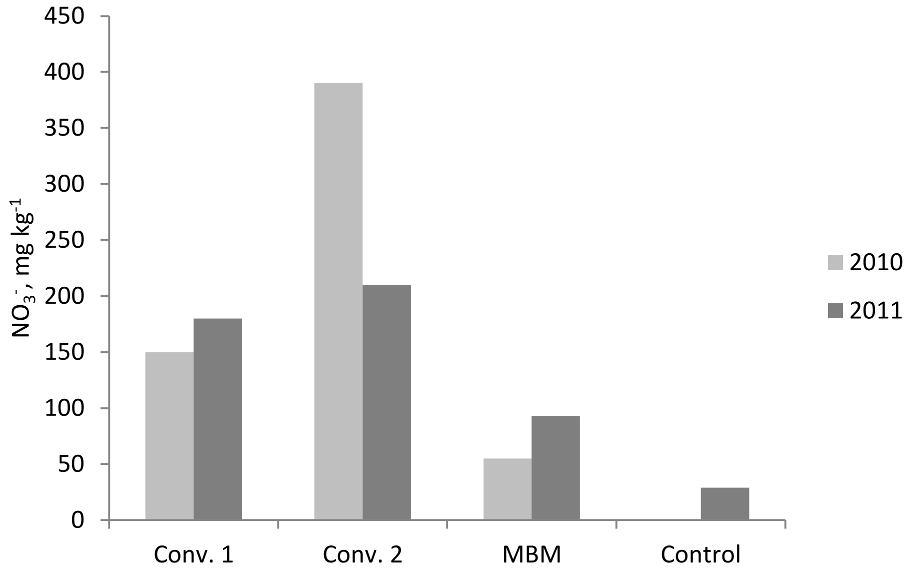

Fig. 5. Nitrate content in carrot fertilized by conventional mineral (Conv.) or by MBM fertilizers. For details of the fertilizers see Table 8. Unfertilized control was included in the 2011 trial only.

The nitrogen (N), calcium (Ca) and copper (Cu) contents appeared to be at lowest for the MBM fertilized carrots (Table 11).

Table 11. Nutrient contents of carrots harvested in 2010 and 2011

Year	Treatment	DM	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn
		%	g kg^{-1}						mg kg^{-1}				
2010	Conventional	11.9	8.3	2.3	22	2.4	1.2	1.6	37	21	<5	8.4	24
	Supplemented and split	11.8	8.7	2.1	21	2.2	1.1	1.4	32	18	<5	7.7	20
	MBM	12.0	6.7	2.0	21	1.9	0.85	1.4	27	18	<5	7.5	23
2011	Conventional split in two	10.2	9.3	2.2	30	2.0	1.1	17	10.2	9.3	210	2.2	30
	Conventional split in three	10.5	9.7	1.9	29	2.1	1.1	19	10.5	9.7	180	1.9	29
	MBM+split KSMg	10.2	7.8	1.9	29	1.6	1.0	17	10.2	7.8	93	1.9	29

Storability

The data of carrot storability did not allow for statistical comparisons. However, MBM alone fertilization treatment appeared to give relatively good results in storability comparisons in both years, in 2010 and 2011 (73% and 98%, respectively) (Table 12). The conventional fertilization 2010 had the lowest storability (36%). The primary agent for storage losses in both years was mildew (*Sclerotinia sclerotiorum*).

Table 12. Post-harvest loss of weight (Wgt loss) of carrots during storage from 5 Oct 2010 to 21 March 2011 (2010 field trial harvest) and from 12 Oct 2011 to 20 April 2012 (2011 field trial harvest), and marketable share (Mkt) of the quantity after the storage

Treatment	2010 harvest		Treatment	2011 harvest	
	Wgt loss, %	Mkt, %		Wgt loss, %	Mkt, %
Conventional	11.6	36	Conventional split in two	1.4	91
Supplemented and split	7.8	80	Conventional split in three	2.0	82
MBM	11.2	73	MBM+split KSMg	0.9	98

Discussion

Sugar beet

The national mean yields of sugar beet were 35 and 38 t ha^{-1} in 2008 and 2009, respectively. All fertilization treatments of both years gave better yields than the national average. The high yields obtained in the trial were partly due to the good nutrient condition of the soil of the study sites and to the optimum fertilization. The MBM-alone treatment gave significantly lower yields of sugar beet in both years than those obtained from the corresponding mineral fertilizer treatments. The initially high P content (≥25 mg l^{-1} acidic ammonium acetate soluble) of the soil at the study site precluded any advantage from using the MBM fertilizer, which contains much P. Draycott and Durrant (1976) suggested that to obtain an economic optimum, no P fertilization is needed when the $NaHCO_3$ soluble P content in the soil is higher than 25 mg l^{-1}. In the 2008 trial site, the P status prior to sowing was relatively high and all fertilizers contained enough phosphorus for normal growing. Therefore, MBM functioned only as an N fertilizer in the trial. In the 2009 trial site, the acidic ammonium acetate extractable P in soil before planting was only 10.9 mg l^{-1}; but even under these soil conditions there was no response in root yield to the addition of P.

The mineral fertilizer HY2 gave the highest root yield in 2008, but the lowest sugar content. This could be explained by the response of sugar beet to N fertilization, thus with increased N fertilization the yield of sugar beet increased and subsequently levelled out. Sugar content has been reported to first decrease slowly then rapidly as more and more N is applied (Cariolle and Duval 2006). N application via the HY2 fertilizer treatment seemed to exceed the optimal for sugar content.

Another reason for the relatively weaker fertilization effect of MBM in 2009 than in 2008 was due to the weather. During the beginning of growth in June 2009, the temperature was notably low, which can be assumed to have a substantial effect on the release of soil nutrients from an organic fertilizer such as MBM. When MBM was mixed with mineral fertilizers, it gave similar yields as MBM-alone for both study years. This can be understood through the dominance of N fertilization effects in the results. In all treatments that had MBM-alone or in combination most of the N (75%-90%) was provided by the MBM component. This suggests that even though the N in MBM is less soluble than that of the mineral fertilizers, it was more effective than its water soluble nitrogen content value indicates.

The result of similar fertilization effects of MBM-alone and of MBM + mineral N fertilizer is in accordance with experiments by Jeng et al. (2004), who found that applying similar N level, MBM-alone and MBM (50% N) combined with mineral N (50%) gave same cereal grain yield in a field trial.

The mean sugar content was 15.8% in 2008, whereas in 2009, the mean sugar content was 19.2%. Differences in (over all treatments) sugar content between the two years could be explained by differences in variety, soil and year-to-year weather conditions. September was very warm and dry, and this weather combination was conducive to increasing the sugar content of the beet.

Large concentrations of sugar and small concentrations of amino-N, K and Na relative to sugar are characteristics of high quality sugar beet (Milford 2006). Many factors can affect these concentrations, including the variety of sugar beet (Jensen and Burba 2001), weather conditions, fertilization, and harvesting time. Drought and high temperatures during growth have adverse effects on root quality, and raise levels of individual amino acids, other N compounds and invert sugar (Oldfield et al. 1979). The difference in sugar content between the two years could be explained by the following factors: the variety used (Jesper in 2008 and Lincoln in 2009); soil (clay loam 2008, sandy clay 2009), and weather conditions i.e. the exceptional weather conditions in 2009. Sugar concentrations of the roots were inversely related to the concentrations of Na, NO_3^-, and amino-N in the roots (Eck et al. 1990).

Carrot

The farmer usually adjusts his fertilization levels to optimize the goals of big leaf area in canopy development, with acceptable nitrogen levels in the harvested roots. More than half of the root yield in Finland is generated after the middle of August, when temperatures decline and the days become shorter (Suojala 2000 a).

Compared to the mean marketable carrot yield in Finland (42 t ha^{-1}; Yearbook of Farm Statistics 2011), both the mineral and the organic MBM-based fertilizations gave relatively high yields. Salo et al. (1999) found that the average total N, P, K application rates in carrot farming in Finland were 80, 35 and 131 kg ha^{-1}, which gave a mean yield of 49 t ha^{-1} in their data. Although the fertilization rates we used were about the same the yields of carrots were much higher in our experiment. The relatively high yields in the farm we worked with may best be explained by good soil conditions, and by good weather condition in the seasons in which the trials were conducted.

Storability (together with size, shape, uniformity, carbohydrates, carotene content, colour, and sensory quality) is a major criterion of high quality carrots. Storability is affected by timing of the harvest and by weather conditions before and during the harvest (Suojala 2000 b). The mean storage loss of carrot in Finland is estimated to be 30% (Lehtimäki 1995). The MBM-alone treatment tended to give better results for storability compared to mineral fertilization treatments; further testing is needed to confirm the possible benefit of MBM fertilizer on the storability of carrots.

The EC 1881/2006 regulation stipulates that maximum acceptable NO_3^- content is 200 mg kg^{-1} for baby food; hence lower levels are desirable (EC 2006b). The NO_3^- content of the carrots grown on MBM fertilizer alone was well under this limit. Again, the benefit from the use of MBM to lowering nitrate risk in addition to the other indications of changes in concentrations of elements, warrant further study for confirmation, and for elucidating the mechanisms involved. According to Pietola and Salo (2000) soil type, amounts of nutrients in the soil such as N, P and K, weather conditions and growing stage had bigger influences on the nutrient contents of carrots than either soil compaction or irrigation.

N and P considerations

Available nitrogen in the soil appeared to be a factor that limited growth in our study. Mean N-efficiency of MBM in relation to mineral fertilizers ranged from 80% (for carrots) to 88% (for sugar beet). This suggests that nitrogen availability is one of the challenges in developing MBM-based fertilizers.

Our post-harvest soil analysis data gave no indication that the high P application rates of the MBM fertilizer resulted in elevated soluble-P concentrations in the soil. Uusitalo et al. (2007) found that annual phosphorus fertilization is unlikely to give measurable yield responses for the majority of Finnish agricultural soils due to high soil test P concentrations, especially in non-cereal plant production and animal production areas. Therefore, MBM use as a fertilizer should be targeted more on those soils with a low P status or as a supplementary fertilizer in crop rotations. Soils low in P would be expected to benefit from being fertilized with MBM high in P and the use of MBM would meet environmental requirements.

Conclusions

We conclude that MBM is a beneficial fertilizer for sugar beet and for carrot, and can substitute for mineral fertilizers. Supplementation of MBM by inorganic nutrients, such as nitrogen or potassium is a possible treatment that warrants further study. MBM application can increase sugar content of sugar beet, and also reduce its nitrate content. Application of MBM can also improve the storage characteristics of carrots. Such improvements in quality compensate for somewhat lower yields for MBM, compared to conventional mineral fertilizers. Even though the P of MBM is less soluble than that of its inorganic counterparts, MBM is a good option for fertilizing soils of low P status.

Acknowledgements

The paper is an outcome of projects “Viljo-lannoitteen käyttö sokerijuurikkaalle” (supported by Honkajoki Oy) and “VIPU” (Uutta vipuvoimaa kasvi- ja puutarhatuotantoon Etelä-Pohjanmaalla, supported by Centre for Economic Development, Transport and the Environment, Oiva Kuusisto Säätiö and Honkajoki Oy). The Kone Foundation provided funds for the project “Recycling rate of nutrients in Finnish agrifood system” for PhD student Lin Chen.

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Appendix 1.

Description of the soil analysis methods. This documentation is produced by the laboratory EUROFINNS Viljavuuspalvelu Oy.

METHODS AND UNCERTAINTIES

Analysis	Method	Reliability in 95% confidence
Soil type (topsoil) a)	MMPIMAAL.DOC. Determination is based on sense perception. AALTONEN, V.T. & VUORINEN, J. 1949. Maaperäsanaston ja maalajien luokituksen tarkistus v. 1949. Maatal.tiet.aikak. 21:37-66.JUUSELA, T. & WÄRE, M. 1956. Suomen peltojen kuivatustila. Soil and Hydrotechn. Res. 8. 89 p. Helsinki.	
Organic matter content a)	MMPIMAAL.DOC. Determination is based on sense perception.	
Electrical Conductivity 10xmS cm^{-1}	Electrical conductivity is measured from soil-water suspension.	
Acidity (topsoil) pH	The pH is measured from soil-water suspension.	
Nitrogen (N), total %	Kjeldahl-method or Dumas-method	
Calcium (Ca) mg l^{-1}a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate, and analyzed with ICP-plasma.VUORINEN, J. & MÄKITIE O. 1955. The method of soil testing in use in Finland. Agrogeol. Publ. 63:1-44.Methods of soil and plant analysis, 1986 Jokioinen.	15 %
Phosphorus (P) mg l^{-1} a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate, and analyzed as a coloured product with spectrofotometer. VUORINEN, J. & MÄKITIE O. 1955. The method of soil testing in use in Finland. Agrogeol. Publ. 63:1-44.Methods of soil and plant analysis, 1986 Jokioinen.	20 %
Potassium (K) mg l^{-1} a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate, and analyzed with ICP-plasma.VUORINEN, J. & MÄKITIE O. 1955. The method of soil testing in use in Finland. Agrogeol. Publ. 63:1-44.Methods of soil and plant analysis, 1986 Jokioinen.	15 %
Magnesium (Mg) mg l^{-1} a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate, and analyzed with ICP-plasma.VUORINEN, J. & MÄKITIE O. 1955. The method of soil testing in use in Finland. Agrogeol. Publ. 63:1-44.Methods of soil and plant analysis, 1986 Jokioinen.	15 %
Sulphur (S) mg l^{-1} a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate, and analyzed with ICP-plasma. VUORINEN, J. & MÄKITIE O. 1955. The method of soil testing in use in Finland. Agrogeol. Publ. 63:1-44.Methods of soil and plant analysis, 1986 Jokioinen.	9 < 15 %; < 9 50 %
Boron (B) mg l^{-1} a)	MMBOORI.DOC. The dried and minced sample is extracted with hot water, and analyzed with ICP-plasma.HATCHER, J.D. & WILCOX, L.V. 1950. Colorimetric method of boron determination. Anal. Chem. 22:567-569. Methods of soil and plant analysis, 1986 Jokioinen. Berger, K.C. & Trug, E. 1944. Boron tests and determination for soils and plants. Soil Sci. 57:25-36.	20 %
Copper (Cu) mg l^{-1} a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate-EDTA -solution, and analyzed with ICP-plasma.LAKANEN, E. & ERVIÖ, R. 1971. A comparison of eight extractants for the determination of plant available micronutrients in soils. Acta Agric. Fenn. 122:223-232.Methods of soil and plant analysis, 1986 Jokioinen.	25 %
Manganese (Mn) a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate-EDTA -solution, and analyzed with ICP-plasma. The result is recalculated as a function of pH.LAKANEN, E. & ERVIÖ, R. 1971. A comparison of eight extractants for the determination of plant available micronutrients in soils. Acta Agric. Fenn. 122:223-232.Methods of soil and plant analysis, 1986 Jokioinen.	25 %
Zinc (Zn) mg l^{-1} a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate-EDTA -solution, and analyzed with ICP-plasma. LAKANEN, E. & ERVIÖ, R. 1971. A comparison of eight extractants for the determination of plant available micronutrients in soils. Acta Agric. Fenn. 122:223-232.Methods of soil and plant analysis, 1986 Jokioinen.	25 %
Iron (Fe) mg l^{-1}	MMVT.DOC. The sample is extracted with acidic ammonium acetate-EDTA, and analyzed with ICP-plasma. LAKANEN, E. & ERVIÖ, R. 1971. A comparison of eight extractants for the determination of plant available micronutrients in soils. Acta Agric. Fenn. 122:223-232.Methods of soil and plant analysis, 1986 Jokioinen.	15 %
Sodium (Na) mg l^{-1} a)	MMVT.DOC. The sample is extracted with acidic ammonium acetate, and analyzed with ICP-plasma. VUORINEN, J. & MÄKITIE O. 1955. The method of soil testing in use in Finland. Agrogeol. Publ. 63:1-44.Methods of soil and plant analysis, 1986 Jokioinen.	35 %
Organic carbon (C) %	MMHUMUS.DOC. Sulphuric acid - dichromate -method. Titrimetric analyse.	

Analysis has been accreditated according to ISO/IEC 17025 by FINAS.