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The Long-Term Permanent Plot Experiments in Israel




I. The Bet Dagan Experiment 1960-1993

II. The Gilat Experiment 1961-1994

B. Bar-Yosef and U. Kafkafi

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Established and carried out by the
Agricultural Research Organization,
Institute of Soil, Water and Environmental Sciences,
Bet Dagan, Israel

Data compilation and evaluation by
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International Potash Institute (IPI), International Fertilizer Association (IFA),
Agricultural Research Organisation (ARO), and Agri-Ecology

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Dedication

In memory of our colleagues Dr. Amos Feigin, Dr. Yaakov Halevy, and MSc Bijan Sagiv of the Institute of Soil, Water and Environmental Sciences, The Agricultural Research Organization, Israel. Amos, Yaakov and Bijan were among the founders of the Bet Dagan and Gilat long-term permanent plot experiments, but unfortunately they all passed away before this project was completed. Their scientific work contributed to the field of soil chemistry and plant nutrition in Israel, and worldwide, and helped establish fertilization recommendations and management tools for all major field and vegetable crops in Israel.

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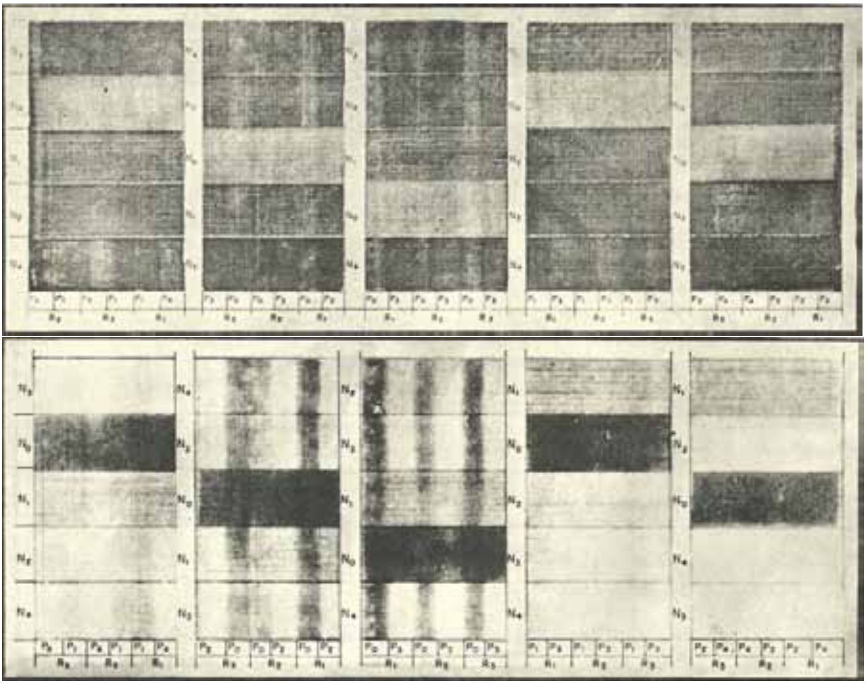

Aerial photographs of 2-month-old wheat crop in Bet Dagan permanent plots experiment (1971): Top - black and white film; bottom - infrared film.

About the authors

Bnayahu (Beni) Bar-Yosef

Beni Bar-Yosef was born in 1941 in Tel Aviv, Israel. He achieved a PhD from the Hebrew University of Jerusalem in 1972 for his thesis “Prediction of plant required soil phosphorus concentration by physico-chemical parameters”. Dr. Bar-Yosef worked as a research soil scientist (1972-2008) as then became head of the Department of Soil Chemistry and Plant Nutrition (1976-1985; 1991-1996) at the Agricultural Research Organization (ARO), Volcani Center Bet Dagan, Israel. In 1990, he was promoted to the highest level for research personnel in the Government Civil Service. On retiring from ARO in 2008, he co-founded AgriEcology - a soil-plant-environment consultancy firm based in the Sdot Negev academic center, Israel.

Dr. Bar-Yosef has published 104 reviewed articles, 45 research reports, and co-edited two books in the field of soil chemistry, ion transport in soil, plant nutrition, drip fertigation theory and practice and greenhouse crop production. In co-operation with the Hebrew University of Jerusalem, he supervised five PhD and five MSc students. He has also been a board member for the Israel Fertilizer Research Center (1980-1983), served as a member and chairman of the Israeli Panel for Evaluating Soil Science Research Proposals (1981-2004), and was involved in the National Steering Committees for Greenhouse Research and Development (1991-1992). Dr. Bar-Yosef also convened the International Greidinger Symposium on Fertigation, and the International Society of Horticultural Sciences Symposium on Models for Plant Growth and Control of the Shoot and Root Environments in Greenhouses. He was also on the organizing committee of seven international symposia focusing on crop growth and modeling under a controlled environment.

Uzi Kafkafi

Uzi Kafkafi was born in 1934 in Tel Aviv, Israel. He was awarded a PhD from The Hebrew University of Jerusalem in 1963 for his thesis “The effect of phosphorus fertilizer placement on the efficiency of phosphorus uptake by plants”. Between 1959 and 1986, he worked as a research soil scientist and head of the Agricultural Research Organization (ARO) Department of Soil Chemistry and Plant Nutrition, Volcani Center Bet Dagan, Israel, before becoming head of the Institute of Soils and Water in 1983. He established and was head of permanent fertilization plots between 1960 and 1976. Two years later, Dr. Kafkafi was promoted to the highest level for research personnel in the Government Civil Service and professor at The

Hebrew University of Jerusalem. In 1987, he was appointed head of the Center for Agricultural Research in Desert and Semi-Arid Lands at The Hebrew University of Jerusalem until his retirement in 1999.

Professor Kafkafi has published 105 reviewed articles and co-authored five books in the area of soil chemistry and plant nutrition and has supervised 12 PhD and 26 MSc students. In addition, he has served as chairman for the Israeli Society for Clay Research (1969-1971) and the Israel Society of Soil Science (1973-1976; 1988-1992), and as general manager for "The southern project" - an interdisciplinary research and development project for glasshouse tomato production for export in Israel (1977-1980). He was a board member for the Israel Fertilizer Research Center (1976-1986), was involved in the Scientific Committee of the International Potash Institute (1986-1998), and has participated in international cooperation missions for knowledge transfer, mainly in South America and Japan.

Executive Summary

Two long-term fertilization experiments (LTFE) were established in Israel in 1961 by the Volcani Institute of Agricultural Research to provide a scientific basis to support the transition from rain-fed to irrigation-fed agriculture that was occurring in many parts of the country. The objectives were to develop and test new fertilization regimes under controlled irrigation conditions in semi-arid and arid climates; to adopt new cash crops grown under irrigation and to study their short and long-term response to fertilizer and manure application rates; and to improve and calibrate soil tests for evaluating nutrients' availability to plants. The first LTFE was established in central Israel at Bet Dagan experimental station, representing semi-arid growth conditions (400-500 mm winter rain), deep alluvial soils, and mechanically-harvested field crops. The second LTFE was founded in southern Israel at the Gilat experimental station, representing arid growth conditions (200-300 mm winter rain), loessial soils, and small farm vegetable crops. The experiments continued until 1993 at Bet Dagan and 1994 at Gilat. The crops grown at Bet Dagan included cotton (grown 11 times), wheat (8), corn (2) and sugar beet (2); and, at Gilat, potato (3 times), Chinese cabbage (3), cucumber (3), onion (3), and carrot (2).

The results in both experiments are presented chronologically. For each year, all the obtained crop, soil and meteorological data are compiled according to treatments in uniform Excel files which are accessible to readers. In addition, a graph or table summarizing the crop response to the main treatments or resulting soil factors are included in the main text. Over the years all of the important crops grown in Israel were characterized with respect to their yield response to nitrogen (N) application rate in relation to phosphorus (P) and potassium (K) status in soil.

The evaluated long-term effects include fertilizer and manure application rate effects on soil fertility, fertilizer use efficiency, leaching of nitrate and chlorides to underground water, crop yield, and N uptake response to available P and K soil concentrations.

The main conclusions include:

(i) crop response to treatments did not change throughout the experiment;

(ii) no significant changes in soil chemical and physical properties occurred over time;

(iii) enhanced dry matter (DM) production due to fertilization reduced nitrate and chloride leaching depth, thus supporting the hypothesis that cumulative transpiration is directly proportional to cumulative DM production;

(iv) cumulative fruit yield and DM production in a treatment that received all the N from an organic source was somewhat lower than a treatment that received the same level of N as mineral-N (19.4 vs. 21.5 kg DM/m^2), but its potential N leaching (supply – uptake – added N in the root zone) was much smaller (65 vs. 542 g N/m^2);

(v) measured N uptake in the Gilat and Bet Dagan control treatment (no N addition) indicated that the long-term soil organic N mineralization rate in both soils is ~4 g N $m^{-2}y^{-1}$, and was quite stable over time;

(vi) long-term N uptake efficiency (N uptake/N supply) was 0.51 in a treatment that received all N as mineral-N (cumulative uptake 406 g N/m^2) and 0.45 in a corresponding treatment that received all N as organic-N (cumulative uptake 343 g N/m^2);

(vii) adding organic-N at 60 ton manure/ha, at the Gilat site, increased soil organic-N (0-120 cm) from 280 to 450 g N/m^2 by the end of the experiment, while in the control that did not receive N at all, soil organic-N only increased to 290 g N/m^2;

(viii) adding dairy manure at 190 t/ha (between 1963 and 1993), at the Bet Dagan site, increased the soil organic-C (SOC) content (0-20 cm) from 0.77% (no manure addition) to 0.86% (treatment N2P2K0). The initial (1963) SOC content was 0.64%. In treatment N0P0K0 the % SOC in 1993 was 0.70 without manure and 0.73% with manure;

(ix) response of all the crops to N, at the Bet Dagan site depended on P fertilizer application rate, but, in all cases, the maximum response to N occurred at the same N level;

(x) exceeding an annual mineral-N dose of 200 kg N/ha or superphosphate P dose of 40 kg P/ha usually caused a reduction in crop yield. At P doses <40 kg P/ha, the crop response to P was significant in all cases and directly proportional to the concentration of bicarbonate extractable P in soil;

(xi) potassium fertilization had a minor effect on crop yield in the Bet Dagan site due to release of illite fixed K in the site's clayey soil, induced by low K concentration in the soil solution stemming from high K demand by plants. A similar effect was found in the Gilat site (loess soil) where K uptake under recommended K fertilization and low manure application exceeded the K addition to soil. The exclusion of K fertilizer caused a decline in soil K values, especially at high N rates and with higher yields. The threshold soil $CaCl_2$ soluble K concentration, beyond which no yield increase was obtained, was 7 to 10 mg K/L, depending on the soil and crop.

Preface

Two long-term fertilization experiments (LTFE) were established in Israel in 1961 by the Volcani Institute of Agricultural Research to provide a scientific basis to support the transition from rain-fed to irrigation-fed agriculture that was occurring in many parts of the country. This process was facilitated by the completion of the National Water Carrier project, which delivers fresh water from the Lake of Galilee in northern Israel to the southern, arid region of Israel (Negev). The aim of the two LTFEs was to address three agro-technical challenges posed by this transition to irrigated agriculture. The first challenge was to develop and test new fertilization regimes for controlled irrigation conditions, especially in the unfamiliar (at that time) loessial soils of the Negev. The second challenge was to adopt new cash crops grown under irrigation, and to study their short and long-term response to fertilizer and manure application rates. The third challenge was to improve and calibrate soil tests for evaluating nutrient availability to plants, fertilizer use efficiency, and leaching of nitrates and chlorides (salts) to underground water.

The first LTFE was established in central Israel at Bet Dagan experimental station, which represented semi-arid conditions (400-500 mm winter rain), deep alluvial soils, and mechanically-harvested field crops. The second LTFE was founded in the Negev at Gilat experimental station, representing arid conditions (200-300 mm winter rain), loessial soils, and small farm vegetable crops. The long-term Bet Dagan and Gilat experiments are presented and analyzed in Parts I and II of this book, respectively.

The timing for publishing this report (two decades after terminating the field work) was affected by two factors. The first is the growing interest in long-term fertilizer and manure effects on soil fertility and sub-soil contamination, particularly under Mediterranean growth conditions, where information is scarce. The second is that time was needed to digest the wealth of information on crop response to nitrogen (N), phosphorus (P) and potassium (K) fertilizer and manure application rates, and nutrient status in the soil. Time was also required for complementary field and laboratory work to be carried out on current and old soil samples, running soil-crop-atmosphere models to elucidate experimental results, and compiling and putting together the text and data included in this publication.

Care has been taken to allow interested readers use of the original results for all individual field plots, thus enabling them to recalculate and re-evaluate the presented results, add new calculations and regressions, and to use the data to test and calibrate soil-crop-atmosphere models.

List of Abbreviations

ANOVA	Analysis of variance
AS	Ammonium sulfate
BD	Bet Dagan
BDPP	Bet Dagan permanent plots
Ca	Calcium ion
CCa	Calcium ion concentration in solution
CEC	Cation exchange capacity
CMg	Magnesium ion concentration in solution
CNa	Sodium ion concentration in solution
DM	Dry matter
EC	Electrical conductivity
Ece	Electrical conductivity of soil saturated extract
Evp	Potential evapotranspiration
F	Fruits
GL	Gilat
GLPP	Gilat long-term permanent plots
IA	Ion addition to soil
IL	Ion leaching depth
IS	Ion accumulated in soil
IU	Ion uptake by plants
K	Potassium
Kfc	Soil hydraulic conductivity at field capacity
KN	Ammonium nitrification rate constant
KR	Potassium, manure
L	Leaching depth
L	Leaves
LTFE	Long-term fertilization experiments
LTPPE	Long-term permanent plot experiments
M	Manure
M0,M,M2	Cattle manure application treatments
MON	Manure organic N

MS	Mean square
N	Nitrogen
Na	Sodium
NAD	N added to soil
$NaHCO_3$	Sodium bicarbonate
NK	Nitrogen, potassium
NO_3-N	Nitrate nitrogen
NPK	Nitrogen, phosphorus, potassium
NUP	N uptake by plant
ºC	Celsius degrees
P	Phosphate
PCO2	Partial pressure of CO2
PKR	Phosphorus, potassium, manure
PR	Phosphorus, manure
R	Organic manure
SAR	Sodium adsorption ratio
SE	Standard error
SOC	Soil organic carbon
SOM	Soil organic matter
SON	Soil organic nitrogen
SON	Soil indigenous organic N
SS	Sum of squares
T	Transpiration
WMAV	Weighted median aggregate diameter
Ɵfc	Soil moisture content at field capacity

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Part I: The Bet Dagan (BD) Permanent Plot Experiment

1 Introduction

1.1 The original objectives of the long-term fertilization experiment (see The Permanent Plot team, 1968)

a) To measure yields of various field crops rotation system on irrigated deep alluvial soil as affected by long-term cumulative application of various combinations of nitrogen (N), phosphate (P), potassium (K) fertilizers, and organic manure.

b) To investigate the effect of cumulative fertilizer application on the pattern of available nutrients in the soil, their accumulation or depletion.

c) To create a wide spectrum of plots with known fertilization history that will serve for calibrating soil tests.

1.2 Design

The following four factors were investigated:

a) Five levels of nitrogen fertilizer, labeled: N0, N1, N2, N3, N4 (in the Excel files- see later- they are called N1, N2, N3, N4, N5 because 0 cannot be used as an index).

b) Five levels of phosphorus fertilizer labeled: P0, P1, P2, P3, P4 (in the Excel files P1, P2, P3, P4, P5).

c) Three levels of potash fertilizer labeled K0, K1, K2 (in the Excel files K1, K2, K3).

d) Three "Organic manure treatments" labeled R1 (no organic manure), R2 (farmyard, or dairy manure), R3 (green manure, usually pea).(The same in the Excel files).

Each treatment was replicated twice. Altogether there were 5 x 5 x 3 x 3 x 2 (=450) field plots, each one measuring 27 x 4 m.

The N, P, K and manure application rates are described for each crop and treatment in the annual Excel reports (see later). The experimental layout (Fig. 1) was designed to allow mechanical fertilization, cultivations and harvesting. Mechanization caused several constraints:

a) The P and K treatments had to be applied to strips at least 70 m long, with at least 15 m intervals between successive strips along the line.

b) The R (organic manure) treatments had to be applied to long strips as above, with each strip being at least two plots across.

c) The maximum convenient contiguous field (block) length was 140 m.

Plot numbers. The first digit in each number is the block number (5 blocks, 90 plots in each block).

Block 1	**R2**						**R3**						**R1**					
	P4			**P1**			**P4**			**P1**			**P1**			**P4**		
	K0	**K1**	**K2**	**K2**	**K0**	**K1**	**K2**	**K1**	**K0**	**K2**	**K0**	**K1**	**K1**	**K0**	**K2**	**K0**	**K2**	**K1**
N3	101	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176	181	186
N0	102	107	112	117	122	127	132	137	142	147	152	157	162	167	172	177	182	187
N1	103	108	113	118	123	128	133	138	143	148	153	158	163	168	173	178	183	188
N2	104	109	114	119	124	129	134	139	144	149	154	159	164	169	174	179	184	189
N4	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190
Block 2	**R3**						**R2**						**R1**					
	P2			**P0**			**P0**			**P2**			**P0**			**P2**		
	K0	**K2**	**K1**	**K1**	**K2**	**K0**	**K0**	**K1**	**K2**	**K1**	**K0**	**K2**	**K2**	**K1**	**K0**	**K0**	**K1**	**K2**
N4	201	206	211	216	221	226	231	236	241	246	251	256	261	266	271	276	281	286
N2	202	207	212	217	222	227	232	237	242	247	252	257	262	267	272	277	282	287
N0	203	208	213	218	223	228	233	238	243	248	253	258	263	268	273	278	283	288
N1	204	209	214	219	224	229	234	239	244	249	254	259	264	269	274	279	284	289
N3	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290
Block 3	**R1**						**R2**						**R3**					
	P0			**P3**			**P0**			**P3**			**P0**			**P3**		
	K0	**K1**	**K2**	**K2**	**K1**	**K0**	**K1**	**K2**	**K0**	**K2**	**K1**	**K0**	**K1**	**K2**	**K0**	**K0**	**K2**	**K1**
N2	301	306	311	316	321	326	331	336	341	346	351	356	361	366	371	376	381	386
N3	302	307	312	317	322	327	332	337	342	347	352	357	362	367	372	377	382	387
N1	303	308	313	318	323	328	333	338	343	348	353	358	363	368	373	378	383	388
N0	304	309	314	319	324	329	334	339	344	349	354	359	364	369	374	379	384	389
N4	305	310	315	320	325	330	335	340	345	350	355	360	365	370	375	380	385	390

Block 4	**R1**						**R2**						**R3**					
	P1			P3			P1			P3			P1			P3		
	K2	**K0**	**K1**	**K1**	**K2**	**K0**	**K0**	**K2**	**K1**	**K2**	**K0**	**K1**	**K0**	**K2**	**K1**	**K2**	**K0**	**K1**
N1	401	406	411	416	421	426	431	436	441	446	451	456	461	466	471	476	481	486
N0	402	407	412	417	422	427	432	437	442	447	452	457	462	467	472	477	482	487
N2	403	408	413	418	423	428	433	438	443	448	453	458	463	468	473	478	483	488
N3	404	409	414	419	424	429	434	439	444	449	454	459	464	469	474	479	484	489
N4	405	410	415	420	425	430	435	440	445	450	455	460	465	470	475	480	485	490
Block 5	**R3**						**R2**						**R1**					
	P2			P4			P4			P2			P2			P4		
	K0	**K2**	**K1**	**K2**	**K1**	**K0**	**K1**	**K0**	**K2**	**K0**	**K2**	**K1**	**K2**	**K1**	**K0**	**K0**	**K1**	**K2**
N1	501	506	511	516	521	526	531	536	541	546	551	556	561	566	571	576	581	586
N2	502	507	512	517	522	527	532	537	542	547	552	557	562	567	572	577	582	587
N0	503	508	513	518	523	528	533	538	543	548	553	558	563	568	573	578	583	588
N4	504	509	514	519	524	529	534	539	544	549	554	559	564	569	574	579	584	589
N3	505	510	515	520	525	530	535	540	545	550	555	560	565	570	575	580	585	590

Fig. 1. The field plots arrangement in the Bet Dagan experiment. Each cell in the Figure represents a single field plot (27 x 4 m). The numeric values are field plot numbers, the first digit denoting the block number. The scheme includes 5 blocks (72 x 135 m each), each consisting of 90 plots (altogether 225 treatments x 2 replicates). Treatment levels (N, P, K, R) are marked on top of each block. The blocks were separated in the field by 25 m wide west-east uncultivated strips, and R treatments were separated by 20 m wide north-south strips.

1.3 Planning assumptions

1. The effect of N is expected to be easily detected, so the statistical sensitivity to it is less important.
2. The P x R and K x R interactions and all other interactions involving more than two factors can be neglected.

Considering these assumptions and above constraints (later it became clear that neglecting the P x R interaction was a mistake), it was decided that the experimental area should entail five blocks (72 x 135 m each). The five N levels were randomized between five 72 x 72 m strips and the three R treatments were randomized between 72 x 72 m strips, and the three R treatments were randomized between three 24 x 135 m strips (running perpendicular to the N strips). In each R strip, the 2 P levels (allotted to that block) were randomized between two 12 x 135 m sub-strips. Thus the dimensions of a single plot were 4 x 27 m. All the randomization (within each block, strip and sub-strip) was performed independently of each other.

Table 1. The analysis of variance table (designed by Dr. J. Putter).

Row	Effect	Degrees of freedom
1	Blocks	4
2	Nitrogen	4
3	Blocks x nitrogen	16
4	Phosphorus within blocks	5
5	P X organic manure within blocks	10
6	Potassium	2
7	Phosphorus X potassium within blocks	10
8	Blocks X potassium	8
9	Potassium X organic manure within blocks and phosphorus levels	40
10	Organic manure	2
11	Blocks X organic manure	8
12	Nitrogen X phosphorus within blocks	20
13	Nitrogen X potassium	8
14	Nitrogen X organic manure	8
15	Residual	304
16	Total	449

The statistical analysis is based on the model described in formula [1].

Following conventional statistical terminology, the terms on the right hand side of the formula are divided into "fixed" effects due to treatments (and denoted by the letter symbols m, a, b, ….h), and "random" effects due to soil variability and other uncontrolled factors and denoted by the capital letter symbols A, B. ….,G).

$$[1]\ X_{bnrpk}=m+a_n+b_r+c_p+d_k+e_{nr}+ f_{np}+g_{nk}+h_{pk}+A_b+B_{bn}+C_{br}+D_{brp}+E_{brpk}+G_{bnrpk}$$

The symbol X_{bnrpk} stands for the result obtained in block b for the treatment combination $N_nR_rPpK_k$. The subscripts run over the values:

b=1, 2, 3, 4, 5; n=0, 1, 2, 3, 4; r=1, 2, 3; p=0, 1, 2, 3, 4; and k=0, 1, 2.

"m" is a "general mean", and the other effects are measured in terms of deviations from m; a, b, c, and d are the "main" (i.e. average) effects of the four factors (N, R, P and K); e, f, g, and h are the four interactions which are **not** assumed to be negligible. A is the block effect; B, C, D, and E are the: strip, sub-strip, and sub-sub strip effects; G is the residual individual–plot effect.

The above analysis of the variance table is divided into several sub-tables. In each sub-table, the last line is the "error" term, whose mean square (MS) provides the denominator for the F ratios. The F ratio for each effect is obtained by dividing the MS of that effect by the "error" MS of the corresponding sub-table. E.g. in the sub-table containing the rows 6-9, the ratio of the MS values in lines 6 and 9 is the F-value of the K effect, and the ration of the MS values in lines 7 and 9 is the F-value of the P x K interaction.

The block effect is in a sub-table without an error term, therefore its significance cannot be tested in this analysis of variance scheme, and it is omitted from the presented analysis of variance tables (see later). With regard to several of the data variables, measurements were taken from some of the plots only. In such cases, the analysis of variance table had to be modified accordingly.

The tabulation of the analysis of variance results is presented for each variable in the appropriate annual reports.

1.4 Data presentation in Excel files

The original annual hard copy reports data (1962-1993) that were arranged in tables as Fig. 1 were copied to Excel files. Each Excel file contains all the experimental results of a single cropping season (e.g. yield, % elements in leaves; N P K soil tests, etc.). Altogether, there are 38 such Excel files corresponding with the number of cropping seasons. The Excel file names begins with BDPP (standing for Bet Dagan Permanent Plots), followed by the year, e.g., BDPP1961.xlsx,

A	B	C	D	E	F	G
Ann. prec	Ann. Evap	Irrig mm	Prec. mm	Evap. a mm	cv =	Amirav
420	1550	394	390	950		
		Converted treatment presentation				
Year	Crop	Treatment				
1963	Sugarbeet	N	P	K	R	Rep
		1	1	1	1	1
		2	1	1	1	1
		3	1	1	1	1
		4	1	1	1	1
		5	1	1	1	1
		1	2	1	1	1
		2	2	1	1	1
		3	2	1	1	1
		4	2	1	1	1
		5	2	1	1	1
		1	3	1	1	1
		2	3	1	1	1

Fig. 2A. The Excel file format. Since the file is long and wide (450 rows, A-to-AJ columns) it was divided here into four parts (2A- columns A-G; 2B- H-K; 2C- M-T and 2D- U-AB). Parts 2B, 2C and 2D are shown below. The first two rows in 2A provide information about the crop: Ann. Prec and Ann. Evap are the annual (Jan to end of Dec) precipitation and Class a pan evaporation (420 and 1550 mm in this example); Irrig (mm), Prec. (mm) and Evap (mm) are irrigation, rainfall and Class a pan evaporation between seeding and harvest (e.g. 15/10/62 to 5/7/63); cv is the crop cultivar. Rows 4-5 describe the year and crop; the N P K R levels and the replicate number.

BDPP1962.xlsx, …BDPP1993.xlsx, and as e.g. BDPP1962a and BDPP1962b, when more than one crop was grown during that year. The data is presented in the new format (Fig. 2) but also saved in the original format (as Fig. 1 above). In the new format, the data per crop is stored in 450 rows, each corresponding to a specific field plot and identified by its N, P, K, R levels (indices) and plot number (columns A to G). The other columns provide results of test variables pertaining to the specific plot.

H	I	J	K
Seeding =	15/10/1962	Harvest =	5/7/1963
1st digit is	For copying	Yield	
block num	in	beet	
Plot #	Original units	kg/46 m^2	kg/ha
238	60	285	61,956.5
224	-	331	71,956.5
196	-	314	68,260.9
227	40	349	75,869.6
232	-	325	70,652.2
223	70	247	53,695.7
243	-	347	75,434.8
289	-	449	97,608.7
309	46	414	90,000.0
237	-	463	100,652.2
282	66	372	80,869.6
203	-	417	90,652.2

Fig. 2B. The first row shows the seeding and harvest dates of the crop. Column H is the plot number in the field. Column I is used to convert original to new format (to be ignored by readers). Columns J and K are yield in original and kg/ha units, respectively. Column L (not shown here) is the canopy weight in original units (continued in Fig. 2C).

M	N	O	P	Q	R	S	T
Fertilization kg element/ha		N 1	N2	N3	N4	N5	P1
or manure kg/ha		0	60	120	180	240	0
	Crop data					Nutrients in plant	
	% sugar	% sugar	Sugar yld	Single beet			
kg/ha	0.10%	%	0.1 kg/46 m^2	kg/ha	kg	% N grain	% N leaf
13,913	175	17.5	497	10,804.35	0.603		
17,391	171	17.1	566	12,304.35	0.8		
15,435	182	18.2	571	12,413.04	0.828		
21,522	180	18	628	13,652.17	0.808		
22,826	168	16.8	546	11,869.57	0.613		
12,391	175	17.5	430	9,347.826	0.537		
10,217	174	17.4	604	13,130.43	0.784		
35,000	187	18.7	840	18,260.87	0.98		
26,739	175	17.5	724	15,739.13	1.098		
43,696	171	17.1	792	17,217.39	1.092		
15,435	181	18.1	673	14,630.43	0.835		

Fig. 2C. In the top 2 rows, columns M-to-T define N (kg element/ha) application rates for each N treatment. Rows 3, 4, 5 define test variables: columns M-to-T are crop related variables (lack of values means no measurements).

1.5 The soil

The Bet Dagan (BD) soil is classified as Vertisol (Chromic Haploxerat/Typic Chromoxert) with the texture described in Table 2. An alternative classification is Grumusol soil.

The cation exchange capacity (CEC) is 410 mmol$_c$/kg with main exchangeable cations being Ca (300 mmol$_c$/kg), K (26 mmol$_c$/kg) and Na (13 mmol$_c$/kg). The bulk density of the soil is 1.25 kg/L; total porosity 0.53 v/v and field capacity 0.26 v/v (0.21 w/w). To estimate the soil organic matter content (%) the soil organic carbon (SOC) in Table 2 should be multiplied by a factor of 1.7. The soil mineralization factor = 1.5% per year which is equivalent to annual mineralization of ~3 g N m^{-2} Y^{-1} in the top 20 cm soil layer.

The soil mineral composition is quartz (40-55%), clay minerals + micas (25-35%), K-feldspar (10%) and calcite (10%) (Sandler *et al.*, 2009). The major clay mineral is illite-smectite (montmorillonite). The soil chemical composition (5 blocks

U	V	W	X	Y	Z	AA	AB
P2	P3	P4	P5	K1	K2	K3	R1
30	60	90	120	0	106	212	0
				Soil 0-20 cm		Soil sampling =	5/7/63
				Soil extract mg/kg			
% P grain	% P leaf	% K grain	% K leaf	NH4N	NO3N	Olsen P mg/kg	CaCl2 K ppm
						6	7.2
						4	5.6
						7	6.6
						4.6	5.4
						6.6	7

Fig. 2D. In the top 2 rows, columns U-to-AA define P and K (kg element/ha) application rates for each P, K treatment. Columns AB-to-AD (AB and AC not shown herein) are dairy or green manure application levels (kg/ha). Rows 3, 4, 5 define test variables: columns U-to-X are continuation of crop related variables and Y-AB are soil related variables. Additional columns (not presented herein) are additional crop data.

average) is 11% Al_2O_3, 63% SiO_2, 6% CaO and 1.1% K. All the mineralogical data were very similar (within the range of analytical error) in the 0-20 and 20-40 cm soil layers.

Table 2. Some soil characteristics of the 0-20 cm soil layer in BD soil.

Block	pH	EC	$CaCO_3$	Clay	Silt	Fine sand	Coarse sand	Texture	C	N
		dSm^{-1}	%						%	
1	7.8	0.73	10.6	48.5	40.9	9.7	0.7	silt clay	0.70	0.075
2	7.8	0.70	9.9	50.5	40.0	8.7	0.8	silt clay	0.77	0.078
3	7.8	0.67	11.7	47.7	41.0	10.6	0.7	silt clay	0.73	0.075
4	7.9	0.62	10.2	50.4	39.0	9.5	1.1	silt clay	0.67	0.084
5	7.8	0.59	8.1	45.8	38.9	13.9	1.4	silt clay	0.66	0.076

1.6 The manures

Dairy manure was applied at a rate of 30 m^3/ha in 1962/1963, and 40 m^3/ha in 1968, 1972, 1981 and 1993. In 1993, the manure was added as pellets to give the same organic matter quantity as in previous years. The manure composition (% of dry weight) was: 47-52% moisture (the range is the difference between years); 25-26% organic matter (by wet digest); 1.54-1.61% total N; 0.64% total P; 2.5% total K; C/N ratio (wet digest) 8.8-9.7:1.

Green manure (pea) was planted in 1964 and 1968 in the R2 plots and incorporated in the soil without harvesting.

1.7 Climate

The climate is characterized by the monthly average air temperatures (Appendix 1), rainfall (Appendix 2) and evaporation from class a pan (Appendix 3) along the experiment. The data was taken from the Israeli Meteorological Service, using a station located ~6 km from the experiment site. For several years, data was also measured on the site. Comparison between the two measurements revealed a deviation which was smaller than 10%.

1.8 Irrigation and fertilization

The irrigation was via sprinklers, applied every 14 days (which was the common practice in BD at the time the experiment took place). The time-averaged ionic composition of the irrigation water (g m^{-3}) was: NO_3-N – 2.4; Cl – 240; SO_4-S – 18; HCO_3 – 193; Na – 112; Ca – 48; K – 0.2 and Mg – 30. The charge balance was: cations 10.0 $mmol_c$/L, anions 10.7 $mmol_c$/L. Using the approximation [10 $mmol_c$/L] = [1.1 dS/m] (Sonneveld *et al.*, 1999), the estimated water EC was ~1.1 dS/m. The P (superphosphate) and K (KCl and in a few cases K_2SO_4) fertilizers were applied ~a month before seeding. Nitrogen fertilization (ammonium sulfate, $[NH_4)_2SO_4]$) was split: ~50% base application a short time before seeding and the rest added in two equal portions at critical growth stages.

1.9 Yield measurements

The yield of 20 m row length in two central crop rows was measured for fruit yield and total dry matter weight. In some selected crops, more parameters at shorter time intervals were determined.

The NPK content in plant tissue was determined in sulfuric acid wet digest. To determine nitrate-N, plants were dried at 60ºC, grinded, extracted with water, and analyzed by the phenoldisulfonic acid method (Bremner, 1965).

1.10 The sequence of crops

During the first 17 years, wheat, chickpea, sugar beet, foxtail millet, vetch, cotton, sorghum, oat and corn were studied (The Permanent Plot Team, 1968, 1971, 1980), reflecting the fact that the response of these crops to fertilizers was unknown by then in Israel. From 1978 onwards, the number of test crops declined and cotton and wheat were the main crops. More detailed information about wheat in the Bet Dagan experiment can be found in Halevy *et al*. (1992). In 1991 and 1993, two relatively unfamiliar crops in Israel were studied: canola and safflower (see also Sagiv *et al*., 1993). The list of the annual test crops, and plant and soil tests that were performed each year is presented in Table 3.

1.11 Opening the crop data files

The per-season data files (e.g. BDPP1983.xlsx) are not shown in the body of this book. To view these files the reader must use an internet connected computer or tablet. There are about 70 data files (in Excel) which are cited, and hyperlinked, in the text. Clicking/tapping on a link will download and open the file.

Table 3. List of crops and measured plant and soil parameters in the Bet Dagan Permanent Plots (BDPP) experiment 1961-1993 (in brackets: variable numbers).

Year	Crop	Excel File name	Seeding date	Harvest date	Variable (and number)		Comment
					Plant	Soil	
1961	Wheat	BDPP1961	Nov 60	June 61	Grain yld (1)	-	Not fertilized
1962	Chick-pea	BDPP1962	Dec 61	June 62	Grain yld (3), straw yld (4)	-	
1963	Sugar-beet	BDPP1963	Oct 62	Jul 63	Beet yld (5), %sugar (7), leaves wt (8), single beet wt (9)	P (11), K (12) at harvest	Manure added
1963	Foxtail millet	BDPP1963a	Aug 63	Sep 63	green yld (14)	-	
1964	Vetch + Oat	BDPP1964	Nov 63	Mar 64	Green yld (15)	NO_3 (17), P (18), K (19) at harvest	Green manure R3
1964	Cotton	BDPP1964a	Apr 64	Oct 64	Raw cotton (33), lint (35), single bole wt (36), leaf petiole NO_3 (21) and P (22)	Soil sampling at end of previous crop	Leaf nutrients determined on 8/6/64
1965	Sor-ghum	BDPP1965	Apr 65	Jul 65	Grain yld (45), head (panicle) num (46), single head wt (47)	NO_3 (155), P (38), K (39)	Soil sampled before seeding
1966	Wheat	BDPP1966	Nov 65	May 66	Grain yld (71), straw wt (72), av seed wt(73), height (h) at heading (74), h at ripening (75), grain yld (71), num of tillers (76), time to spiking (77), time to ripening (78)	P (66), K (67)	Soil sampled end of Apr 66. This ends original Report 1 (1961-66)
1967	Chick-pea	BDPP1967	Jan 67	Jun 67	Grain yld (81)	P (152), K (151)	Soil sampled Apr 67
1968	Sugar-beet	BDPP1968	Oct 67	Jun 68	Beet yld (157), leaves wt (160), sugar yld (161), petiole NO_3 (178)	-	

Year	Crop	Excel File name	Seeding date	Harvest date	Variable (and number)		Comment
					Plant	Soil	
1968	Corn silage	BDPP1968a	Jul 68	Oct 68	Ear yld (170), dry ear yld (176) , green fresh yld (163), green DM yld (168), fresh single ear (175), dry single ear (177)	Soil P (181)	Green (pea) manure R3. Soil sampled before fertilization and planting
1969	Cotton	BDPP1969	Apr 69	Oct 69	Raw cotton yld (194), lint yld (196), single boll wt (187)	Soil NO_3N (182), soil P (183), soil K (184)	Pea (R3) was harvested. Soil sampled after seeding
1970	Wheat	BDPP1970	Nov 69	May 70	Grain yld (206), straw yld (203), 1000 seeds wt (232), optical density aerial photo (185)	Soil P (229), soil K (231)	Soil sampled at emergence before top N dressing. This ends original Report II (1966-70)
1971	Chick-pea	BDPP1971	May 70	Jul 70	-	-	Crop not harvested (disease)
1972	Sugar-beet	BDPP1972	Oct 71	Jun 72	Beet yld (240), %sugar (241), sugar yld (242), single beet wt (244), K in sugar (246), Na in sugar (247)	Soil NO_3N (258), soil NH_4N (259), soil P (253), soil K (254)	Manure added. Soil sampled before planting after fertilization
1972	Corn silage	BDPP1972a	Jul 72	Sep 72	Forage yld (255)	-	
1973	Cotton	BDPP1973	Apr 73	Oct 73	Raw cotton yld (256), lint yld (290)	Soil P (263), soil K (263)	No fertilizer
1974	Vetch	BDPP1974	Nov 73	Jun 74	-	-	No fertilizer. No measurements

Year	Crop	Excel File name	Seeding date	Harvest date	Variable (and number)		Comment
					Plant	Soil	
1975	Wheat	BDPP1975	Nov 74	Jun 75	Grain yld (331), DM grain+straw yld (337), N yld (342), P yld (343), K yld (344)	-	Partial results except grain yld
1976	Sor-ghum	BDPP1976	Mar 76	Aug 76	Dry grain yld (347), % DM grain (346)	Soil P 0-20 (349), soil K by $NaHCO_3$ (350), soil P 20-40 (352), soil K $NaHCO_3$ 20-40 (353)	Soil test Apr 76. No fertili-zation. From this year Tr R3 did not get P, K (N yes) and serves to study P, K residual effects
1977	Oat	BDPP1977	Nov 76	Jun 77	-	-	No data was collected
1977	Corm	BDPP1977a	Jun 77	Oct 77	-	-	No data collected. This ends original Report III (1970-77)
1978	Cotton	BDPP1978	Apr 78	Oct 78	Lint yld (368), raw yld (370)	-	Partial crop sampling
1979	Cotton	BDPP1979	Apr 79	Oct 79	Raw yld (419)	-	
1980	Cotton	BDPP1980	Apr 80	Oct 80	Raw yld (433), lint yld (468), boll wt (463), %lint (462),	NO_3 0-20, 20-40 (440, 457), P 0-20, 20-40 (441, 458), K 0-20, 20-40 (442, 459)	
1981	Cotton	BDPP1981	Apr 81	Oct 81	Raw yld (469)	-	Manure added
1982	Cotton	BDPP1982	Apr 82	Oct 82	Raw yld (470a)	-	
1983	Cotton	BDPP1983	Apr 83	Oct 83	Raw yld (473), boll wt (474)	-	
1984	Cotton	BDPP1984	Apr 84	Oct 84	Raw yld (475), boll wt (476)	-	

Year	Crop	Excel File name	Seeding date	Harvest date	Variable (and number)		Comment
					Plant	Soil	
1985	Cotton	BDPP1985	Apr 85	Oct 85	Raw yld max (478), Raw yld (477), lint yld (484), boll wt (479)	-	
1986	Wheat	BDPP1986	Nov 85	Jun 86	Grain yld (501)	-	
1987	Wheat	BDPP1987	Nov 86	Jun 87	Grain yld (502)	-	No P, K added (only N). Soil sampled 0-210 cm in 120 plots, 0-12 m in 10 plots
1988	Wheat	BDPP1988	Nov 87	Jun 88	Grain yld (503)	-	No P, K fertilization
1989	Wheat	BDPP1989	Nov 88	Jun 89	Grain yld (504)	-	
1990	-	BDPP1990			-	-	Fallow
1991	Canola	BDPP1991	Sep 90	Jun 91	Grain yld (505)	-	N, P, K added
1992	Wheat	BDPP1992	Nov 91	Jun 92	Grain yld (506)	-	P, K not added. Pre-seeding soil sampling in all plots
1993	Saf-flower	BDPP1993	Jan 93	Jul 93	Grain yld	-	Partial plant sampling. N, P, K, pelleted manure added

2 Results

2.1 Annual crop reports

The data encompass 37 annual reports covering 32 years. The difference stems from the fact that in four years two crops were grown per year. The annual Excel reports are too long to be included in the text and they are replaced by inserted hyperlinks that recall the files from a predefined folder, or diskette, if the reader is using the e-version of this report. Each of the presented crop reports includes an ANOVA table of the investigated variables, and main-treatments average results copied from the original Permanent Plot reports (The Permanent Plot Team, 1968, 1971, 1980; Halevy *et al.*, 1992).

2.1.1 The 1961 season (wheat)

The 1961 report can be viewed by clicking (and simultaneously pressing Control) the link: BDPP1961. In this season only the wheat grain yield was measured, and the wheat was not fertilized in order to evaluate the field uniformity at time 0 (Fig. 3).

To evaluate the uniformity, the yield is presented according to blocks (1-to-5). It can be seen that the largest spatial variability in yield was obtained in block 5 (14 plots with yield >2,800 kg/ha), followed by block 2 (9 plots with yield <2,000 kg/ha); in most of the plots the yield ranged between 2,000 and 2,700 kg/ha.

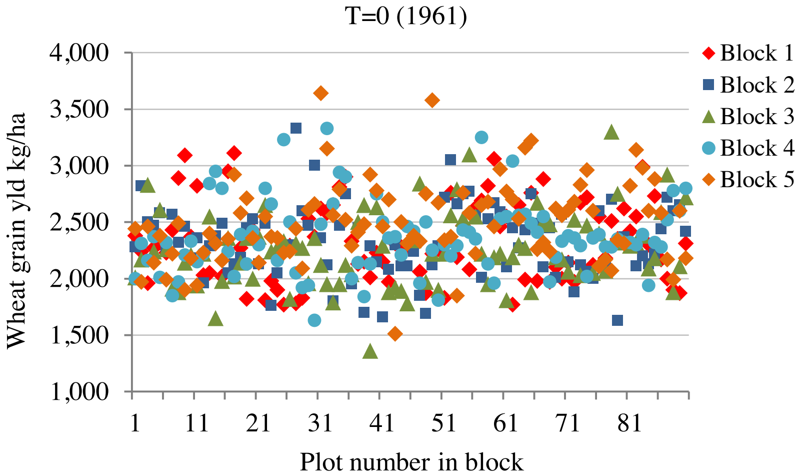

Fig. 3. Wheat grain yield in all field plots at time 0 (seeding 29/10/1960). The data points are grouped according to blocks (1 to 5, 90 plots per block).

2.1.2 The 1962 season (chickpea)

The 1962 report can be viewed by clicking: BDPP1962. The studied variables were chickpea grain and straw yields. The plots were fertilized before seeding.

Table 4. The ANOVA of the chickpea grain yield.

Chickpea grain yield (1962)				
Factor	SS[a]	DF[b]	MS[c]	ANOVA F
N	0.66525 D06	4	0.1663 D06	4.56
P in BL[d]	0.10181 D05	5	0.2036 D04	0.14
K	0.26071 D04	2	0.1303 D04	0.31
P x K in BL[d]	0.31356 D05	10	0.3135 D04	0.76
R	0.48871 D05	2	0.2443 D05	1.08
N x P in BL[d]	0.10004 D06	20	0.5002 D04	1.08
N x K	0.27891 D05	8	0.3486 D04	0.75
N x R	0.14821 D06	8	0.1853 D05	4.00
Remainder	0.14090 D07	304	0.4634 D04	-
Total	0.47412 D07	449	-	-

Note: [a]Sum of squares. [b]Degrees of freedom. [c]Mean square. [d]BL = block.

It can be seen that among the main factors (N, P, K and R), only N had a significant (F=4.56) effect on chickpea grain yield: 6,090; 5,778; 5361; 5,381; and 4,970 kg/ha in treatments N1, N2, N3, N4, and N5, respectively (standard error, SE=201.3). A graph depicting the yield response to N under different P and K levels (Fig. 4) underscores the adverse effect of N on yield. It also shows that the effects of P (P1-to-P5) and K (K3 vs. K1) on yield at a given level of N were inconsistent, and that differences between replicates 1 and 2 were considerable. Due to the variability between replicates stemming from the field's spatial variability, the results in forthcoming annual reports will be limited to replicate-1 only. Interested readers can find the replicate 2 results in the hyperlinked BD1962 Excel report.

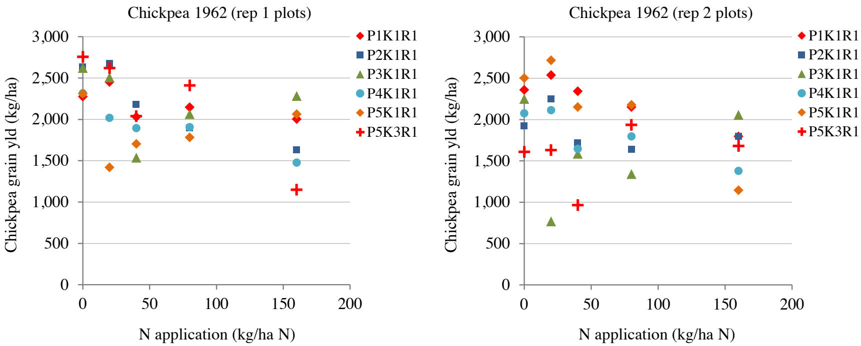

Fig. 4. Chickpea grain yield response to N and P fertilization at K level K1. In one case (P5) the K level is K3. The left and right hand Figures refer to replicates 1 and 2, respectively.

2.1.3 The 1963 season (sugar beet and foxtail millet)

The 1963 sugar beet report can be viewed by clicking: BDPP1963. The measured variables this year were beets, canopy and sugar yields, % sugar in beets, single beet weight, and soil P and K concentrations at harvest. Seeding was preceded by NPK fertilization and manure application (R2).

The beets yield was mostly affected by N: 65.6; 85.1; 94.4; 100.8; and 102.4 t/ha (SE=2.50) in treatments N1, N2, N3, N4, and N5, respectively. The other main factors (P, K and R) had negligible effect on beets yield.

The 0-20 cm soil-P concentration ($NaHCO_3$ method) at harvest was 5; 6.1; 7; 8.7; and 11.4 mg/kg P in treatments P1, P2, P3, P4, P5, respectively. The N, K, R treatments had negligible effect on soil P availability.

Figure 5 shows that the yield response to N was clearer as P application rate increased. The response to P at any N level was bell-shaped with P5 giving lower yields than P4. At N application >120 kg/ha and P5, the K3 treatment gave higher beets yield than K1.

Table 5. The ANOVA of the beet (top) and sugar yields (bottom).

Sugar beet beets yield (1963)				
Factor	SS	DF	MS	ANOVA F
N	0.17250 D07	4	0.4312 D06	36.27
P in BL	0.26382 D06	5	0.5276 D05	2.62
K	0.16002 D05	2	0.8000 D04	2.60
P x K in BL	0.16311 D05	10	0.1631 D04	0.53
R	0.45756 D05	2	0.2288 D05	2.51
N x P in BL	0.11402 D05	20	0.5701 D03	0.70
N x K	0.35654 D04	8	0.4457 D03	0.55
N x R	0.16221 D05	8	0.2028 D04	2.51
Remainder	0.24604 D06	304	0.8093 D03	-
Total	0.31054 D07	449	-	-
Sugar beet sugar yield (1963)				
Factor	SS	DF	MS	ANOVA F
N	0.56836 D07	4	0.4639 D06	33.63
P in BL	0.80281 D06	5	0.1606 D05	3.05
K	0.15959 D05	2	0.7980 D04	1.16
P x K in BL	0.31617 D05	10	0.3162 D04	0.46
R	0.13040 D06	2	0.6520 D05	2.35
N x P in BL	0.61826 D05	20	0.3092 D03	0.92
N x K	0.10679 D05	8	0.1335 D04	0.40
N x R	0.55733 D05	8	0.6966 D04	2.07
Remainder	0.72 D06	304	0.81 D03	-
Total	0.78 D07	449	-	-

Note: BL = block

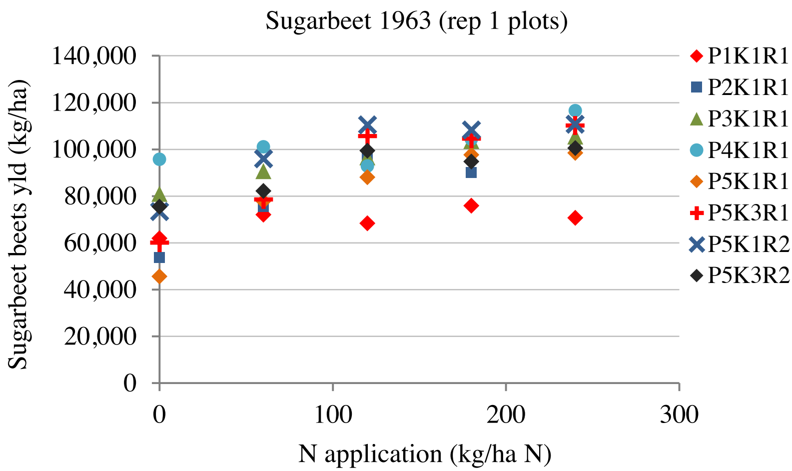

Fig. 5. Sugar beet yield response to N and P fertilization at level K1. Also shown is the response to N at K3 (P5K1R1 vs. P5K3R1) and at R2 (P5K1R2 vs. P5K1R1, and P5K3R2 vs. P5K3R1). All data points belong to replicate-1 plots.

The 1963 millet report can be viewed in: BDPP1963a. Only one variable was studied - green yield; its shortened ANOVA report (omitting the SS and MS) is given below. After the crop was harvested, a green manure crop was grown in R3 plots.

Table 6. The short (lacking SS and MS data) ANOVA of the millet green yield.

Foxtail millet green yield (1963)		
Factor	DF	ANOVA F
N	4	20.1
P in BL	5	1.50
K	2	1.59
P x K in BL	10	0.60
R	2	0.79
N x P in BL	20	2.94
N x K	8	0.73
N x R	8	3.16
Remainder	304	-
Total	449	-

Note: BL = block

2.1.4 The 1964 season (vetch + oats, and cotton)

In 1964 two crops were grown: vetch and cotton. The vetch report is retrieved by clicking: BDPP1964.The studied variables were: green yield, and soil NO_3-N, P, K in the 0-20 cm soil layer at harvest.

Table 7. The short ANOVA of the vetch green yield.

Vetch + oats green yield (1964)		
Factor	DF	ANOVA F
N	4	2.94
P in BL	5	6.5
K	2	1.19
P x K in BL	10	0.45
R	2	11.26
N x P in BL	20	1.6
N x K	8	1.51
N x R	8	4.78
Remainder	304	-
Total	449	-

Note: BL = block

The soil tests (0-20 cm, at vetch harvest) reveal that in the main N treatment, the NO_3-N concentrations (mg/kg) varied between 14.5, 15.0, 15.7, 16.7, and 16.6 in treatments N1, N2, N3, N4, and N5, respectively (SE=0.65). In the main R treatment, the averaged concentrations in levels R1 and R2 were 14.9, and 16.4 mg NO_3-N/kg, respectively (R3 - green manure - was not sampled).

The $NaHCO_3$ extractable P concentrations (mg P/kg soil) in the main P treatment were 4.5; 6.6; 7.8; 14.7; and 15.2 in treatments P1, P2, P3, P4, and P5, respectively. In the main R treatment, the P concentration in R1 and R2 were 9.2 and 10.3 mg P/kg, respectively.

The 0.01M $CaCl_2$ extractable K concentrations (mg K/L) in the main K treatment were 5.4; 7.8; and 10.0 in treatments K1, K2, and K3, respectively. In the main R treatment, the concentrations in R1 and R2 were 7.4 and 10.3 mg K/L, respectively.

The cotton report can be viewed by clicking: BDPP1964a. The studied variables were: raw cotton yield, lint yield, single boll weight, leaf petiole NO_3-N and P (petioles were only partly sampled). Soil sampling was done after harvesting the previous crop (the soil data is presented in that report).

Table 8. The short ANOVA of the cotton yield.

		Cotton yield components (1964)		
Factor	DF	Raw cotton yield	Lint yield	Boll wt
			ANOVA F	
N	4	3.62	28.2	23.1
P in BL	5	1.05	30.34	18.91
K	2	2.27	2.43	0.55
P x K in BL	10	1.36	0.49	0.84
R	2	2.11	2.0	6.64
N x P in BL	20	0.70	1.79	0.63
N x K	8	1.03	1.67	1.32
N x R	8	2.88	5.21	2.25
Remainder	304	-		
Total	449	-		

Note: BL = block

The lint yield in the main N treatment varied between 1,807 kg/ha (N1) and 1,830 (N2) (SE=14.9). In the main P treatment, it varied between 1,800 kg/ha (P1) and 1,856 (P2). The effects of K and R were negligible and inconsistent.

The response in raw cotton yield resembled the response in lint yield, varying between 4,720 kg/ha (N1) and 4,950 kg/ha (N2).

The average boll weights in the main N treatment were 8.2; 8.4; 8.6; 8.6; and 8.5 g/boll in treatments N1, N2, N3, N4 and N5, respectively (SE=0.03); in the main P treatment they were 8.3; 8.4; 8.4; 8.6; and 8.6 g/boll in treatments P1, P2, P3, P4, and P5, respectively. The K and R effects on boll weight were negligible.

An example of the raw cotton yield response to N at various P, K and R levels is presented in Fig. 6. In general, a stronger yield response to N was observed as P and K application rates increased. At K1R1 and N application >0 the yield was greatest in P3. The yield in the K3 treatment exceeded, at any N level, the yield in K1 treatment (compare P5K3R1 vs. P5K1R1); in treatment R2 (dairy manure), the yield was higher at all N levels than the yield in the un-manured treatment R1 (compare P5K3R2 vs. P5K3R1).

The mid-June leaf petiole NO_3-N concentrations in the main N treatment were 1,627, 1,767, and 1,858 mg NO_3-N/kg in treatments N1, N3, and N5, respectively (SE=18). In the main R treatment, the concentrations in R1, R2, and R3 were 1,699; 1,759; and 1,794 mg NO_3-N/kg, respectively (SE=36). The petiole P concentrations in the main P treatment (mg P/kg) were 2,330; 2,580; 2,540; 2,590; and 2,700 in treatments P1, P2, P3, P4, and P5, respectively. In the main R treatment, the concentrations in R1, R2 and R3 were 2,540, 2,640, and 2,480 mg P/kg (SE=65).

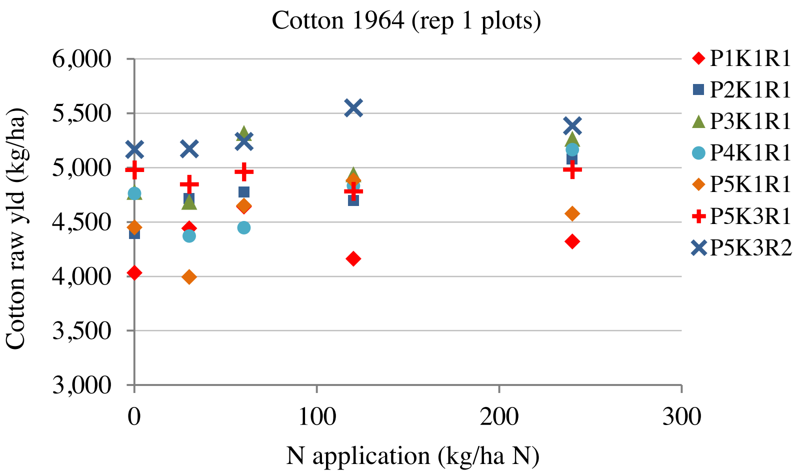

Fig. 6. The raw cotton yield response to N under various P, K and R application levels (two levels of K - P5K1R1 vs. P5K3R1; two levels of R- P5K3R1 vs. P5K3R2). All data points belong to replicate-1 plots.

2.1.5 The 1965 season (sorghum)

The sorghum report is in: BDPP1965. The studied variables were grain yield, heads (panicles) number, single head weight, and NO_3-N, P ($NaHCO_3$), and K ($CaCl_2$) concentration in soil.

Table 9. The short ANOVA of the sorghum yield.

Sorghum yield components (1965)				
Factor	DF	Grain yield	Heads number	Head wt
			ANOVA F	
N	4	38.93	2.93	50.6
P in BL	5	20.60	0.68	2.33
K	2	1.34	2.73	1.64
P x K in BL	10	1.45	1.04	0.76
R	2	7.03	0.72	0.06
N x P in BL	20	2.84	1.05	0.84
N x K	8	0.98	0.83	0.87
N x R	8	2.78	1.36	4.64
Remainder	304	-		
Total	449	-		

Note: BL = block

Soil sampling was done before fertilization. The sorghum grain yield response to N at representative P, K and R treatments is presented in Fig. 7. The response until 120 kg N/ha was nearly linear at all P levels but at higher N, the curves flatten. At any N level, the yield increased as P application increased from P1 to P2, P3 or P4, but at P5 the yield declined. The K3 level gave higher yield at any N level in comparison with K1 (P5K3R1>P5K1R1); treatment R2 gave lower yields at all N levels than the corresponding un-manured treatment (P5K3R2 < P5K3R1).

The canopy (leaves + stems) dry matter (DM) weight at harvest was measured in part of the field plots and is therefore not included in the report. The average DM weight in plots that were sampled was 35.9, 32.1, 32.6, 29.9 and 28.9 g/plant in treatments N1, N2, N3, N4 and N5, respectively (SE=3.15); and 32.0, 29.8 and 33.8 g/plant in treatments K1, K2 and K3, respectively (SE=2.08).

Table 10. The short ANOVA of the soil tests.

		Soil available nutrients prior to fertilization (1965)		
Factor	DF	NO_3-N	Olsen P	K in $CaCl_2$
		ANOVA F		
N	4	455.33	0.85	0.90
P in BL	5	0.42	9.46	4.45
K	2	0.04	0.27	82.45
P x K in BL	10	3.08	0.78	1.26
R	2	0.09	1.13	2.56
N x P in BL	20	0.86	1.12	1.16
N x K	8	0.84	0.73	0.60
N x R	8	1.41	0.88	2.75
Remainder	304	-		
Total	449	-		

Note: BL = block

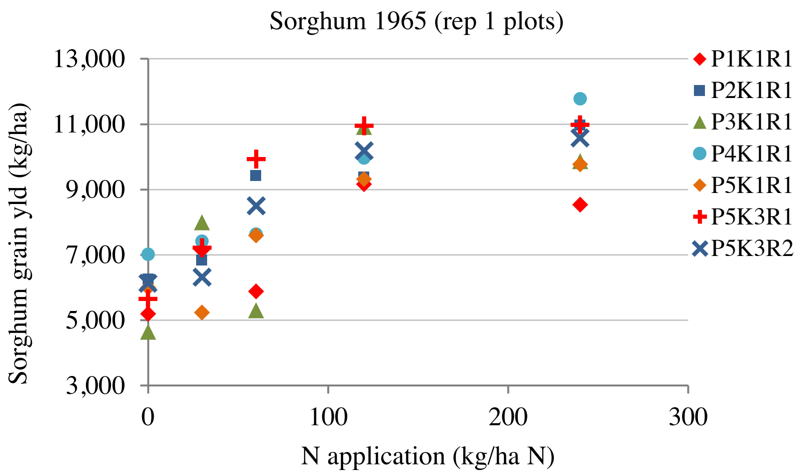

Fig. 7. The sorghum grain yield response to N and P application levels under K1, and the yield under two K levels (P5K1R1 vs. P5K3R1) and two manure treatments (P5K3R1 vs. P5K3R2). All data points belong to replicate-1 field plots.

2.1.6 The 1966 season (wheat)

In 1966 the crop was wheat. The file can be viewed by clicking: BDPP1966. The studied variables were grain yield (kg/ha), straw weight (kg/ha), average seed weight (mg), plants height at spiking and ripening (cm), single spike weight, number of tillers per plant, number of days to spiking and maturation and P, K soil tests in the 0-20 cm soil layer (sampled April, 1966).

Table 11. The short ANOVA of the wheat yield components.

		Wheat yield components (1966)					
Factor	DF	Grain yield	Straw yield	Seed weight	Tillers number	Soil P	Soil K
		ANOVA F					
N	4	136.8	121.46	71.58	24.68	1.69	1.53
P in BL	5	9.23	19.80	14.86	166.6	27.29	0.49
K	2	0.07	0.99	1.54	0.97	0.36	92.5
P x K in BL	10	1.62	0.47	0.65	1.52	0.95	1.55
R	2	6.4	1.73	5.53	6.77	0.39	2.09
N x P in BL	20	4.86	6.24	5.41	15.2	1.23	0.99
N x K	8	0.46	1.62	1.38	0.55	1.08	2.0
N x R	8	4.18	3.14	4.07	2.76	0.85	0.81
Remainder	304	-	-	-	-	-	-
Total	449	-	-	-	-	-	-

Note: BL = block

The main N treatment grain yield (kg/ha) was 781; 1,349; 1,757; 1,751; and 1,735 in treatments N1, N2, N3, N4, N5, respectively (SE=36). The effect of manuring was significant: 1,396, 1,546 and 1,481 kg/ha (SE=29.6) in treatments R1, R2, and R3, respectively. The K effect on grain yield was insignificant, whilst the P effect was significant and strongest for tiller number. The combined effect of N, P, K, R on grain yield is presented in Fig. 8.

The straw yield (kg/ha) in main treatment N was 827; 2,336; 3,006; 3,364; and 3,441 for N1, N2, N3, N4, and N5, respectively (SE=98.1). The effects of R and P were also significant: 2,455, 2,697 and 2,633 kg/ha (SE=95.4) in treatments R1, R2, and R3, and 2,120; 2351; 2,775; 2,653 and 3,062 kg/ha in treatments P1, P2, P3, P4, and P5, respectively. The K effect on straw yield was insignificant.

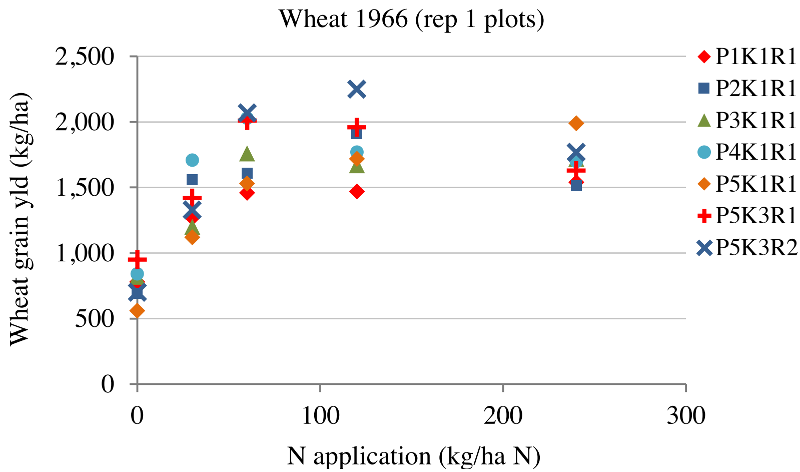

Fig. 8. The obtained response in wheat grain yield to five levels of N and five levels of P at K1; two levels of K (P5K1R1 vs. P5K3R1), and addition of manure (P5K3R1 vs. P5K3R2). The data belong to replicate-1 only.

The seeds weight was clearly affected only by the N treatments showing a bell-shaped response: 39.9, 43.4, 41.9, 35.9, 34.9 mg/seed (SE=0.42) in the N1, N2, N3, N4 and N5 levels, respectively.

The main factor that was affected by P was tillering: 1.12, 1.27, 1.37, 1.55 and 1.87 tillers/ plant in treatments P1, P2, P3, P4, and P5, respectively. The N effect was bell-shaped: 1.0, 1.22, 1.52, 1.78, and 1.67 tillers/plant (SE=0.07) in treatments N1, N2, N3, N4, and N5, respectively.

Manure also increased tillering: 1.37, 1.47 and 1.48 tillers/plant in treatments R1, R2, and R3, respectively

The soil was sampled at the end of April 1966 (before harvest). The $NaHCO_3$ soil P concentration in the main P treatment was 4.4, 5.8, 6.5, 9.9 and 18.5 mg/kg P in treatments P1, P2, P3, P4, and P5, respectively. The N treatments had a small effect on soil P concentration: 9.7, 8.9, 9.0, 9.0, and 8.8 mg P/kg in treatment N1, N2, N3, N4, and N5 respectively (SE=0.28). The K and R treatments also had small effects: 8.9, 9.1, and 9.2 mg/kg P (SE=0.27) in treatments K1, K2, K3, and 8.7, 9.7 and 8.7 mg/kg P (SE=0.89) in treatments R1, R2 and R3, respectively. The main K treatment soil K (in 0.01M $CaCl_2$) concentration was 4.0, 5.7, 7.5 mg K/L (SE=0.18) in treatments K1, K2 and K3, respectively. In treatments R1, R2 and R3, the averaged soil K values were 5.4, 5.7 and 6.1 mg K/L (SE=0.24).

2.1.7 The 1967 season (chickpea)

In 1967 the studied crop was chickpea. The report can be viewed by clicking: BDPP1967. The studied variables were: chickpea grain yield (kg/ha), and soil P and K in the 0-20 cm soil layer (April 1967).

Table 12. The short ANOVA of the chickpea grain yield.

		Chickpea (1967)		
Factor	DF	Grain yield	Soil K	Soil P
		ANOVA F		
N	4	3.41	2.01	7.02
P in BL	5	4.3	1.69	114.3
K	2	0.89	231.1	0.28
P x K in BL	10	1.54	0.64	1.65
R	2	2.40	1.52	3.50
N x P in BL	20	1.35	1.57	1.58
N x K	8	0.84	0.73	0.51
N x R	8	6.74	1.54	0.88
Remainder	304	-	-	
Total	449	-	-	

Note: BL = block

The chickpea response to N was negative: 2,532, 2,404, 2,252, 2,340 and 2,208 kg/ha (SE=69.3) in treatments N1, N2, N3, N4 and N5, respectively. The impact of P was positive: 2,196, 2,276, 2,395, 2,427, and 2,420 kg/ha in treatments P1, P2, P3, P4 and P5, respectively. The effects of K and R were ambiguous. The interaction between N, P, K and R in is presented in Fig. 9.

The soil K (in 0.01M $CaCl_2$ extract) was only significantly affected by the K treatment: 1.6, 2.35, 2.9 mg/L K (SE=0.04) in treatments K1, K2, K3.

The $NaHCO_3$ extracted soil P in the P1, P2, P3, P4 and P5 treatments was 2.2, 4.15, 4.9, 8.6 and 16.8 mg P/kg, respectively. Increasing the N dose reduced soil P from 8.3 in N1 to 6.8 in N5. The soil P in the R1, R2 and R3 treatments was 6.8, 7.6 and 7.7 (SE=0.28), respectively. The K had no effect on soil P concentration.

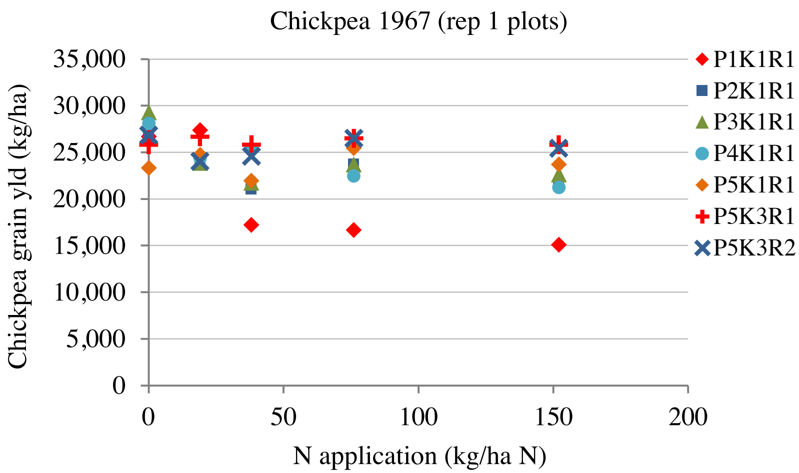

Fig. 9. Chickpea grain yield response to N at various P, K (P5K1R1 vs. P5K3R1), and manure (P5K3R1 vs. P5K3R2. Values in y-axis are real yield x 10.

2.1.8 The 1968 season (sugarbeet and silage corn)

In 1968 two crops were studied: sugarbeet and silage corn. The sugarbeet report can be viewed in: BDPP1968. The studied variables were: beet yield (kg/ha), canopy yield (kg/ha), sugar yield (kg/ha), and petiole NO_3-N concentration. Before sugarbeet seeding, cattle manure was applied in treatment R2. The ANOVA is shown in Table 13.

The beet yield gradually increased with N level: 52.6, 68.7, 79.4, 90.0, 92.7 t/ha (SE=2.38) in treatment N1, N2, N3, N4, and N5, respectively. The effect of P was limited to P1 and P2: 57.1 vs. 78.2 t/ha; higher P levels did not increase yield. Treatment R2 (note that dairy manure was applied just before seeding) enhanced beet yield relative to R1: 86.9 vs. 71.1 t/ha. Potassium had no effect on beet yield. The interaction in yield between N, P, K and R is shown in Fig. 10.

In agreement with the above observation, the manure increased beet yield in the P5K3 treatment at all N levels but the effect was too small to be of practical importance. The sugar yield response to N level was 8.85, 11.56, 12.85, 13.24 and 12.30 t/ha (SE=0.359) in treatments N1, N2, N3, N4, and N5, respectively. The impact of P level was 8.25, 12.25, 12.85, 13.17, and 12.35 t/ha in treatments P1, P2, P3, P4 and P5, all respectively. The effects of R was 11.05, 13.36 and 10.86 t/ha (SE=53.4) in treatments R1, R2 and R3. The K effect was insignificant.

Table 13. The short ANOVA of the sugarbeet variables.

		Sugarbeet (1968)		
Factor	DF	Beet yield	Tops yield	Sugar yield
			ANOVA F	
N	4	48.0	101.1	23.62
P in BL	5	3.19	2.77	3.85
K	2	0.03	0.54	0.18
P x K in BL	10	0.68	0.82	0.52
R	2	4.89	0.98	6.78
N x P in BL	20	3.25	3.73	3.90
N x K	8	0.22	0.51	1.14
N x R	8	2.34	2.18	6.40
Remainder	304	-	-	
Total	449	-	-	

Note: BL = block

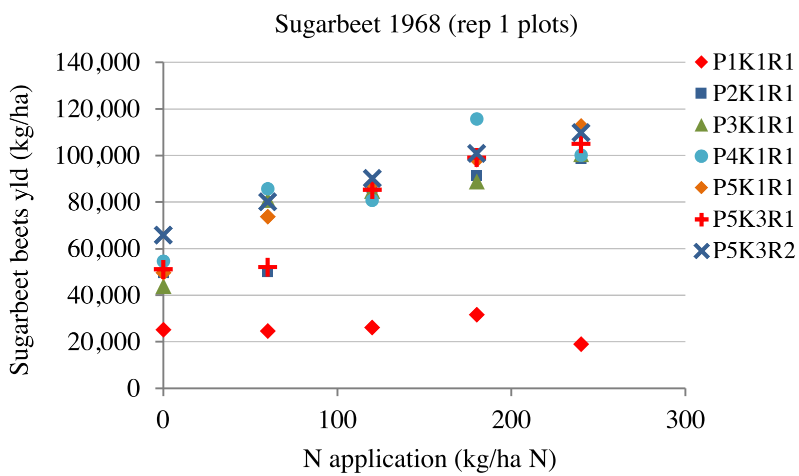

Fig. 10. The response in sugarbeet beet yield to five levels of N x five levels of P at K level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots.

The silage corn report can be viewed by clicking: BDPP1968a. Prior to seeding, a green manure crop was grown in R3. The tested variables were: ear yield; dry ear yield, fresh weight yield, green DM yield, fresh single ear weight, dry single ear weight, and soil P before fertilization ($NaHCO_3$ extractable P).

Table 14. The short ANOVA of the silage corn variables.

		Silage corn variables (1968)					
Factor	DF	Fresh ear wt	Dry ear wt	Dry ear yld	Fresh ear yld	Dry green yld	Soil P
		ANOVA F					
N	4	35.81	13.19	10.18	22.17	23.37	0.89
P in BL	5	4.14	9.02	7.05	3.41	2.04	20.58
K	2	0.24	0.34	0.04	0.45	0.38	0.07
P x K in BL	10	0.71	1.29	1.04	0.93	1.22	0.57
R	2	2.07	3.80	9.86	19.96	1.90	12.87
N x P in BL	20	1.39	1.68	1.83	1.78	1.01	4.65
N x K	8	1.01	0.79	0.61	0.32	1.59	0.59
N x R	8	1.76	1.35	3.0	3.98	1.53	0.68
Remainder	304	-	-	-	-	-	-
Total	449	-	-	-	-	-	-

Note: BL = block

The corn fresh ear yield (October 1968) was 12.43 t/ha in treatment N1 and 16.52-17.01 in treatment N2, N3, N4, and N5, respectively (SE=415). The response to P was 14.76 t/ha in treatment P1 and 15.53-16.66 in treatments P2 to P5. The ear yield in treatments R1, R2 and R3 were 15.80, 16.38 and 15.56 t/ha, respectively (SE=94). The interaction between the main factors is shown in Fig. 11.

The effect of N and P on dry ear yield was bell-shaped: 4,380, 5,870, 5,740, 5,440, 5,390 kg/ha in treatments N1, N2, N3, N4, and N5, respectively (SE=183), and 4.450, 5.350, 5.470, 5.850 and 5.560 kg/ha in treatments P1, P2, P3, P4, and P5, respectively. The yield in treatments R1, R2 and R3 was 5.180, 5.760 and 5,150 kg/ha, respectively (SE=109). The effect of K was insignificant.

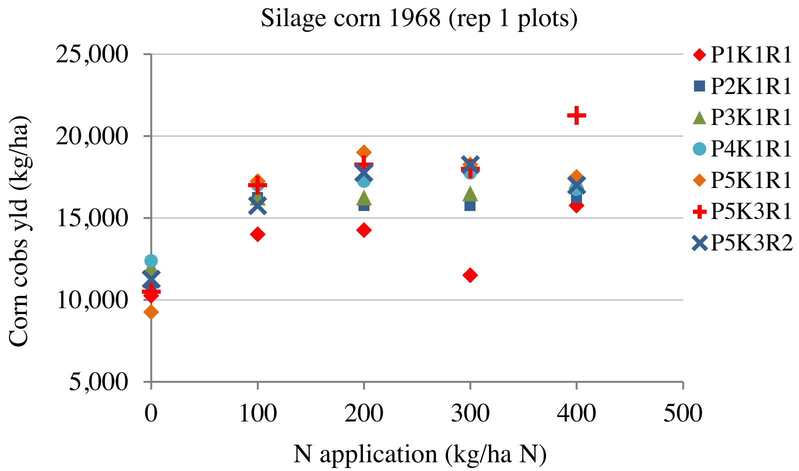

Fig. 11. The response in silage corn cob yield to five levels of N x five levels of P at K level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). All data points belong to replicate-1 plots.

The effects of N and P on dry ear weight were bell-shaped: 95, 128, 124, 118, 117 g/ear in treatments N1, N2, N3, N4, and N5, respectively (SE=3.5), and 98, 117, 117, 135 and 118 g/ear in treatments P1, P2, P3, P4, and P5, respectively. The weight in treatments R1, R2 and R3 was 113, 124 and 112 g/ear, respectively (SE=3.4). The K effect was insignificant. The corn dry canopy yield (green yield) was 7,120 kg/ha in treatment N1 and 8,400-8,690 in treatment N2, N3, N4, and N5. The effects of P, K and R were small and practically not important.

The fresh ear weight in the main N treatment was lowest at level N1 (270 g/ear); in other main treatments it varied between 321 and 401 g/ear, the latter in main treatment P at level P3.

More in-depth information on the 1968 treatment effects on corn yield; N, P, K, Ca content in leaves; N, P, K, Ca uptake rates, and P and N reactions and status in soil can be found in two papers by Bar-Yosef and Kafkafi (1972a and 1972b): sssaj72.pdf and sssaj72a.pdf (the latter paper includes a P adsorption isotherm to BD soil at time zero). Additional analyzed data showing temporal K and Mg contents in plant, K status in soil, and estimated plant N and P threshold concentrations for high yield can be found in Kafkafi and Bar-Yosef (1971, p. 8-33). To avoid overlapping, data appearing in Bar-Yosef and Kafkafi (1972) was not included in the text.

2.1.9 The 1969 season (cotton)

In 1969 the studied crop was cotton. The cotton report can be viewed by clicking: BDPP1969. The studied variables were: raw cotton yield, lint yield, single boll weight, and soil P ($NaHCO_3$ method) and K ($CaCl_2$ extract). The soil samples were taken after seeding.

Table 15. The short ANOVA of the cotton yield.

		Cotton yield components (1969)		
Factor	DF	Raw cotton yield	Lint yield	Boll wt
		ANOVA F		
N	4	19.05	28.2	39.86
P in BL	5	2.51	30.34	18.64
K	2	10.67	2.43	0.35
P x K in BL	10	1.75	0.49	1.17
R	2	5.40	2.0	4.82
N x P in BL	20	1.77	1.79	1.32
N x K	8	0.83	1.67	0.84
N x R	8	19.77	5.21	3.59
Remainder	304	-	-	-
Total	449	-	-	-

Note: BL = block

The lint yield in the main N treatment varied between 1,807 kg/ha in N1 and 1,830 kg/ha in N2 (SE=14.9). In the main P treatment, the lint yield varied between 1,800 kg/ha (treatment P1) and 1,856 kg/ha (P2). The effects of K and R were negligible and inconsistent.

The response in raw cotton yield to N level was bell-shaped: 3,985, 4,913, 5,083, 5,068, and 4,912 kg/ha in treatments N1, N2, N3, N4, and N5 (SE=105). The response to P was: 4,521, 4,885, 4,810, 4,920 and 4,805 kg/ha in treatments P1, P2, P3, P4 and P5, respectively. The K effect was: 4,679, 4,852 and 4,846 kg/ha in treatments K1, K2 and K3 (SE=30), and the R effect was 4,592, 4,960 and 4,825 kg/ha in treatments R1, R2 and R3 (SE=81), all respectively.

The average boll weight increased linearly with N level: 6.75, 7.33, 7.76, 8.08 and 8.25 g/boll in N1, N2, N3, N4, and N5, respectively (SE=0.096). The effect of P was 7.35, 7.62, 7.54, 7.93, and 7.68 g/boll in treatments P1, P2, P3, P4, and P5, respectively. The effects of K and R were negligible. The interaction in yield between N, P, K is shown in Fig. 12. The manure that was added the previous year was still effective and treatment P5K3R2 gave a higher yield in all N levels than P5K3R1.

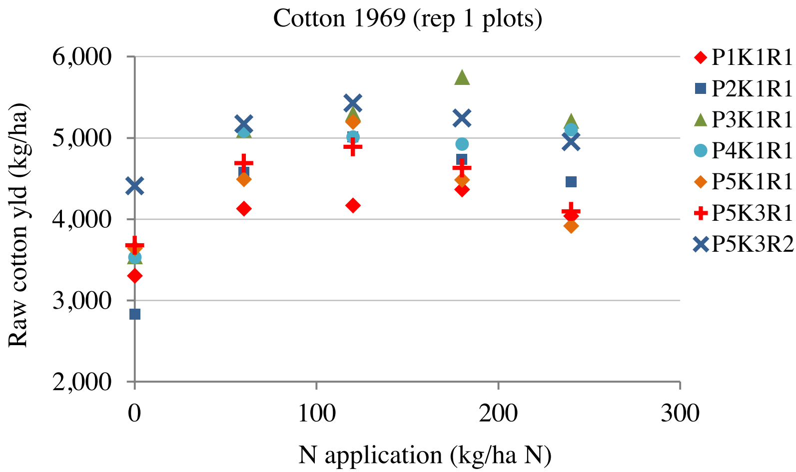

Fig. 12. The response in raw cotton yield to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data refer to replicate-1 only.

The soil P ($NaHCO_3$) was affected significantly by P level (F=39.53). The concentrations in P1, P2, P3, P4 and P5 levels were 4.5, 9.5, 7.1, 11.5 and 19.8 mg P/kg, respectively. Manure increased soil P from 10.2 to 12.8 mg/kg (F=1.3 and SE=1.3). The N application level also affected the soil P concentration, but adversely: the P concentration significantly fell from 12.0 mg/kg in treatment N1 to 10.7 in treatment N5 (SE=0.40, F=2.8), probably due to greater P uptake by plants. Unlike N, elevating the K application level from K1 to K2 increased the soil P concentration (F=1.81) from 10.4 to 11.3 mg/kg (SE=0.37) but further increase in K3 had no additional effect.

The soil K ($CaCl_2$ extract) concentration was 5.0, 7.6 and 9.8 mg/L K in treatments K1, K2 and K3, respectively (F=144.2 and SE=0.20). Dairy and green manure increased the soil K concentration from 6.7 mg/L in treatment R1 to 8.7 mg/L in R2, and 7.1 mg/L K in R3 (SE=0.61). Increasing N levels reduced soil K concentration (F=6.0) from 8.0 (treatment N1) to 7.4 mg/L in the other N levels (SE=0.13), probably due to greater K uptake.

2.1.10 The 1970 season (wheat)

In 1970, the tested crop was wheat. The report can be viewed by clicking: BDPP1970. The studied variables were: grain yield (kg/ha), straw yield (kg/ha), 1,000 seeds weight (g), optical density of black & white film of aerial photo of the experimental field, and P ($NaHCO_3$ method) and K ($CaCl_2$ extract) concentration in soil (0-20 cm) determined at seedlings emergence.

Table 16. The short ANOVA of the wheat variables.

		Wheat variables (1970)				
Factor	DF	Grain yield	Straw yield	1,000 seeds wt	Soil K	Soil P
		ANOVA F				
N	4	226.3	192.71	44.07	3.22	1.67
P in BL	5	19.80	29.30	2.48	0.35	160.0
K	2	2.70	3.46	0.11	637.2	0.67
P x K in BL	10	0.74	1.64	1.59	0.83	1.02
R	2	6.34	3.18	0.97	24.2	3.50
N x P in BL	20	7.63	9.22	6.28	0.95	1.87
N x K	8	0.37	0.99	0.36	0.99	0.90
N x R	8	0.84	1.58	6.57	1.82	0.45
Remainder	304	-	-	-		-
Total	449	-	-	-	-	-

Note: BL = block

The wheat grain yield (kg/ha) in treatments N1, N2, N3, N4, N5 (main N treatment) was 1,420, 2,438, 3,436, 4,517, and 4,124 kg/ha (SE=84). The effect of P was: 2,567, 3,326, 3,315, 3,443 and 3,286 kg/ha in treatments P1, P2, P3, P4 and P5, and that of R: 2,982, 3,374 and 3,205 kg/ha (SE=78) in R1, R2, and R3, all respectively. The K effect on grain yield was insignificant.

The wheat straw yield in treatments N1, N2, N3, N4, N5 (main N treatment) was 515, 1,703, 2,986, 4,579, and 4,437 kg/ha (SE=126). The effects of R and P were also significant: 2,708, 2,983 and 2,841 kg/ha (SE=77) in treatments R1, R2, and R3, and 1,957, 2,799, 3,194, 3,201 and 3,076 kg/ha in treatments P1, P2, P3, P4, and P5, all respectively. The interrelationships between the main factors is presented in Fig. 13.

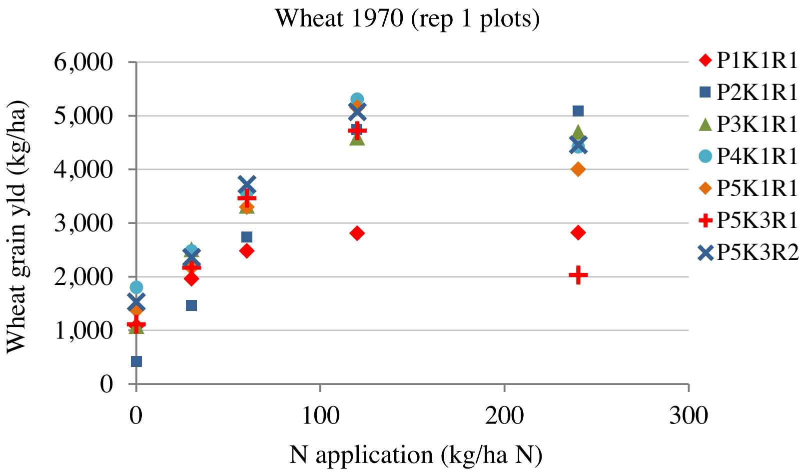

Fig. 13. The response in wheat grain yield to five N levels x five P levels at level K1five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data belong to replicate-1 plots.

The 1,000 seed weight was affected only by N, the response having a bell-shape: 39.9, 43.0, 43.0, 40.4, and 37.4 g/1,000 seed (SE=0.36) at the N1, N2, N3, N4 and N5 levels, respectively.

Soil tests were done at plant emergence (P, K fertilization took place before seeding). The soil P ($NaHCO_3$ method) concentration was 3.2, 7.7, 12.0, 23.6 and 40.5 mg P/kg in levels P1, P2, P3, P4, and P5, respectively. The N levels had a small effect on soil P: between 18.0 mg/kg at N1 to 16.2 mg P/kg in N5 (SE=0.59). The K levels had no effect on soil P, while manuring increased it from 15.9 in R1 to 19.0 and 17.4 mg P/kg (SE=0.82) in treatments R2 and R3, respectively.

The soil K (in $CaCl_2$ 0.01M) concentrations in the main K treatment K1, K2 and K3 levels were 6.8, 10.9, 15.0 mg/L K (SE=0.16). In manure treatments, R1, R2 and R3, the soil K concentrations were 10.1, 11.4 and 11.3 mg/L K (SE=0.15). The N effect was negligible.

More in-depth information on N, P, K temporal and spatial distributions in soil, organic-N mineralization rates, DM accumulation and N, P, K uptake rates by wheat as a function of plant age can be found in Kafkafi and Bar-Yosef (1971, p. 34-48).

2.1.11 The 1971 season (chickpea)

In 1971 the studied crop was chickpea. Due to disease problems, the crop was not harvested and no crop and soil data were taken. For climate and water data and fertilization details, the 1971 report can be viewed by clicking: BDPP1971.

2.1.12 The 1972 season (sugarbeet)

In 1972 two crops were studied: sugarbeet and silage corn. The sugarbeet report can be viewed by clicking: BDPP1972. The studied variables were: sugarbeet beet yield (kg/ha), sugar yield (kg/ha), sugar content (% in beet), K and Na content in sugar, and NH_4, NO_3, P and K in soil. Prior to seeding, dairy manure was applied to treatment R2. The soil was sampled after fertilization.

Table 17. The short ANOVA of the sugarbeet variables.

		Sugarbeet (1972)		
Factor	DF	Beet yield	% Sugar	Sugar yield
			ANOVA F	
N	4	43.68	99.4	24.2
P in BL	5	4.70	1.86	4.81
K	2	1.22	0.05	1.42
P x K in BL	10	0.61	0.28	0.85
R	2	8.97	0.45	7.58
N x P in BL	20	3.55	3.51	2.22
N x K	8	0.63	1.01	0.85
N x R	8	1.19	3.74	5.20
Remainder	304	-	-	
Total	449	-	-	

Note: BL = block

The beet yield increased with N application level: 50.2, 63.2, 70.8, 82.2 and 82.4 t/ha (SE=2.06) in treatment N1, N2, N3, N4, and N5, respectively. The effect of P was limited to the change from P1 to P2: 42.1 vs. 73.0 t/ha, whereas at higher P levels the yield increased mildly to 75.5-80.2 t/ha. Potassium and manure had negligible effect on beet yield. The interaction between the main factors is presented in Fig. 14.

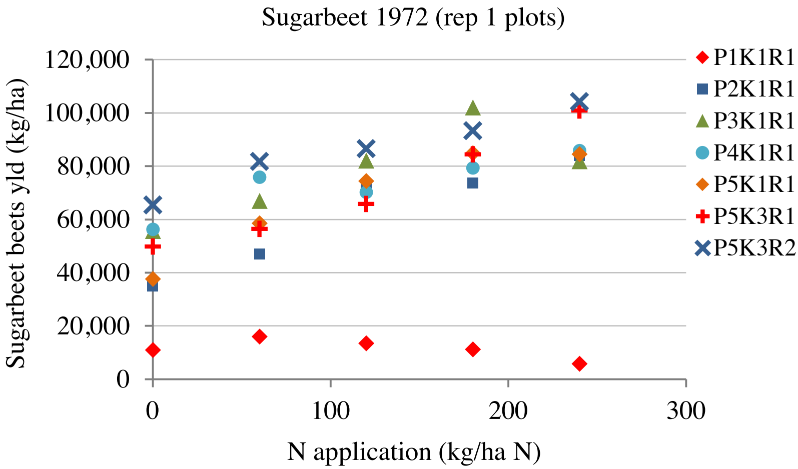

Fig. 14. The response in sugarbeet beets yield to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure treatment (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots

The sugar content in beets (%) was affected only by N, exhibiting a bell-shaped response: 15.2, 17.8, 16.9, 14.9 and 12.7% (SE=0.23) in N levels N1, N2, N3, N4, and N5, respectively.

The sugar yield response to N application was: 9.21, 11.31, 12.11, 12.35 and 10.32 t/ha (SE=0.26) in levels N1, N2, N3, N4, and N5, respectively. The impact of P level was: 3.86, 11.71, 12.14, 12.64, and 12.30 t/ha sugar in treatments P1, P2, P3, P4 and P5, respectively. The effects of R was 9.77, 12.93 and 10.50 t/ha (SE=0.60) in treatments R1, R2 and R3, respectively. The effect of K was insignificant.

The Na content in sugar was significantly and consistently affected by N application levels (F = 85.8). The value in levels N1, N2, N3, N4, and N5 were 6.9, 9.8, 16.9, 38.1 and 72.3 meq Na/100 g sugar, respectively (SE=2.95). Enhanced K application level somewhat reduced the sugar Na content: 30.8, 28.0, 28.3 meq/100g in treatments K1, K2 and K3, respectively (F=2.79 and SE=0.91). P had no significant effect on this parameter.

The K content in sugar was significantly affected by N and K application levels. The content in levels N1, N2, N3, N4, and N5 (F =89.6) were 25.4, 26.4, 27.8, 29.1 and 32.6 meq K/100 g sugar, respectively (SE=0.23). Enhanced K application increased the sugar K content (F=16.7): 26.6, 28.1, 29.1 meq K/100g in K levels K1, K2 and K3, respectively (SE=0.30). The effects of P and R were inconsistent and small.

The soil K (in $CaCl_2$ extract) was meaningfully affected only by the K application levels: 4.9, 7.1 and 6.9 mg/L K in levels K1, K2 and K3, respectively (SE=0.16).

The soil P in levels P1, P2, P3, P4, and P5 was 17, 10, 21.5, 21.9 and 25.7 mg/kg P, respectively. Increasing N application levels reduced soil P: 20.5, 19.7, 20.0, 19.4, and 15.7 mg/kg in treatment N1, N2, N3, N4, and N5, respectively (SE=0.61). The effect of R and K treatments was small and inconsistent.

The soil mineral N (NH_4+NO_3) concentration varied between 18 and 26 mg/kg N with no apparent effect of any treatment. Note: soil sampling was carried out after fertilization.

Table 18. The short ANOVA of the sugarbeet soil test.

		Sugarbeet soil tests (1972)			
Factor	DF	Soil mineral N		Soil P	Soil K
		NH_4-N	NO_3-N		
		ANOVA F			
N	4	4.38	35.1	1.21	3.46
P in BL	5	0.26	1.85	23.16	0.67
K	2	2.66	0.97	1.30	166.9
P x K in BL	10	1.45	2.16	1.26	0.68
R	2	7.82	7.62	4.10	11.90
N x P in BL	20	1.19	0.69	0.74	1.21
N x K	8	0.65	0.38	1.00	2.77
N x R	8	0.68	0.52	0.48	1.78
Remainder	304	-		-	
Total	449	-		-	

Note: BL = block

The silage corn report can be viewed by clicking: BDPP1972a. Only one variable was tested - forage yield (dried in the field). The forage yield (kg/ha) in N levels N1, N2, N3, N4, N5 (F = 25.4) was 6,867, 9,704, 8,048, 8,161, and 6,723 kg/ha

(SE=522). The effect of P was: 4,905, 8,654, 8,405, 8,651 and 7,415 kg/ha (F=0.96) in treatments P1, P2, P3, P4 and P5, all respectively. The effect of R (F=2.11) was: 7,358, 8,598 and 7,746 kg/ha (SE=125) in R levels R1, R2, and R3, respectively. The K effect on forage yield was inconsistent. The interaction between the main factors is presented in Fig. 15. No practical conclusion can be drawn from the graph because of the large variability in forage yield determination.

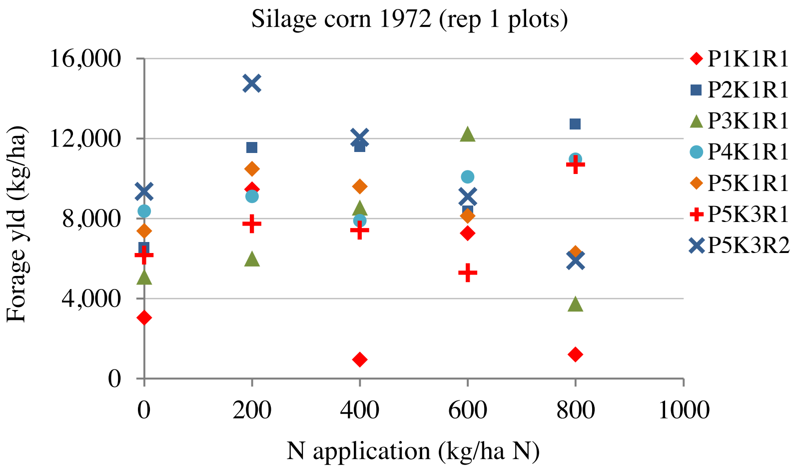

Fig. 15. The response in silage corn forage yield to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure treatment (P5K3R1 vs. P5K3R2). The data belong to replicate-1 plots.

2.1.13 The 1973 season (cotton)

In 1973 the studied crop was cotton. The statistics report can be viewed by clicking: BDPP1973. The studied variables were: raw cotton yield, lint yield, and soil P ($NaHCO_3$ method) and soil K ($CaCl_2$ extract) concentrations. The soil samples were taken after seeding. No fertilization was applied this year.

The raw cotton yield (kg/ha) in the main N treatment levels N1, N2, N3, N4, and N5 was 3,719, 4,194, 4,335, 4,275, and 4,360 kg/ha (SE=99.8). The effect of P was: 3,814, 4,766, 4,165, 4,466 and 4,651 kg/ha in treatments P1, P2, P3, P4 and P5, all respectively. The effect of R was: 4,109, 4,206 and 4,234 kg/ha (SE=71.7) for levels R1, R2, and R3, respectively. The K effect was 4,071, 4,172, 4,287 kg/ha raw cotton in levels K1, K2 and K3 (SE=66.1). A graphical presentation of the interrelationships between N, P, K and R is given in Fig. 16.

Table 19. The short ANOVA of the cotton variables.

Cotton variables (1973)					
Factor	DF	Raw cotton yield	Lint yield	Soil data	
				P (Olsen)	K (in $CaCl_2$)
		ANOVA F			
N	4	6.92	5.93	0.42	2.47
P in BL	5	1.83	2.65	10.4	1.57
K	2	2.07	3.0	0.07	323.3
P x K in BL	10	0.92	0.94	1.49	0.47
R	2	1.15	1.01	2.15	5.29
N x P in BL	20	1.37	1.49	0.85	1.11
N x K	8	1.61	1.83	1.0	0.94
N x R	8	2.37	2.26	0.95	1.13
Remainder	304	-	-	-	
Total	449	-	-	-	

Note: BL = block

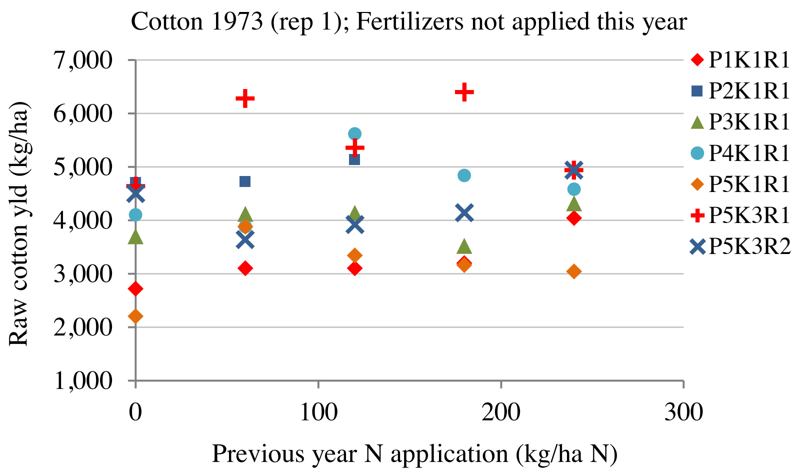

Fig. 16. The response in raw cotton yield to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure treatment (P5K3R1 vs. P5K3R2). The data refer to replicate-1 only. Note that fertilizers were not applied to this crop.

The lint yield (kg/ha) in levels N1, N2, N3, N4, N5 was 1,553, 1,726, 1,769, 1,744, and 1,761 kg/ha, respectively (SE=38.2). The effect of P was: 1,583, 1,812, 1,715, 1,735 and 1,733 kg/ha in levels P1, P2, P3, P4 and P5, respectively. The effect of R was: 1,681, 1,729 and 1,733 kg/ha (SE=28.6) in levels R1, R2, and R3, respectively. The K effect was 1,669, 1,713, 1,761 kg lint/ha in levels K1, K2 and K3 (SE=26.5).

Treatments effect on soil P concentration was limited to P application rate: 1.5, 5.5, 4.8, 6.5 and 16.2 mg P/kg in levels P1, P2, P3, P4, and P5, respectively. In treatment R2, the soil P concentration exceeded the concentration in R1: 9.0 vs. 5.2 mg/kg.

The relationship between $NaHCO_3$-P (0-20 cm) and cotton raw yield is presented for some selected NK treatments in Fig. 17. In the three K1 treatments the maximum response to soil P was obtained at a concentration of ~ 15 mg P/kg soil. At level K3, the positive response to soil P increased up to 30 mg P/kg and declined thereafter.

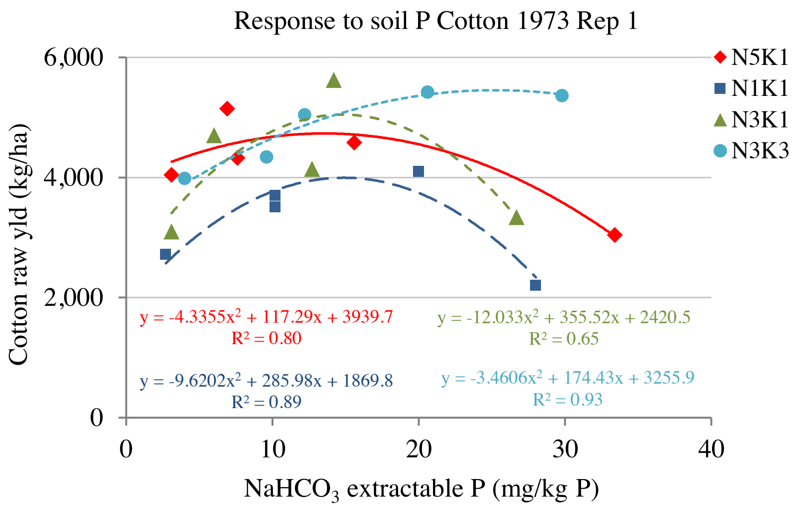

Fig. 17. The relationship between $NaHCO_3$ extractable P in soil (0-20 cm soil layer) and raw cotton yield under different NK level combinations (1973). Data points belong to replicate-1 plots.

The soil K concentration ($CaCl_2$ extract) was affected significantly by the K application rate: 6.7, 9.3, 12.2 mg K^+/L in treatments K1, K2 and K3, respectively (SE=0.15). The corresponding exchangeable K in K levels K1 and K3 was 10.5 and 16.1 meq K/100 g soil.

The response in raw cotton yield to soil $CaCl_2$ soluble K (1:7 extract) is presented in Fig. 18. The results show different trends, and only in combination with N1P1R1 was a positive response in yield to soil K> 5 mg/L obtained. The encircled point seems to be an experimental deviation. More insight into this relationship can be obtained by analyzing the entire data set in the above Excel file.

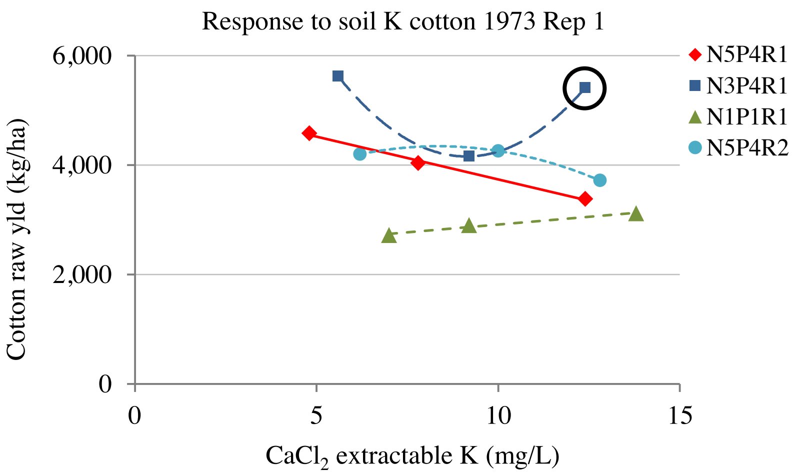

Fig. 18. The relationship between 0.01 M $CaCl_2$ extractable K in soil (0-20 cm soil layer, soil: solution ratio 1:7) and raw cotton yield under different NPK level combinations (1973). The encircled point seems to be an experimental deviation in yield determination.

2.1.14 The 1974 season (vetch)

In 1974, the studied crop was vetch. No fertilizers were applied during this season and due to technical problems no measurements were taken. The file can be viewed for climate data by clicking: BDPP1974.

2.1.15 The 1975 season (wheat)

In 1975, the studied crop was wheat. The tested variables were grain yield and N, P, K yields. The file can be viewed by clicking: BDPP1975.

Table 20. The short ANOVA of the wheat variables.

		Wheat variables (1975)			
Factor	DF	Grain yld	N yld	K yld	P yld
		ANOVA F			
N	4	0.88	23.6	17.8	7.75
P in BL	5	9.45	5.95	10.7	5.02
K	2	3.27	3.27	0.12	1.83
P x K in BL	10	0.85	1.45	1.04	3.50
R	2	3.72	1.21	230.7	0.32
N x P in BL	20	8.29	0.45	0.26	0.39
N x K	8	0.31	0.24	0.07	0.32
N x R	8	6.96	0.13	1.93	0.11

Note: BL = block

The wheat grain yield (kg/ha) in the main N treatmentN1, N2, N3, N4, N5 levels was 4,533, 4,807, 4,776, 5,004, and 4,717 kg/ha (SE=180). The effect of P was: 4,193, 4,823, 4,951, 5,009 and 4,859 kg/ha in levels P1, P2, P3, P4 and P5, all respectively. The effect of manure was: 4,598, 4,787 and 4,817 kg/ha (SE=72) in treatments R1, R2, and R3, respectively. The effect of K on grain yield was significant but adverse.

A graphical presentation of the interrelationships in grain yield between N, P, K and R is given in Fig. 19. The high yield at zero N application in P5 treatments is surprising and attributed to experimental error in yield determination. Excluding these points, the response to N level is bell-shaped with a maximum around 150 kg N $ha^{-1}year^{-1}$. At any N level, the yield in P5K3R1 exceeded the yield in P5K3R1. The effect of P in Fig. 19 is hard to evaluate.

The plants were sampled at the end of the season to determine the N, P, K yields (note: not all field plots were sampled). The N yield in treatments N1, N3, N5 was 88, 88 and 160 kg/ha N (SE=8.8) and, in treatments P1, P3, P4 and P5, 81, 135, 115 and 143 kg/ha N, all respectively. The K and R treatments had no clear effect on N yield.

The plant K yield was 223 and 228 kg/ha K (SE=9.0) in treatments K1 and K3, respectively. In treatments R1 and R2, the K yield values were 214 and 237 kg K/ha (SE=1.1). In N1, N3 and N5, the K yield was 201, 187 and 287 kg K/ha (SE=18.9). In P rates P1, P3, P4 and P5 the K yield was 164, 245, 255 and 297 kg K/ha.

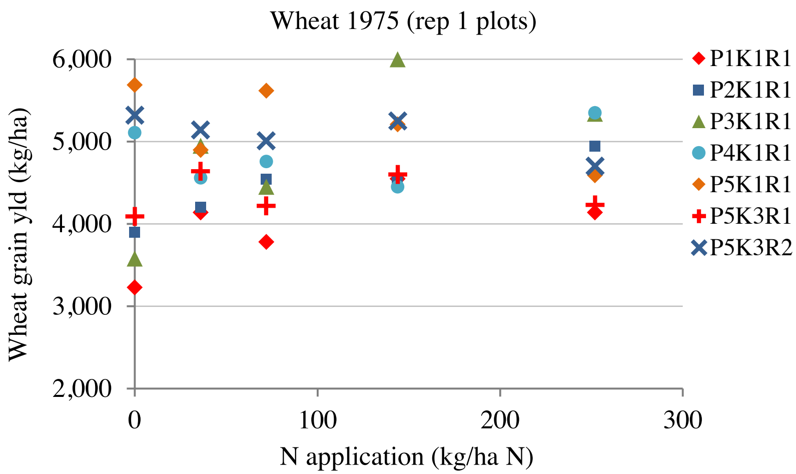

Fig. 19. The response in wheat grain yield to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure treatment (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots.

The wheat P yield was only significantly affected by the P treatment: 9.6, 14.5, 16.3 and 21.5 kg/ha P in treatments P1, P3, P4, and P5, and respectively.

2.1.16 The 1976 season (sorghum)

The sorghum report can be viewed by clicking the link: BDPP1976. Studied variables were dry grain yield, % dry matter (DM) in grains, and soil P and K (both by $NaHCO_3$ extraction) in the 0-20 and 20-40 cm soil layers. Soil sampling took place in April 1976. No fertilizers were applied during this season. Note: from this year on treatment R3 did not receive P and K fertilizers and green manure (N fertilizer as before).

The dry grain yield of the sorghum plants at harvest was 2,521, 2,876, 2,986, 3,117 and 3,210 kg/ha for treatments N1, N2, N3, N4, and N, respectively (SE=3.15). The yield was invariant to K and R treatments (varying between 2,446 and 3,252 kg/ha). A graphical presentation of the interrelationships in grain yield between N, P, K and R is given in Fig. 20.

The statistics of the % DM content in grain was missing in the original report but the data is itself available in the above link.

Table 21. The short ANOVA of the sorghum variables.

Factor	DF	Sorghum variables (1976) Dry grain yield	% DM in grain	Soil P, K P 0-20	P 20-40	K 0-20	K 20-40
		ANOVA F					
N	4	2.40	data	11.4	9.2	10.7	11.8
P in BL	5	5.77	(variable	84.6	86.4	2.52	6.23
K	2	1.17	346)	0.07	0.10	181.3	129.9
P x K in BL	10	1.11	missing	1.16	0.58	1.13	0.20
R	2	1.0		12.49	5 .79	8.85	2.50
N x P in BL	20	1.75		2.32	1.55	0.79	1.51
N x K	8	1.43		1.16	1.15	0.37	1.18
N x R	8	3.45		2.05	3.46	2.71	1.07
Remainder	304	-					
Total	449	-					

Note: BL = block

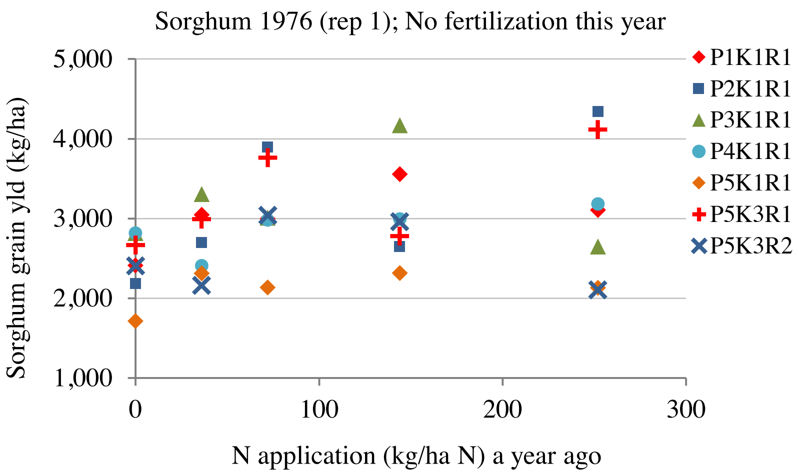

Fig. 20. The response in sorghum dry grain yield to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure treatment (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots.

The $NaHCO_3$ (0.5 M) extractable K concentration in the 0-20 cm soil layer was affected significantly by K application level: 121, 137 and 156 mg/kg K in levels K1, K2 and K3, respectively (SE=1.3). The same effect was found in the 20-40 cm soil layer where the soil K concentration in levels K1, K2 and K3 was 118, 136 and 159 mg/kg K, respectively (SE=1.8).

The relationships between the sorghum dry grain yield and $NaHCO_3$ extractable K in soil (Bar-Yosef and Akiri, 1978) are shown in Fig. 21. The response to K was negative under N5P4 and N3P4, and positive in N1P1; under R2 (dairy manure) the response was positive when moving from level K2 to K3.

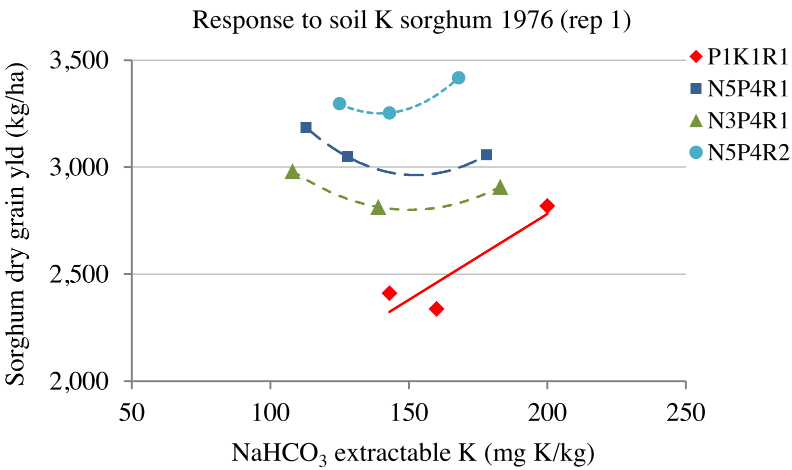

Fig. 21. The relationships between sorghum dry grain yield and pre-seeding $NaHCO_3$ extractable K in soil. All the data points belong to treatment R1 and replicate 1.

The soil P concentration in the 0-20 cm soil layer increased with increasing P fertilization level: 5.6, 8.5, 10.5, 11.6 and 18.6 mg/kg P in levels P1, P2, P3, P4, and P5, respectively. It declined with increasing N fertilization level: 11.7, 11.2, 10.8, 10.2 and 10.2 in N levels N1, N2, N3, N4 and N5, respectively (SE=0.2). The soil P in R levels R1, R2 and R3 was 11.0, 12.5 and 9.4 mg/kg P (SE=0.42). The K level had no effect on soil P in the top soil layer.

The relationship between $NaHCO_3$ extractable soil P (0-20 cm) and sorghum dry grain yield is shown in Fig. 22. No fertilizers were applied this year, which may explain the unsmooth functions.

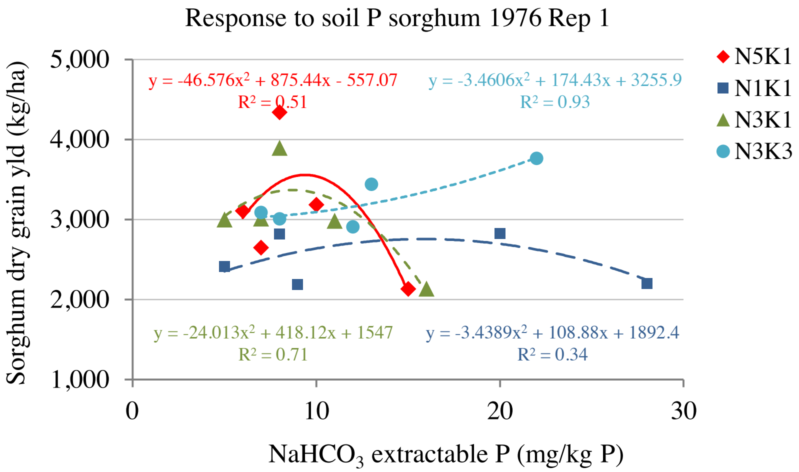

Fig. 22. The relationships between sorghum dry grain yield and pre-seeding $NaHCO_3$ extractable P in soil. All the points were subject to treatment R1 and replicate-1.

The soil P concentration in the 20-40 cm soil layer increased with increasing P fertilization level: 5.9, 8.6, 9.4, 11.1 and 17.6 mg/kg P in treatments P1, P2, P3, P4 and P5, respectively. Soil P concentration was barely affected by N and K fertilization levels, but in treatment R1, R2 and R3 it was 9.4, 12.3 and 9.9 mg/kg P (SE=0.63).

2.1.17 The 1977 season (oats and corn)

In 1977, two crops were grown: oats and corn. Due to technical problems no measurements were carried out in these two crops. The files with their fertilization, irrigation and weather data, can be viewed by clicking: BDPP1977 (for oats) and BDPP1977a (for corn).

2.1.18 The 1978 season (cotton)

In 1978, the study crop was cotton. The tested variables were raw and lint cotton yield. Only part of the experiment was sampled, therefore the routine ANOVA statistics are missing. The crop file entailing the partial results can be viewed by clicking: BDPP1978.

The raw cotton yield response to N, in combination with three levels of P (at K1R1), two levels of K (at P1R1 and P2R1) and two levels of R (at P1K1), is presented in Fig. 23. In all PKR combinations, the response to N was bell-shaped with a maximum yield obtained at an N application rate of ~150 kg N/ha. The maximum and minimum yields were obtained under P3K3R2 and P1K2R1, respectively. Potassium level K2 had no advantage in yield over K1 under P1R1, and K3 did not increase yield relative to K2 under P2R1.

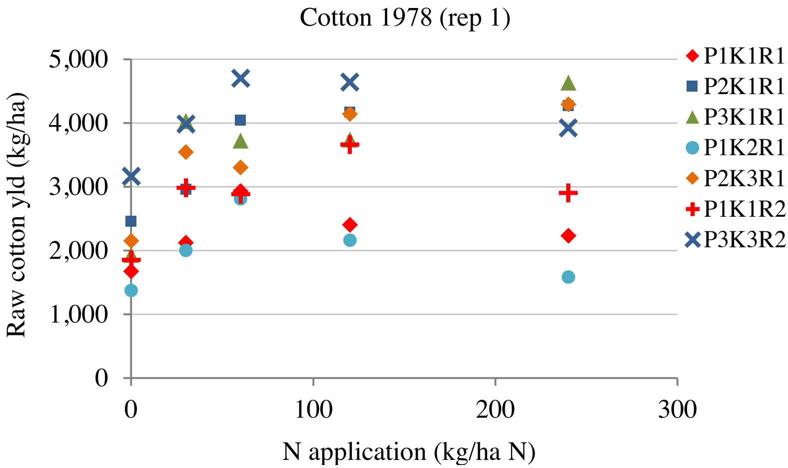

Fig. 23. The response in raw cotton yield to five levels of N and three levels of P under level K1; to two levels of K (P1K1R1 vs. P1K2R1), and to manure treatment (P1K1R1 vs. P1K1R2, and P3K3R2). The data points belong to replicate-1 plots.

2.1.19 The 1979 season (cotton)

In 1979, the study crop was cotton. The only tested variable was raw cotton yield. The routine ANOVA statistics are missing because the experiment was sampled only partially. The data file can be viewed in: BDPP1979. A very clear bell-shaped response in raw cotton yield to N application level was obtained, with similar dependency on the P addition rate (response curve not presented), which is compatible with the 1978 cotton results.

2.1.20 The 1980 season (cotton)

In 1980, the study crop was cotton. The tested variables were raw cotton yield, lint yield, % lint, single boll weight, and soil NO_3-N, P and K in the 0-20 and 20-40 cm soil layers. The routine ANOVA statistics are missing in the original report for this year even though all the experimental plots were sampled. The cotton file for 1980 can be viewed by clicking: BDPP1980. A graph of the main treatment effects on raw cotton yield is presented in Fig. 24.

The fluctuations in yield were considerable in this cropping season, masking the actual response to P and K. The overall effect of N was clearer, showing a positive response to N addition from 0 to 120 kg N/ha. Further increases to 240 kg N/ha did not increase yield.

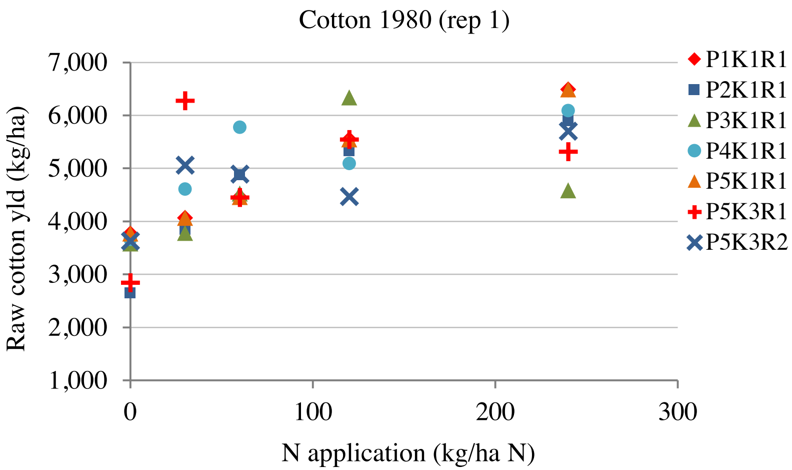

Fig. 24. The response in raw cotton yield (1980) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure treatment (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots.

The relationships between $NaHCO_3$ extractable P and K (Bar-Yosef and Akiri, 1978) and raw cotton yield are shown in Figs. 25 and 26, respectively. The response to soil P was insignificant at N1K1 and N5K1, but in treatments N3K1 and N3K3, where N is not a growth limiting factor, it was bell-shaped, with a maximum at ~30 mg P/kg.

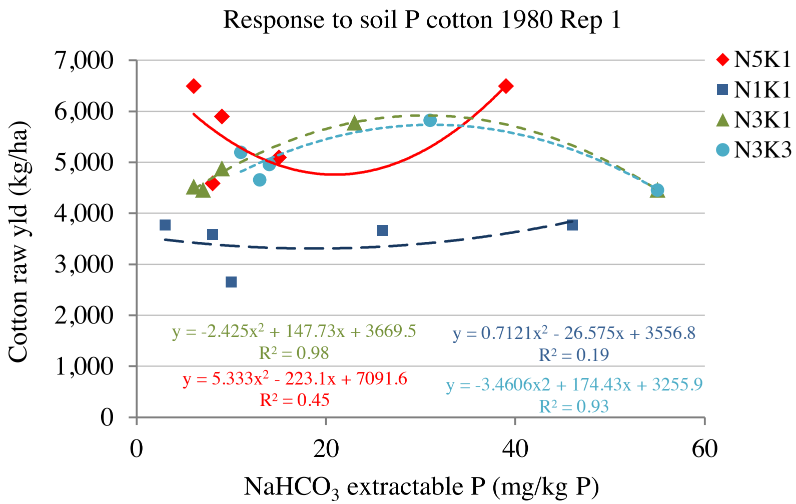

Fig. 25. The relationship between raw cotton yield (1980), concentration of $NaHCO_3$ extracted P in soil (0-20 cm), and NK application rates.

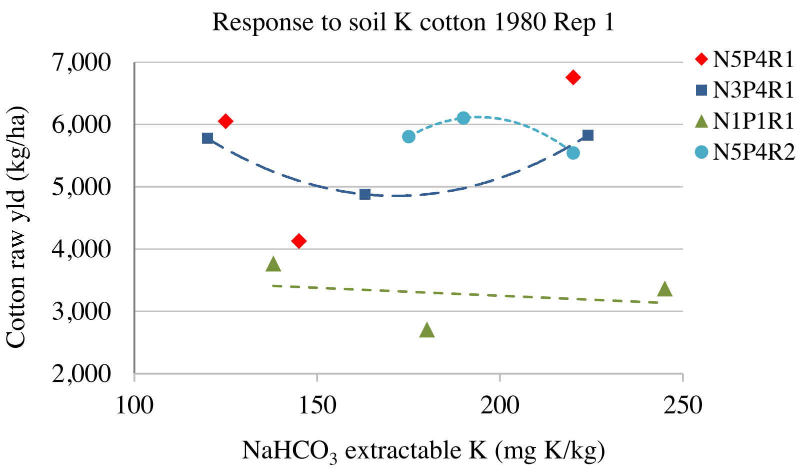

Fig. 26. Cotton raw yield as a function of soil available K (0-20 cm) under four NPR application levels (0-20 cm).

The response in raw cotton yield to available K (estimated by the $NaHCO_3$ extracting method, Bar-Yosef and Akiri, 1978) is depicted in Fig. 26. No clear relationship was obtained in any of the presented four NPR combinations.

In 1980, the 20-40 cm soil layer was also sampled. A comparison between the concentration of $NaHCO_3$ extracted P in the 0-20 and 20-40 cm soil layers in the plots of three blocks is shown in Fig. 27. A similar comparison for $NaHCO_3$ extracted K is presented in Fig. 28.

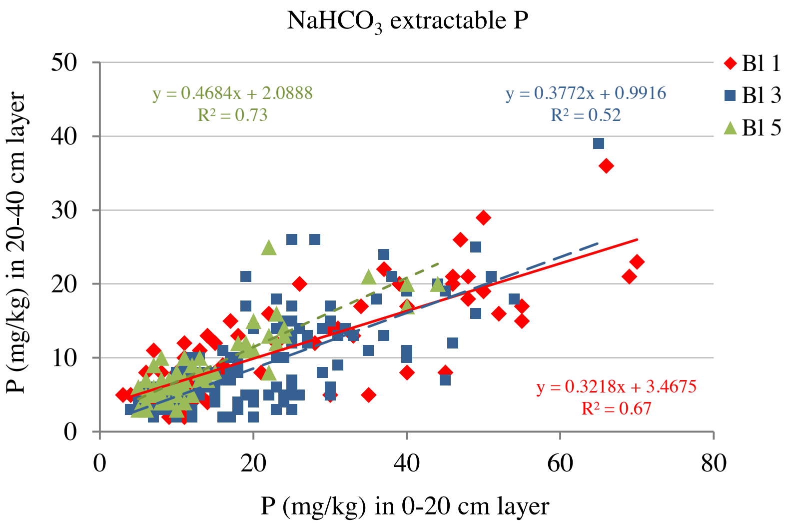

Fig. 27. The concentration of $NaHCO_3$ extracted P in the 0-20 cm soil layers vs. the concentration in the 20-40 cm soil layer. Soil samples were taken from three out of the five experimental blocks.

The results indicate that the concentrations of available P in the 20-40 cm soil layer were 32 to 47% of the concentrations in the 0-20 cm soil layer, depending on block number. In the case of K the concentrations in the 20-40 cm layer were 45% of the concentrations in the top soil layer, but only in blocks 1 and 3; in block 5 the results were illogical.

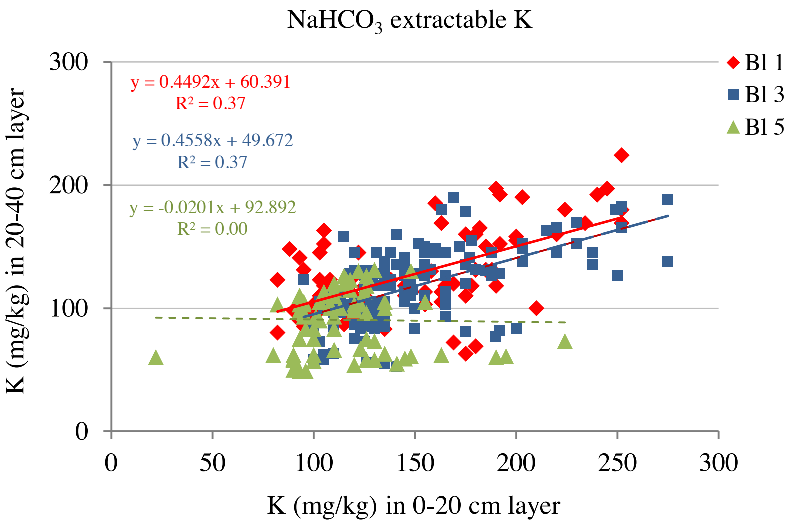

Fig. 28. The concentration of $NaHCO_3$ extracted K in the 0-20 cm soil layers vs. the concentration in the 20-40 cm soil layer. Three out of five blocks (Bl) were sampled.

2.1.21 The 1981 season (cotton)

In 1981, the study crop was cotton. Dairy manure was added in treatment R2. The only tested variable was raw cotton yield. The routine ANOVA statistics are missing in the original report for this crop. The cotton file 1981 can be viewed by clicking: BDPP1981.

Graphical presentation of main treatment effects on raw cotton yield is shown in Fig. 29.

The obtained response to N was very similar to that in 1980, but in this year (1981), the crop responded better to P and K: while in 1980, levels P3 and K1 were optimal, in 1981 the P4 and K3 levels were best. It is noted, however, that in Fig. 29 the P and K performance were tested in combination with a limited number of KR and PR application rates, respectively, and in order to characterize their effect more thoroughly, the entire hyperlinked data set (BDPP1981.xlsx) should be analyzed.

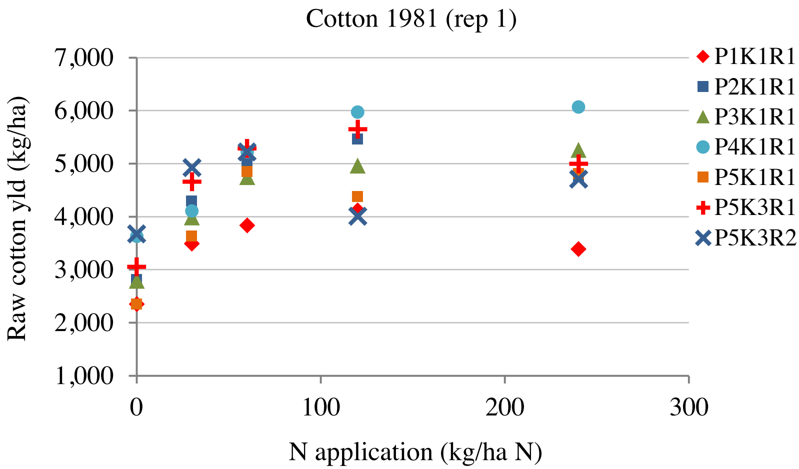

Fig. 29. The response in raw cotton yield (1981) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots.

2.1.22 The 1982 season (cotton)

In 1982, the study crop was cotton. The only tested variable was raw cotton yield. The routine ANOVA statistics are unavailable for this crop. The link to the file is: BDPP1982.

Graphical presentation of the main treatment effects on raw cotton yield is given in Fig. 30.

The yield in 1982 was higher than in previous years and the response to N extended to ~250 kg N/ha, which is about the peak of the bell-shaped response line. Likewise, the maximum yield was obtained in P and K levels P5 and K3. Manuring did not increase yield.

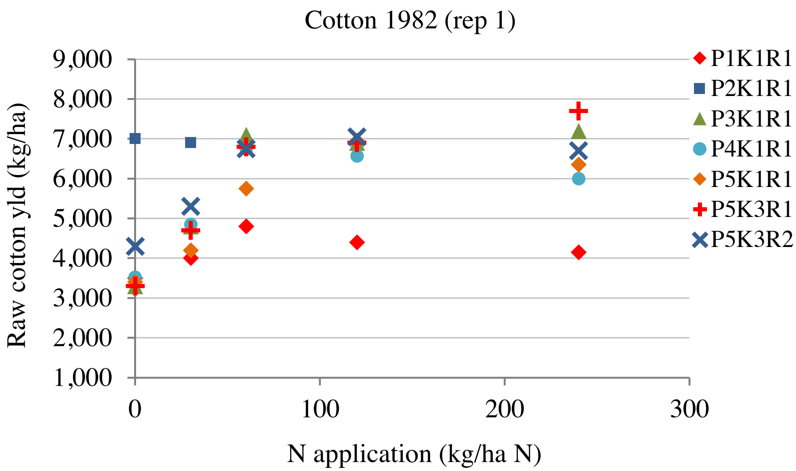

Fig. 30. The response in raw cotton yield (1982) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data points belong to replicate-1plots.

2.1.23 The 1983 season (cotton)

In 1983, the study crop was again cotton. Two variables were tested: raw cotton yield and single boll weight. The routine ANOVA statistics are unavailable for this crop. The cotton file 1983 can be viewed by clicking: BDPP1983.

Graphical presentation of the main treatment effects on raw cotton yield is shown in Fig. 31. The response to N is bell-shaped with a maximum at ~180 kg N/ha. The optimum P and K rates were P4 and K3 (K2 not presented and not compared). Manuring had no positive effect on the raw cotton yield.

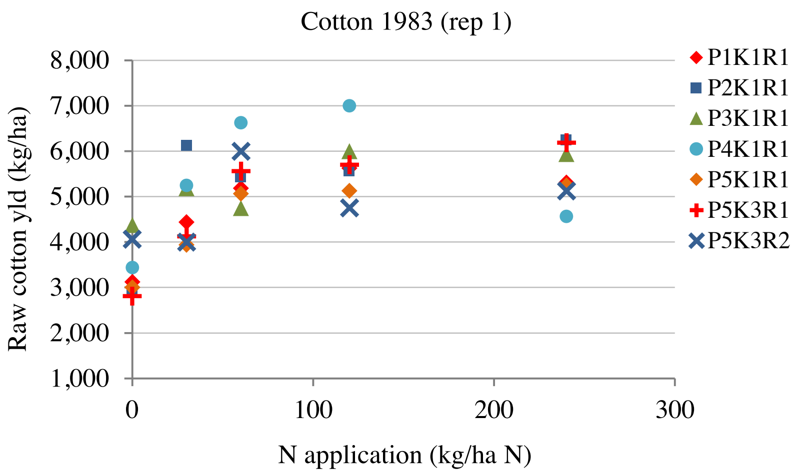

Fig. 31. The response in raw cotton yield (1983) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data refer to replicate-1 only.

2.1.24 The 1984 season (cotton)

In 1984, the study crop was cotton. The tested variables were raw cotton yield and boll weight. The routine ANOVA statistics are not available for this crop. The 1984 cotton file is found in: BDPP1984. The main treatment effects on raw cotton yield are shown in Fig. 32.

Despite the relative lower yield that was obtained in the years 1980-1983, the response to N, K and R was very similar to that reported earlier. In the case of P, the response stopped at P3 whereas in the previous years it extended to P4.

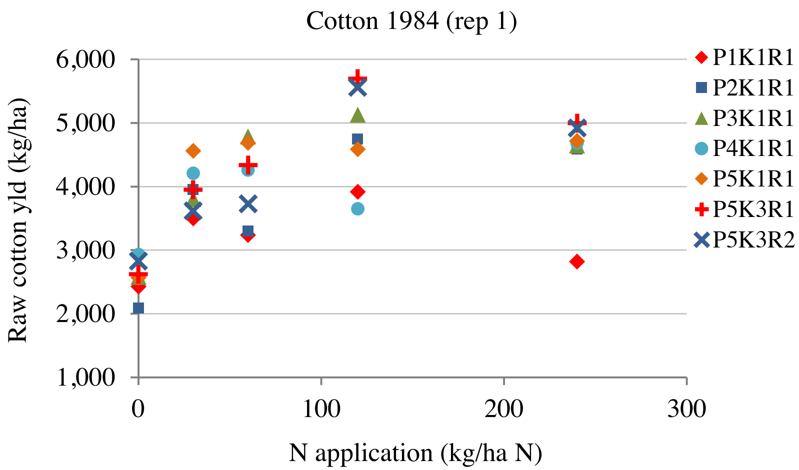

Fig. 32. The response in raw cotton yield (1984) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots.

2.1.25 The 1985 season (Cotton)

In 1985 the test crop was cotton. The studied variables were: raw cotton yield, maximum raw cotton yield (selected plants having the highest yield in given field plots), lint yield and single boll weight. The ANOVA statistics are not available for this crop. The cotton file 1985 can be viewed by clicking: BDPP1985. Graphical presentation of the main treatment effects on routine raw cotton yield is shown in Fig. 33A. The results of selected plants that gave the highest yield in each field plot are shown in Fig. 33B.

The response curves in the two figures are identical, and the difference in yield between the mean and best performing plants was ~15%. The peak in yield coincided with an N dose of ~160 kg N/ha and P level P5. Under the given growth conditions, the dairy manure treatment (R2) increased yield relative to the un-manured treatment R1 (at P5K3), and the effect of K1 was equal to the effect of K3 (at P5R1).

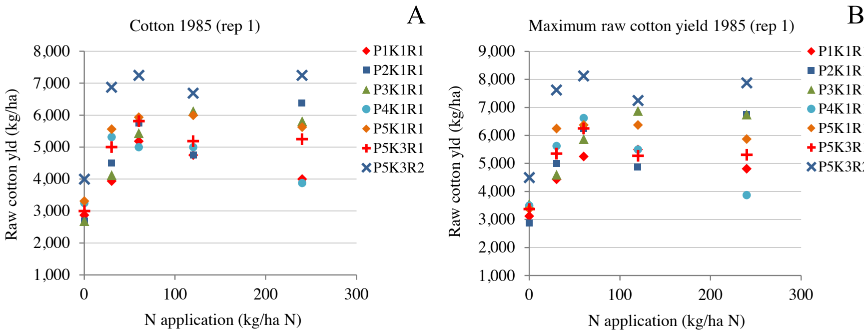

Fig. 33. The response in raw cotton yield (1985) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data refer to replicate-1 only. A. Average yield (as in previous Figures). B. Maximum yield obtained by picking parts of rows with highest yield per plant.

2.1.26 The 1986 season (wheat)

In 1986, the study crop was wheat. One variable was tested: grain yield. The routine ANOVA statistics are not available for this crop. The wheat file 1986 can be viewed by clicking: BDPP1986.

A graph of the main treatments effects on grain yield is presented in Fig. 34.

The optimal N, P and K doses (representing the treatment combinations presented in Fig. 34) were 150 kg N/ha and levels P4 and K1, compatible with the optimal values in the 1970 wheat experiment. In both cases, dairy manure had no positive effect on yield.

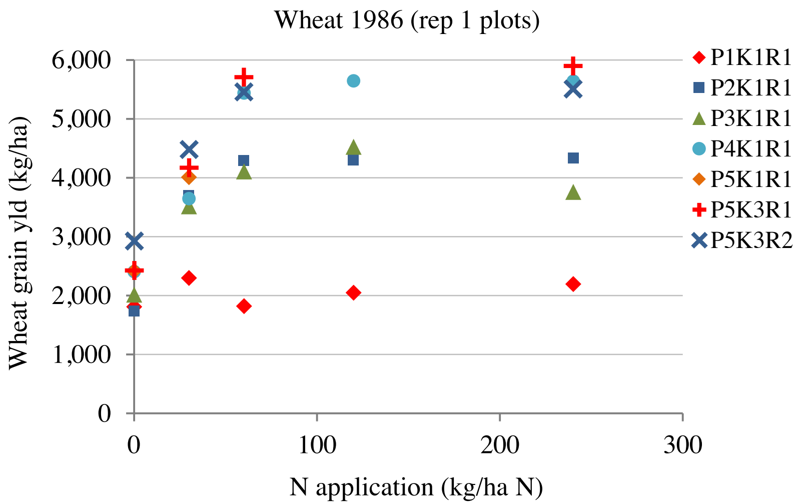

Fig. 34. The response in wheat grain yield (1986) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots.

2.1.27 The 1987 season (wheat)

In 1987, the study crop was wheat. In this year only N fertilizer was applied to the field. One variable was tested: grain yield. After harvest the soil in selected treatments (N1P1K1, N5P1K3, N3P3K1, N4P5K1 and N5P5K3) was sampled to a depth of 12.0 m, and in 120 plots (60 treatments) the soil was sampled down to 2.10 m. Unfortunately the original files containing the concentration profile values vanished, therefore only scanned graphs from the original hardcopy report could be used.

The 1987 wheat file can be viewed by clicking: BDPP1987. The standard ANOVA statistics of this crop are unavailable. The main treatments effects on grain yield are shown in Fig. 35. Despite the high yield (up to 8,000 kg/ha), the response to N, P, K was very similar to the response in 1970, 1975 and 1986 that had a yield<6200 kg grain/ha.

The 0-210 cm soil profile depicting the Cl^- and EC distribution in the soil as function of N application rate is presented in Fig. 36.

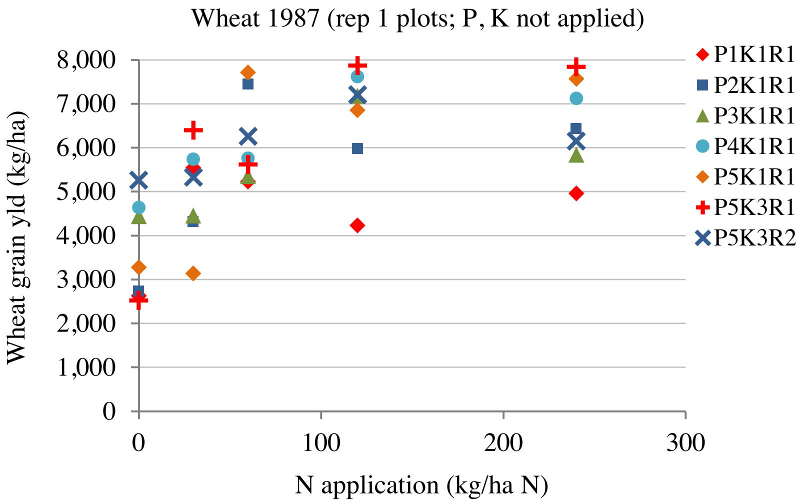

Fig. 35. The response in wheat grain yield (1987) to long-term five levels of N x five levels of P x one level of K. Also presented is the response to two levels of K (P5K1R1 and P5K3R1), and to manure application (P5P5K3R1 and P5K3R2). All data points belong to replicate-1 plots. Note that P and K have not been added to the experimental plots in 1987.

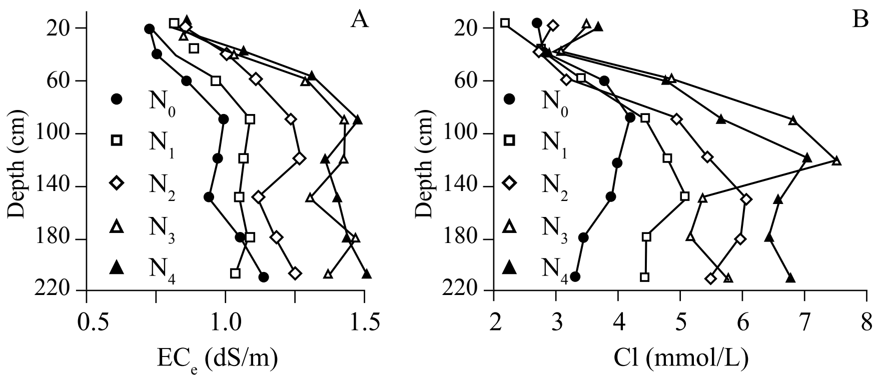

Fig. 36. A. The effect of five N application levels (at zero P fertilization) on the distribution of EC in soil (saturated extract, ECe) in July 1987. B. The same, only Cl^- instead of EC and level P5. Note that N0, N1, N2, N3 and N4 in the Figures are called N1, N2, N3, N4 and N5, respectively, in the above Figures and in the Excel files. Each point in the Figure is the average of 24 field plots. Source: Feigin and Halevy (1995).

The distribution of EC_e and Cl^- in the 0-1200 cm soil profiles is presented in Fig. 37. A clear salts accumulation zone, starting at a depth of ~9 m, is observed. This peak is much larger than the secondary peak found at a depth of ~1 m (Fig. 36). In the high fertilization rate treatments (e.g. N4P2K2, N3P4K0), the main peak is less deep than the peak of the low fertilization rate treatments (N0P0K0, N2P2K0). This stems from lower transpiration by nutrient-deficient plants than by larger, unstressed plants, which leaves more water available for leaching.

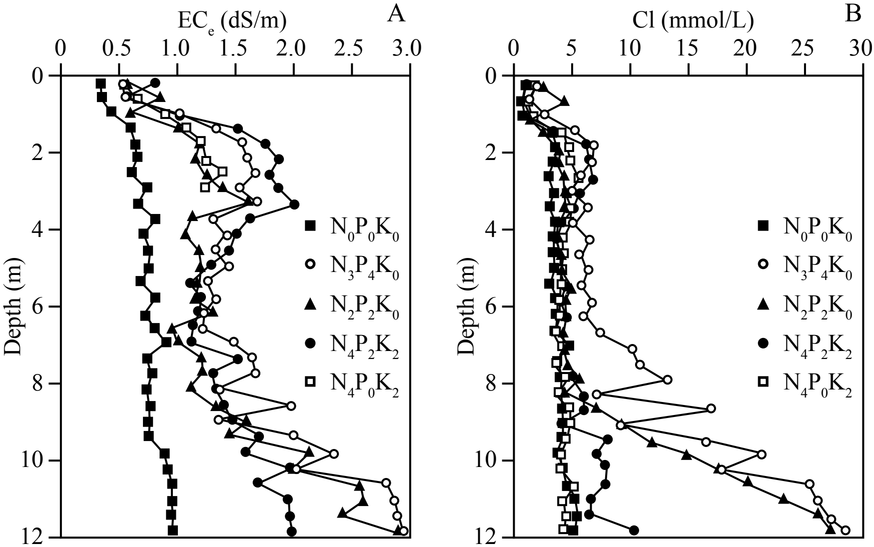

Fig. 37. The effect of NPK application rates on the distribution of EC_e and Cl^- (both in saturation extract) in soil on August 1987. Note that soil depth is 12 m. Source: Feigin and Halevy (1995).

The distributions of specific nutrients in 1987 are shown in Figs. 38 to 40. The nitrate profile (Fig. 38A) was quite uniform with depth, with an exception at a depth of ~1 m where a minimum concentration is observed. This minimum coincides with the main soil root volume of the studied crops. The order of nitrate profiles agrees with the N application rates to the soil.

The sulfate profiles (Fig. 38B) show a very pronounced peak at a depth of ~2 m, which is outside the soil root volume. The concentration of the water soluble SO_4^{2-} reached values similar to those prevailing in gypsum saturated solution. The SO_4^{2-} originated from the ammonium sulfate fertilizer. The concentration peak could not be shallower because Ca and SO_4 were leached by the irrigation water.

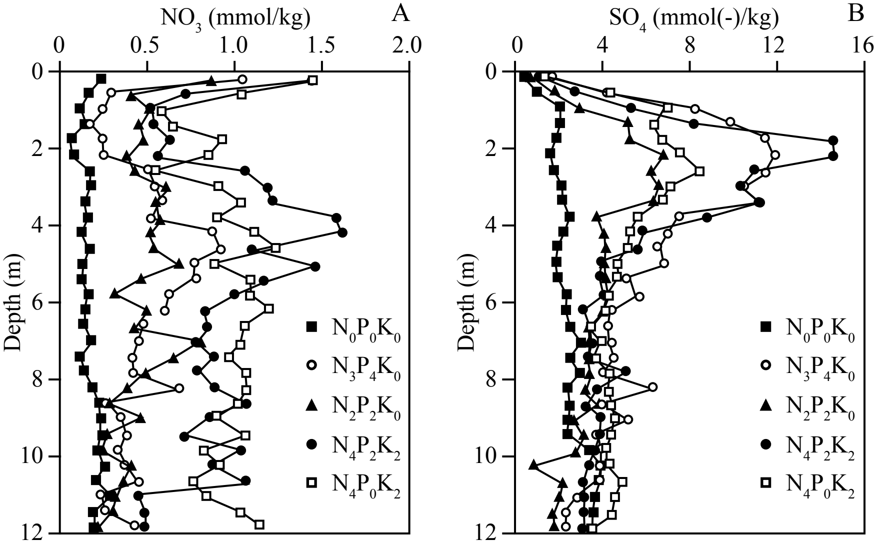

Fig. 38A, B. Effects of NPK application levels on the distributions of KCl extracted NO_3^- (a) and water soluble (saturation extract) SO_4^{2-} (b) in soil. The soil was sampled during August 1987. Source: Feigin and Halevy (1995).

The Ca leaching (Fig. 39A) was induced by $CaCO_3$ dissolution, stimulated by decreased pH stemming from NH_4 nitrification and uptake by roots. Like sulfate, the water soluble Ca^{2+} concentration was highest in all treatments at a depth of ~2 m. Water soluble K concentration also had a peak at that depth (Fig. 39B) but was much smaller than Ca. Another difference between K and Ca was that the highest K concentration was found at a depth of 0.5 to 1 m, resulting from annual fertilizations. The suggested mechanism that Ca leached due to $CaCO_3$ dissolution in the root zone is supported by the profile of $CaCO_3$ concentration in the soil at the same time (Fig. 40). Another source of labile Ca was the superphosphate fertilizer; the data in Fig. 39A proves it by showing that, at any soil depth, the water soluble Ca^{2+} concentration increased as the P application level increased. In all reported treatments, the concentrations of both Ca^{2+} and K tended to accumulate at a depth below 7 m.

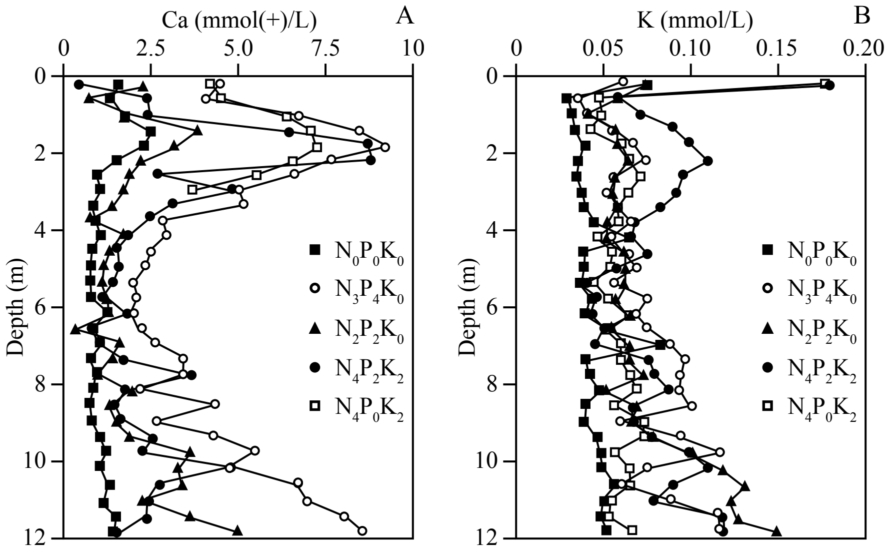

Fig. 39A, B. The effect of NPK treatments on the distribution of Ca^{2+} (A) and K^+ (B) in soil saturation extract during August 1987. Source: Feigin and Halevy (1995).

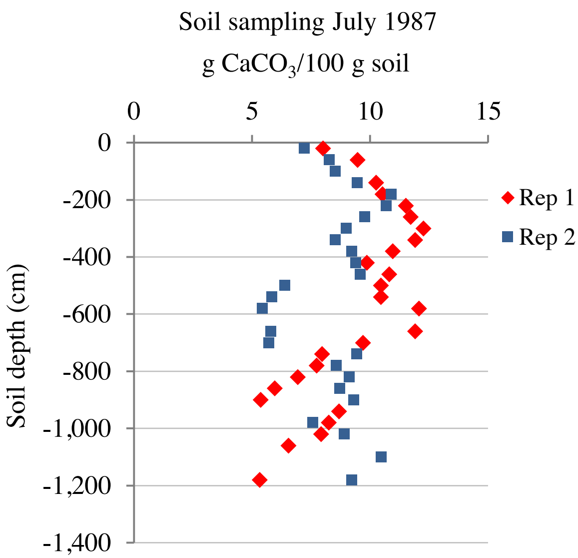

Fig. 40. The carbonate concentration in soil as a function of depth in two replicates of treatment N5P5K3. Soil was sampled during July 1987. Source: P. Fine, ARO, Institute of Soil, Water and Environmental Sciences. Unpublished material.

Like Ca^{2+}, water soluble Mg^{2+} concentration had a peak at a depth of 2m (Fig. 41A). The source of Mg could be indigenous dolomite in the soil displaced from the soil root volume by dissolution and leaching. The water soluble Na profile in soil (Fig. 41B), showing gradual accumulation in the soil, is characteristic of a non-precipitating, easily displaced exchangeable cation, which is added in irrigation water in large quantities, and leached by winter rain and excess irrigation water deep into the soil.

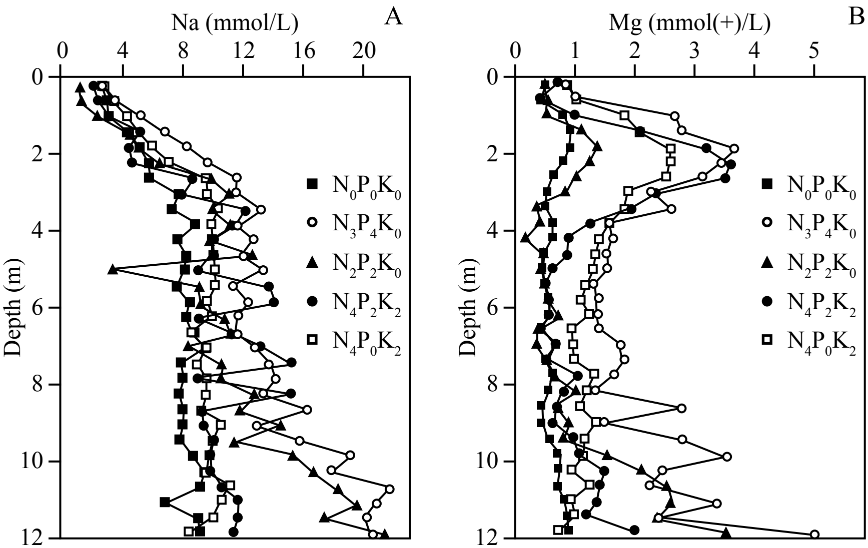

Fig. 41A, B. The effect of NPK treatments on the distribution of (A) Na^{+} and (B) Mg^{2+} concentrations in soil (saturation extract). Soil sampling was done in August 1987. Source: Feigin and Halevy (1995).

2.1.28 The 1988 season (wheat)

In 1988 the study crop was wheat. In this year, only N fertilizer was applied to the field. One variable was tested: grain yield. The routine ANOVA statistics are unavailable for this crop. The data file can be viewed by clicking: BDPP1988. The main treatments effects on the grain yield are shown in Fig. 42. The lack of P and K fertilization drastically reduced the grain yield relative to previous years, but the response to N application level was linear, not showing the bell-shaped response prevailing when all nutrients are added at sufficient levels. Application levels P5, K3 and R2 were optimal under the specific growth conditions during this year. It is suggested that level N5 enhanced grain yield because the extra effect of NH_4^+ on displacing exchangeable-K and reducing soil pH and thus dissolving precipitated P was imperative under the imposed growth conditions during this year.

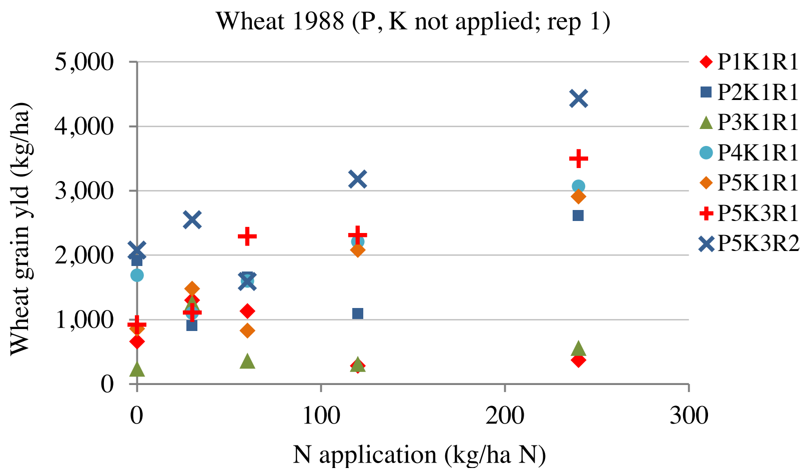

Fig. 42. The response in wheat grain yield (1988) to five levels of N, five levels of P, two levels of K and dairy manure. In this season, P and K have not been applied and their residual effect is examined. The data points belong to replicate-1 plots.

2.1.29 The 1989 season (wheat)

In 1989, the study crop was wheat. No fertilizers were applied to the field during this season. One variable was tested: grain yield. The routine ANOVA statistics are unavailable for this crop. The wheat file 1989 can be viewed by clicking: BDPP1989. The one year interruption in N supply shows that the residual effect of N is very limited and, except in application levels P5K1R1, there was no response to N application levels (Fig. 43). Level P5 was associated with the highest yield at levels N4 and N5 but, at lower N rates, the optimal level was P4. In the case of K, it was opposite: at levels N4, N5, level K1 gave higher yields than K2; and at N3, N2, the yield in K2 was higher. The dairy manure treatment (R2) gave a higher yield than un-manured plots (R1) but the comparison was done only under P5K3.

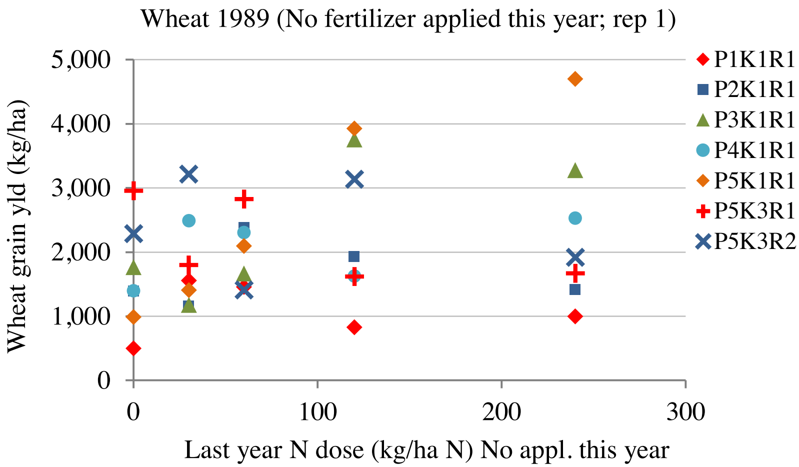

Fig. 43. The response in wheat grain yield (1989) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The effect of N, P, K is residual as none of them was added during this year. The data refer to replicate-1 only.

2.1.30 The 1990 season (fallow)

In 1990, the experimental plots were neither cropped nor fertilized. To see the weather data the 1990 file can be viewed by clicking: BDPP1990.

2.1.31 The 1991 season (canola)

In 1991, the study crop was canola. Fertilization was resumed according to the original plan. One variable was tested: canola grain yield. The routine ANOVA statistics are unavailable for this crop. The canola file 1991 can be viewed by clicking: BDPP1991. The grain yields in the N main treatment at application levels N1, N2, N3, N4 and N5 were 2,580, 2,490, 2,170, 2,080, and 2,130 kg/ha, respectively (F = 10.1). In main treatment P, application levels P1, P2, P3, P4 and P5, the yield was 1,980, 2,330, 2,440, 2,200 and 2,500 kg/ha, respectively (F = 8.9). The K level had no significant effect on canola grain yield. These responses are also depicted in Fig. 44 that shows some of the interactions in yield between N, P and K. At all levels of P and K, the grain yield increased by about 20% relative to the unfertilized control when 50 kg N/ha was added to the soil (level N1). Further increases in N application reduced the yield almost linearly. The optimal P application rate was P3 and only in N5 was it replaced by level P2. The difference in grain yield between levels K3 and K1 (at P5R1) was negligible at application levels N1 and N2, but in N3, N4 and N5, the yield for K3 was higher. Adding dairy manure at any N level (in combination with P5K3R2) had no positive effect on yield relative to the un-manured treatment (P5K3R1). As in previous test-crops, the reader is encouraged to explore for additional relationships and responses by analyzing the entire data file attached to this crop report.

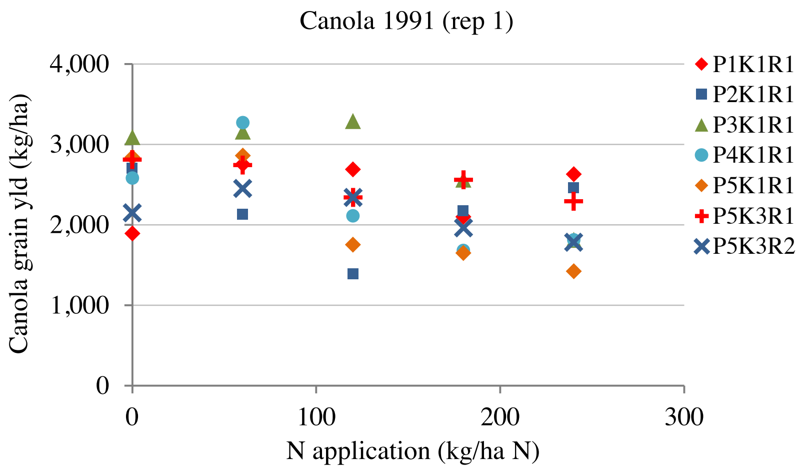

Fig. 44. The response in canola grain yield (1991) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). The data points belong to replicate-1 plots.

2.1.32 The 1992 season (wheat)

In 1992, the study crop was wheat. This crop was fertilized only by N (one dose before seeding as urea). The only measured variable was grain yield. The wheat file 1992 can be viewed by control/clicking: BDPP1992.

Table 22. The short ANOVA of the wheat grain yield.

Wheat grain yield (1992)		
Factor	DF	ANOVA F
N	4	8.56
P in BL	5	13.99
K	2	4.60
P x K in BL	10	2.16
R	2	8.66
N x P in BL	20	1.77
N x K	8	1.27
N x R	8	3.66
Remainder	304	-
Total	449	-

Note: BL = block

The grain yields in the main N treatment, application levels N1, N2, N3, N4 and N5 were 3,360, 4,120, 4,020, 4,480 and 5,210 kg/ha, respectively (SE=232). In the main P treatment, levels P1, P2, P3, P4 and P5, the yields were 3,240, 3,890, 4,620, 4,530 and 4,920 kg/ha, respectively. In the main K treatment, the application rates K1, K2 and K3 gave yields of 4,230, 4,060 and 4,420 kg/ha grains (SE=83). Note that P and K were not applied this year. Dairy manure (R2) gave ~10% higher yield than R1; R3 (received no P, K fertilizer for the last 15 years) gave ~15% lower yield than R1.

Some interactions between N, P and K are presented in Fig. 45. At levels P5, P4 and P3 the response in grain yield to N application rate was nearly linear with small slope common to the three P application levels. In P2 and P1 levels, the response to N was very weak and unclear.

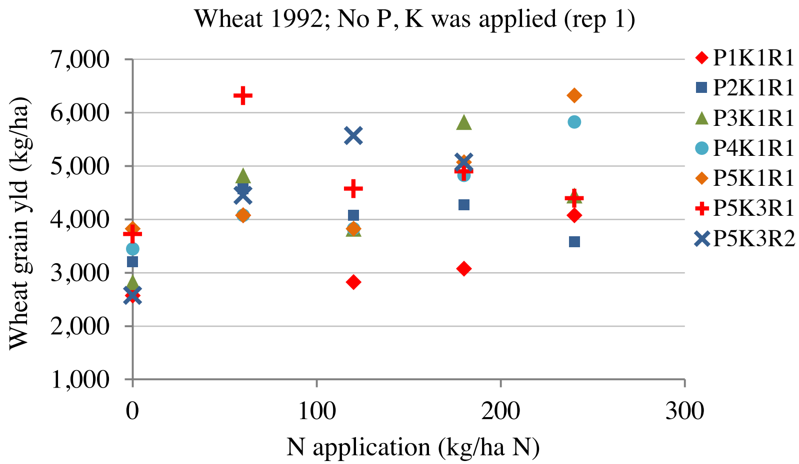

Fig. 45. The response in wheat grain yield (1992) to five N levels x five P levels at level K1; to two levels of K (P5K1R1 vs. P5K3R1), and to manure application (P5K3R1 vs. P5K3R2). No P, K was applied this year. The data points belong to replicate-1 plots.

2.1.33 The 1993 season (safflower)

In 1993, (the last experiment in the Permanent Plots experiment) the study crop was safflower. In this year, all the fertilizers were applied to the experimental plots and pelleted cattle manure replaced the bulk dairy manure in treatment R2. One variable was tested (not in all field plots): grain yield. All field plots were sampled (0-20 cm) 40 days after seeding but chemical analyses have not been carried out. Since only part of the field plots were sampled for yield the routine ANOVA statistics are unavailable for this crop. The safflower file 1993 (without any crop data) can be viewed by clicking: BDPP1993. The following verbal and graphical descriptions of the results were taken from the published report of this crop that did not include per plot data.

The safflower grain yield in the main N treatment, application levels N1, N2, N3, N4 and N5, was 1,550, 1,720, 1,710, 1,790, and 1,970 kg/ha (F = 15.0). In the main P treatments, application levels P1, P2, P3, P4 and P5, the yield was 1,300, 1,890, 1,880, 1,680 and 1,980 kg/ha, respectively (F = 18.3). In the main K treatment, the K level had no significant effect on safflower grain yield (average of K1, K2, K3 = 1750 kg/ha). In the main R treatment, the yields in R1 (no manure), R2 (dairy manure) and R3 (green manure and P, K fertilization ceased 16 years ago) were 1,810, 1,790 and 1,640, respectively (F = 8.3). The interactions between N (abscissa) and P are shown in Fig. 46 and between P (abscissa) and N in Fig. 47. There is a trend showing near linear increase in yield as N level increased from 0 to 240 kg N/ha (yield increase of ~20%). In the case of P, an increase from 0 to 12 kg P/ha increased yield (the magnitude depending on the N application level) but further increases in P had no effect on yield. Note that since the original yield data was unavailable, the original graphs from the hardcopy report are presented.

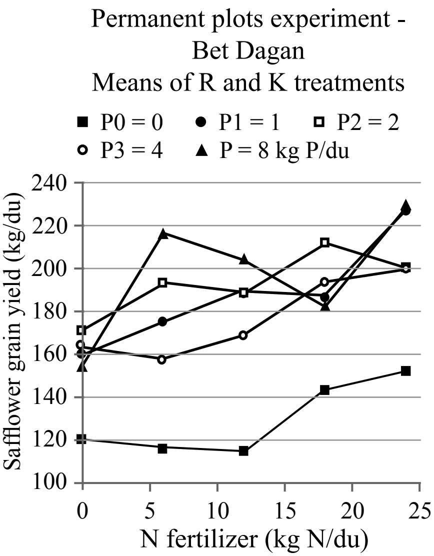

Fig. 46. Copy of the original graph showing safflower grain yield response to N addition at different P levels (means of K and R).

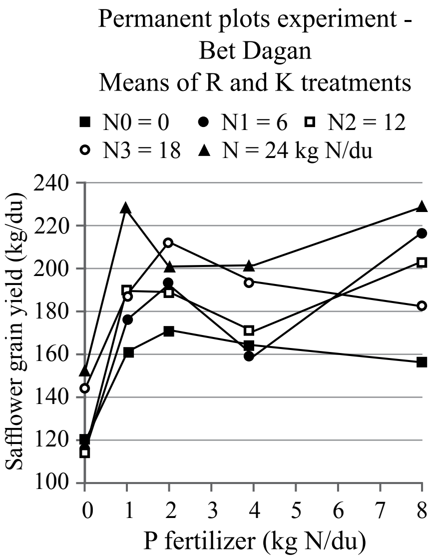

Fig. 47. Copy of the original graph showing safflower grain yield response to P doses at different N levels (means of K and R).

Note: A. In both Figures N0, N1, N2, N3, N4 and P0, P1, P2, P3, P4 are called in text N1, N2, N3, N4, N5 and P1, P2, P3, P4, P5. B. 1 dunam (du) = 1,000 m^2. C. The figures were copied as is in the hardcopy report.

3 Discussion

3.1 Annual response of different crops to fertilization

In Results, the per season yield response to fertilization was described. It included (where available) statistical analysis of main factors effect (N, P, K and manure) on yield and response curves of yield versus N application rate at different levels of P and K. The obtained response functions were crop dependent.

In chickpea (1962 and 1967), there was no positive response to N, or even small decline in yield as the dose increased from N0 to N4 (N1 to N5 in the Figures). The response to K and R was unclear and the optimum P level was P2.

Canola (1991) showed a response to N when its application rate was raised from 0 to 60 kg N/ha but further increases in the N level brought forth a decline in grain yield. The optimal P level was between level P2 and P3 (at K1R1); K3 gave a higher yield than K1 (at P5R1), and manuring had no effect on yield. Safflower (1993) is another crop with very narrow response in grain yield to N and P: from 0 to level N1 and from zero to level P1. Addition of K had no effect on yield.

In sugarbeet (1963, 1968, 1972), the response to N level was nearly linear up to a threshold of 120 kg N/ha in 1963 and ~180 kg/ha in 1968, but increases to higher N rates had negligible effect on yield. The optimum P varied between level 2 and 5, depending on year. The effect of K was negligible and dairy manure (R2) had a positive effect on yield in 1963 only.

Silage corn (1968, 1972) had a bell-shaped response to N, with a maximum yield obtained at 250 kg N/ha (1968). The response to P at any N level was linear in the range P1 to P5. The effect of K was negligible. In 1972, the range of N application was extended and the optimal N was found to be ~500 kg/ha with decline at 600 and 800 kg N/ha; optimal P was level P2.

The yield response to N in sorghum (1965 and 1976) was also bell-shaped with maximum at ~180 kg N/ha; optimum P was level P3; yield was higher at K3 than at K1 (at P5R1) and there was no advantage to R2 over R1. In wheat (grown 9 times between 1961 and 1992) the maximum grain yield varied over time from 2200 to 8000 kg/ha. In all experiments with wheat, the response to N was bell-shaped with maxima varying between 150 and 175 kg N/ha but a pronounced decrease in yield at higher N application rates. The optimal P level was between P 3 and P4, depending on N treatment and the year. No beneficial effects of K3 relative to K1, and R2 relative to R1 were found, except in years in which no fertilizers were applied. Under such conditions, P5, K3 and R2 had an advantage in grain yield.

Cotton was grown in 11 seasons, and in 8 years consecutively (1978-1985). The highest raw cotton yield varied between 4,400 and 7,800 kg/ha (in the years 1978 and 1982, respectively), but despite this difference the response to N was bell-shaped in all the years with a peak in yield at 150-180 kg N/ha. At yield below 6,000 kg/ha the optimal P level was P3; between 6,000 and 7,000 P4, and above 7,200 kg/ha the optimal P level was P5. In five growing seasons, level K3 gave higher yields than K1 while in the other seasons K1 gave higher yields than K3, or equal to it, all under P5R1. The effect of dairy manure application on yield was beneficial in four seasons while, in the others, it had no effect or even decreased yield.

The above response relationships constitute only part of the total number of yield determining interrelationships that are stored in annual crop reports. To obtain more insight into effects of nutrients supply, soil variability, time, and climate on plant performance and yield, interested readers should visit the pertinent crop response report and analyze the data themselves.

3.2 Long-term fertilization effects on crop yield

Analysis of long-term fertilization effects on crop yield must account for at least three factors: 1. Alterations in soil physical and chemical characteristics and nutrients status in soil along the experiment. 2. Changes in rainfall and irrigation practices over time. 3. Fluctuations in temperature and relative humidity between years. Moreover, long-term effects may be expressed differently in different crops. To avoid this confusion, we limited the discussion in this section to cotton and wheat that were grown during 11 and 9 seasons, respectively. No other crop was grown for more than three seasons therefore additional crops could not be used for evaluating long-term management effects. Another point is that due to space limitation we chose six representative treatments to analyze and present the long-term effects. The file which includes all the treatments and all the Figures which are shown in the forthcoming text can be viewed by control/clicking the hyperlink: BD yield time effects.xlsx. The data in this file was copied from the annual crop reports presented in the Results section.

3.3 Long-term nitrogen effects

3.3.1 Cotton

Five treatments (Fig. 48) were chosen to show the long-term N effect on cotton yield (1964 to 1985). The control treatment N0P0K0R0 (in the Excel files it is assigned as N1P1K1) exhibited a continuous decline in yield between 1964 and 1978 (~50%) when irrigation was low (290-360 mm/season). When irrigation increased by ~50%, the yield increased at the same rate and, between 1980 and 1984, it fluctuated according to variations in water supply (left hand side of Fig. 48). Treatment N0P4K0R0 also showed a decline in yield over time when irrigation was low, but treatment N4P0K0R0 remained steady over the entire period, and its yield fluctuated when irrigation: EVp ratios dropped to around 0.40. Treatment N4P4K2R0 increased in yield over the entire period but it was also subject to yield fluctuations after 1978. In treatment N4P4K0R0, the time effect is unclear due to missing experimental points. The above conclusion that yields fluctuated after 1978 due to low irrigation: EVp ratio is based on the fact that water supply was high (see left hand side of Fig. 48) so apparently the growth limiting factor was hot days with high potential evapotranspiration values and lack of knowledge in those years to compensate for it by enhancing irrigation. It is mentioned that the irrigation interval was 14 days and compensation under such conditions is problematic. The question why treatment N4P4K2R0 was more resistant to water stress than the other treatments is still open, but could be related to larger root systems in better fertilized plots.

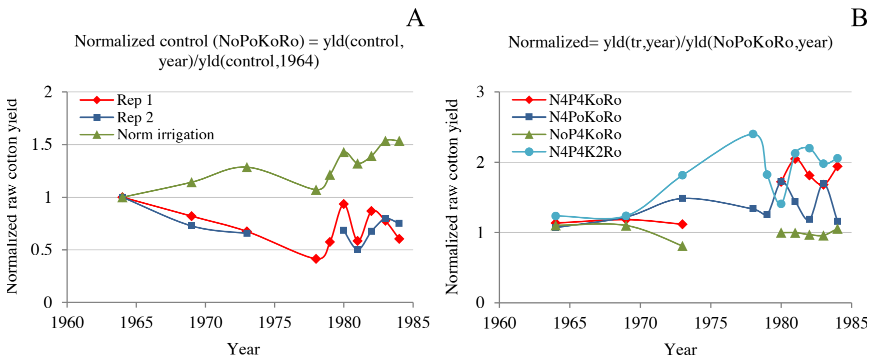

Fig. 48A, B. A. Normalized (norm) irrigation rate and raw cotton yield in the control treatment (N0P0K0R0) as a function of time. Numbers near Rep show the replicate number. B. Normalized raw cotton yield in four representative fertilization treatments as a function of time. In 1964 (the reference year), the irrigation rate was 290 mm and the yield in replicates 1 and 2 was 4,030 and 4,717 kg raw cotton/ha. The irrigation/EVp ratio varied between 0.28 (first 2 years) and 0.40 (last 2 years). In the years 1973 and 1974 fertilization was omitted.

3.3.2 Wheat

The yield in the control treatment fluctuated strongly between 1961 and 1987, closely following the rainfall variation during this period (Fig. 49). In some cases, a relatively small drop in annual rainfall induced a large decrease in yield (e.g. 1966), which can be explained by undesired rainfall distribution in this season. The monthly rain data (Appendix 1) can be used by interested readers to evaluate the rain distribution effect on yield. Treatment N0P4K0R0 (right hand side of Fig. 49) behaved similarly to the control treatment while treatments receiving N4P4 exhibited an increase in yield between 1961 and 1989. The decrease in yield in 1992 may be related to the high rainfall that year, which caused excessive leaching of mineral N from the root zone. The drop in yield in all treatments in 1987/8 was the result of two effects: a small drop in rainfall, and no P, K fertilization. An interesting comparison is between 1975 and 1985, which had rainfall of 600 and 400 mm/year, respectively. As expected, the yield in the N0P0 treatments was lower in 1985, but in the N4P4 treatments the yield was higher despite the reduced rain. This indicates that above 400 mm, leaching adversely affected yield in the N4P4 treatments (in agreement with the 1992 data), but it had a negligible negative effect on low fertilization treatments.

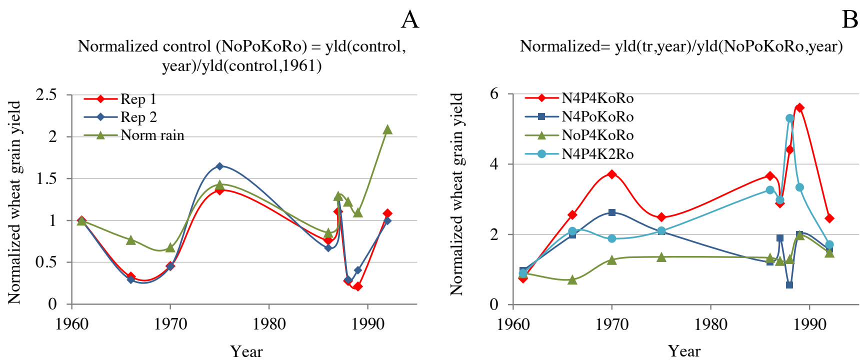

Fig. 49A, B. A. Normalized (norm) rain and wheat grain yield in two replicates of the control treatment (N0P0K0R0N0P0K0R0) as a function of time. B. Normalized wheat grain yield in four representative fertilization treatments as a function of time along the experiment. In the reference year, 1961, the irrigation rate was 420 mm and the yield in replicate-1 and 2 was 2,380 and 2,340 kg grain/ha, respectively. The irrigation/ EVp ratio varied between 0.50 (first 2 years) and 1.1 (last 3 years). In 1973 and 1974, fertilization was omitted from all plots and, in 1987, P and K have not been added to experimental plots.

Interested readers can evaluate the effect of time and climate on yield of other crops and different treatments by creating files like BD yield time effects.xlsx that uses the pertinent data from the annual crop reports.

3.4 Long-term phosphorus effects

3.4.1 Cotton

Cotton yield response to P application was evaluated four times along the experiment but it was insufficient to obtain meaningful time-curves as was carried out in the case of N. The time effect is depicted therefore by presenting side by side the yield response to P in the different years. In order not to overload the Figure, the response to P was presented only at the highest N level (N4, Fig. 50). Except for one deviating point in the year 1980, the four response curves were bell-shaped with a maximum at P addition rate of ~35 kg P $ha^{-1}Y^{-1}$. Above this annual P application, a yield reduction in raw cotton was obtained. The difference between curves does not follow the chronological order, therefore it seems that the response to P was affected mainly by differing weather conditions in the reported years. At zero N application (N0 in the graph), P addition had negligible effect on yield.

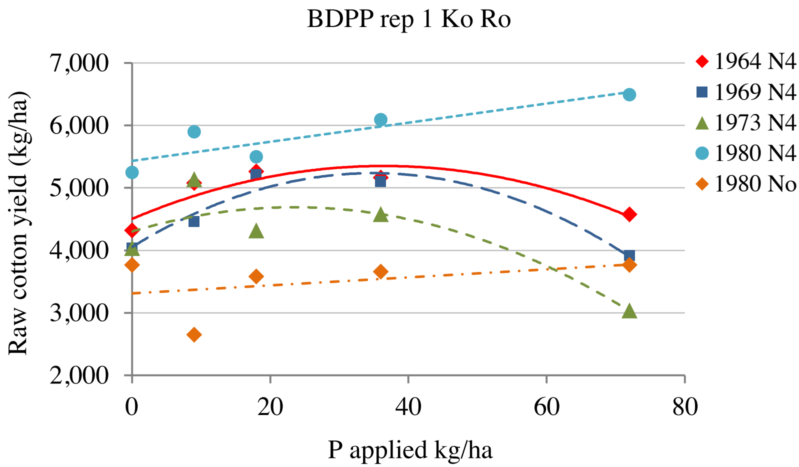

Fig. 50. Raw cotton yield in the years 1964, 1969, 1973 and 1980 as a function of annual P application rate. The K and R levels were identical in all cases (K0R0). The P application 0, 9, 18, 36 and 72 kg/ha correspond to treatments P0, P1, P2, P3 and P4, respectively. Note that in 1973 and1974 fertilization did not take place.

The relationship between yield and the concentration of available P in soil ($NaHCO_3$ extractable P) in the same test years (Fig. 51) is also parabolic with peaks in all curves between ~10 and 20 mg P/kg soil. Concentrations exceeding 20 mg P/kg coincided with reduced yield. As time advanced, the concentration of $NaHCO_3$ extractable P increased and in treatments N0 and N4, year 1980, it reached 45 and 39 mg P/kg, respectively, but with negligible effect on yield.

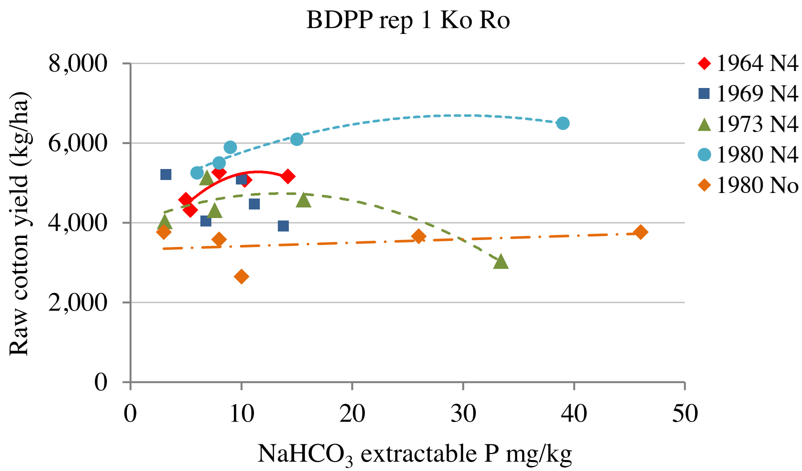

Fig. 51. Raw cotton yield as a function of $NaHCO_3$ extractable P concentration in soil in the years 1964, 1969, 1973 and 1980. The K and R levels were identical in all cases (K0R0). Note that in 1973 and 1974, no fertilization took place.

The buildup of $NaHCO_3$ extractable P in soil depended on treatment (P application level) and time (Fig. 52). In 1964 and 1969, (3 and 8 years of P application with N4) the P concentration in soil was hardly affected by the P treatments. This is explained by the strong P adsorption by the BD soil (see the adsorption isotherm in Appendix 4) and the fact that the efficacy of $NaHCO_3$ to desorb P is relatively low (~30%, Bar Yosef and Akiri, 1978). In 1973 and 1980, the concentration of the $NaHCO_3$-P in soil in treatments P3 and P4 (application of 35 and 70 kg P $ha^{-1}Y^{-1}$) increased, and an almost linear relationship with the annual P application rate was obtained (Fig. 52). In treatment N0, which had low yield and low P uptake, the relationship was precisely linear in 1980 (R2=0.97) with a slope of ~[0.6 mg $NaHCO_3$-P kg^{-1}soil]/[kg P added as fertilizer $ha^{-1}y^{-1}$]. To obtain in 1980 a $NaHCO_3$ soluble P concentration of 20 mg/kg, which was required for high raw cotton yield (Fig. 51), the annual P application rate between 1961 and 1980 should be ~45 kg P/ha.

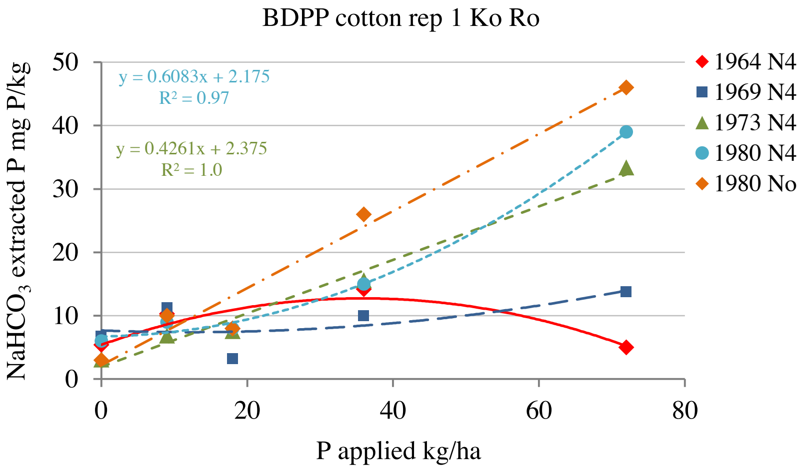

Fig. 52. The concentration of $NaHCO_3$ extractable P in soil in 1964, 1969, 1973 and 1980 as a function of annual P application rate in cotton. The application of 0, 9, 18, 36 and 72 kg P/ha correspond to treatments P0, P1, P2, P3 and P4, respectively. Note that in 1973 and 1974 no fertilization took place.

The relationship between $NaHCO_3$-P accumulation in soil and time is depicted in another format in Fig. 53. In the zero P addition treatment (N4P0K0R0), the available P concentration slightly decreased between 1961 and 1980; in treatment N4P2K0R0, the available P concentration increased from 5 to 17 mg P/kg and in N4P4K0R0 from 5 to 39 mg P/kg. In N0P4K0R0 the available P accumulation rate was steadier with time and lacked the reduced P accumulation rate between 1973 and 1980 that characterized the other treatments.

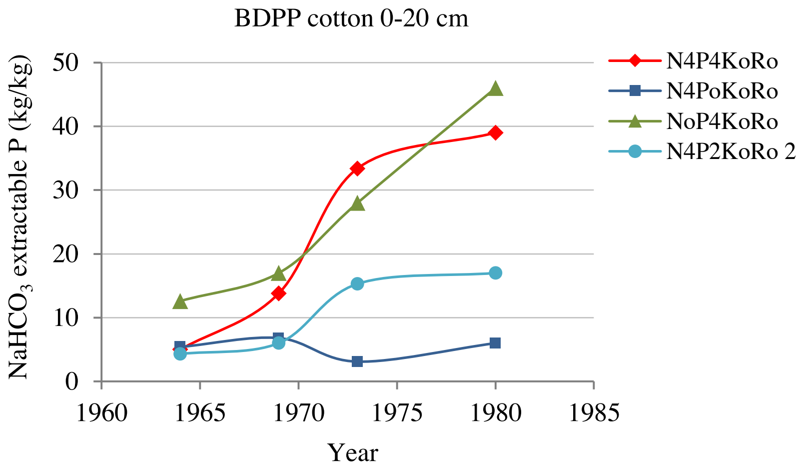

Fig. 53. The time and treatment effect on concentrations of $NaHCO_3$ extractable P in soil (0-20 cm soil layer). Except treatment N4P2K0R0, all the results belong to replicate-1.

3.4.2 Wheat

The wheat yield response to annual P application rate in 1966 and 1970 is presented in Fig. 54. Under zero N application (N0), the yield was limited by N therefore the response to P was minimal. With N4, the yield in 1966 was still very low, and the increase in

By replacing "P applied" in the abscissa of Fig. 54 by "$NaHCO_3$ extractable P concentration in soil" a similar response in yield is obtained (Fig. 55); only in this case, a threshold available P concentration in soil is obtained (1970). The threshold value, above which yield declines, is ~15 mg P/kg (the maximum point of the N4 parabola in Fig. 55).

The aforementioned results allow estimating the quantitative relationship between annual P application level over time and $NaHCO_3$-P concentration in soil (Fig. 56). After five years of continuous P application (1962 to 1966), the relationship was curvilinear, indicating that part of the added P at the highest level (~150 mg P kg^{-1} soil over five years if all the added P was mixed in the 0-20 cm soil layer) became un-extractable by $NaHCO_3$. After nine years, the relationship was linear with a slope of 0.43 mg $NaHCO_3$-P kg^{-1} soil/kg P applied ha^{-1}. At each P application level, the $NaHCO_3$-P was higher in treatment N0 than in N4 due to lower P uptake by the crop.

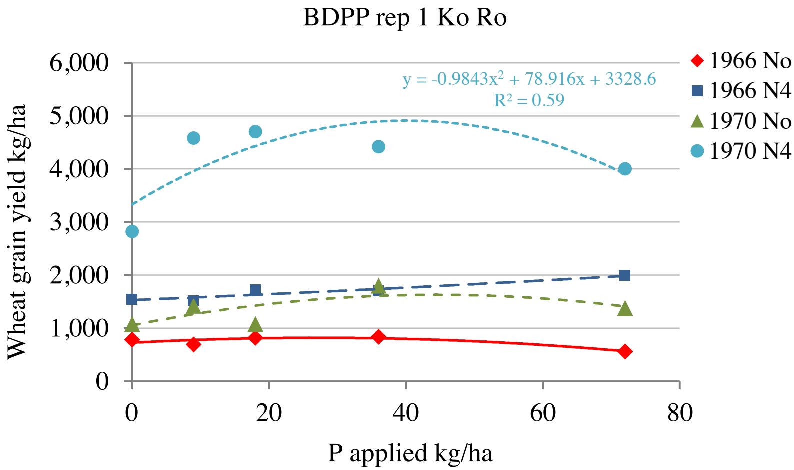

Fig. 54. Effects of annual P dose in combination with N4K0R0 or N0K0R0 on wheat grain yield in 1966 or 1970. The application of 0, 9, 18, 36 and 72 kg P/ha correspond to treatments P0, P1, P2, P3 and P4, respectively. Rainfall and EVp during the season amounted to 357 and 634 mm, respectively, in 1966 and 315 and 618 mm in 1970. In 1966 the increase in grain yield due to P fertilization was minor, indicating that yield was inhibited by factors other than N or P. In 1970 (after 10 years of P addition), a pronounced response to P application in the range of 0 to ~30 kg/ha was obtained. Exceeding 30 kg P/ha reduced the grain yield.

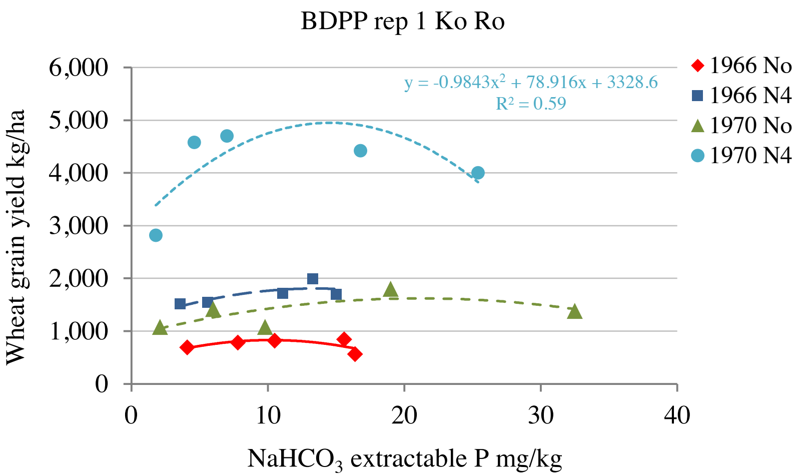

Fig. 55. Effects of $NaHCO_3$ extracted P concentration in soil (0-20 cm) on wheat grain yield in the years 1966 or 1970. The symbols N0 and N4 refer to treatments N0K0R0 and N4K0R0, respectively.

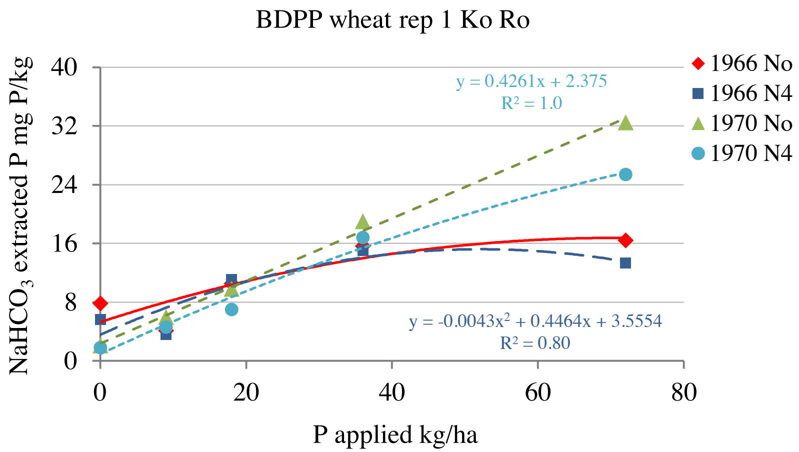

Fig. 56. $NaHCO_3$ extracted P concentration in soil in the years 1966 and 1970 as a function of annual P application rate in wheat. The applied P values (0, 9, 18, 36 and 72 kg P/ha) refer to treatments P0, P1, P2, P3 and P4, respectively. It is mentioned again that in the Excel files treatments P0, P1, P2, P3, P4 are called P1, P2, P3, P4 and P5.

The data presented above, and additional information on wheat in 1970 that was published by the Permanent Plot team (1974), allows evaluating the P mass balance in the soil-plant system during the period 1961-1970. Let us use treatment N4 as a test case. The $NaHCO_3$-P concentration in soil in 1970 at the P4 application level (72 kg P $ha^{-1}Y^{-1}$) was 25 mg P kg^{-1}soil (0-20 cm). This concentration comprises ~16% of the maximum P adsorption capacity by the BD soil (~160 mg P kg^{-1}; see Appendix 4). According to the Permanent Plot Team (1974), the concentration of $NaHCO_3$-P in the 20-40 cm layer was ~50% of that in the 0-20 cm layer. Taking a soil bulk density of 1.25 kg/L, these concentrations amount to ~94 kg $NaHCO_3$-P ha^{-1} (0-40 cm). According to Bar-Yosef and Akiri (1978), the recovery percentage of sorbed P in BD soil is 35%, which elevates the above mentioned 94 kg $NaHCO_3$-P ha^{-1} to ~282 kg P ha^{-1}. The total P uptake by wheat in 1970 (treatment N4P4) was ~30 kg P ha^{-1} (The Permanent Plot team, 1974). Assuming that this annual P uptake prevailed during the 1961-1970 period brings the total P uptake to ~300 kg P ha^{-1}. Neglecting the initial (1960) amount of available P in soil, the increase in soil P between 1961 and 1970 plus the estimated P uptake by crops = 582 kg P ha^{-1}. Comparing this value with the 576 kg P ha^{-1} added to the soil as fertilizer (eight applications of 72 kg ha^{-1} and zero application in 1961) proves a very good agreement between the two, indicating trustworthy experimental results.

3.5 Long-term potassium effects

3.5.1 Cotton

In the zero K application level, the raw cotton yield clearly declined from the year 1964 to 1969 and 1973 (ordinate of Fig. 57). Annual K application of 160 kg ha^{-1} had a small or no effect on cotton yield in 1964 and 1969, but in 1973 the yield increased from 3 t/ha in zero addition to 5.5 t/ha.

Increasing the annual K application to 320 kg/ha had no further effect on yield and, in 1973, the enhanced K even decreased it. The effect of concentration of available K in soil ($CaCl_2$ soluble-K) on yield in 1969 was negligible, but in 1964 and partly in 1973 a parabolic response curve is obtained (Fig. 58) with a peak at 7 mg K/L and a decline in yield at higher concentrations. In 1964 and 1973, K fertilization of 150 and 300 kg K ha^{-1} caused an increase in $CaCl_2$ soluble K. The increase was more pronounced in 1964 than in 1973 because, in the latter, no K fertilizer was added to the plots. In 1964, the concentration rose from 3 to 5 and 10 mg K/L, respectively (Fig. 59). In 1969, the increase from 150 to 300 kg K/ha reduced the $CaCl_2$ soluble K, but the difference (~2-3 mg K/L) was within the range of experimental error.

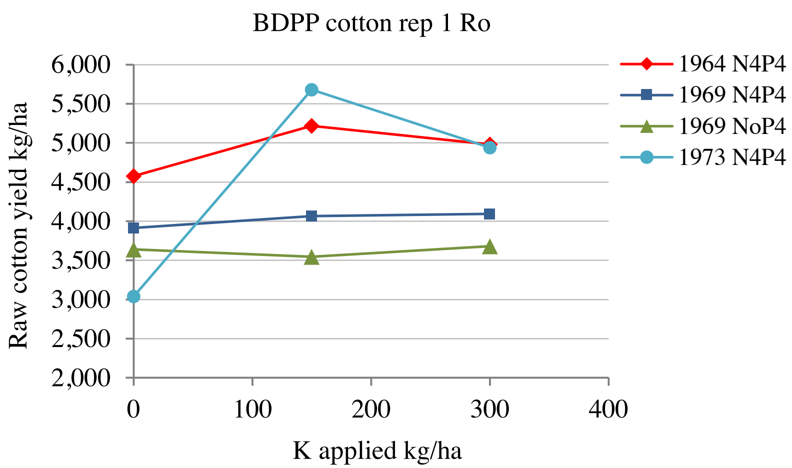

Fig. 57. Annual K application rate effect on raw cotton yield in the N4 and N0 nitrogen application levels in the years 1964, 1969 and 1973.

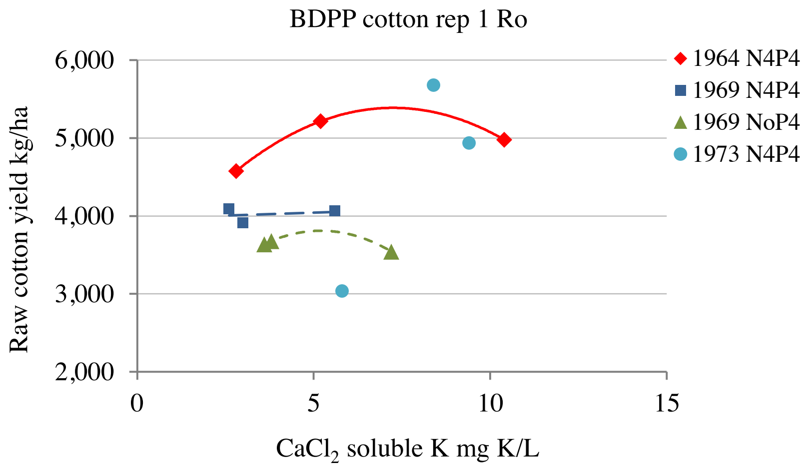

Fig. 58. Soil available K (in 0.01M $CaCl_2$) effect on raw cotton yield in combinations N4P4 and N0P4 in 1964, 1969 and 1973.

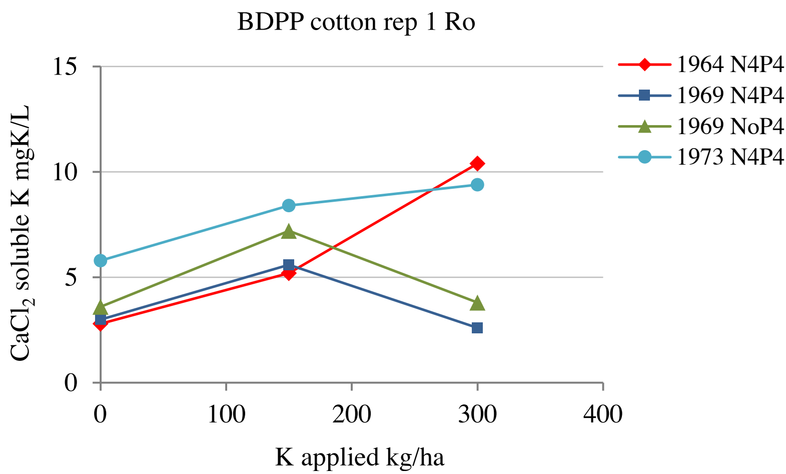

Fig. 59. The annual K application rate effect on $CaCl_2$ soluble K concentration in soil in treatments N4P4 (1964, 1969, 1973) and N0P4 (1969). In these years, the crop was cotton. Note that in 1973 no fertilization took place.

The combined effect of time *per se* and cumulative K application rates on soil $CaCl_2$ soluble K was quite similar in treatments K0, K1, K2 in combination with N4P4R0 (Fig. 60). In all cases, the concentration in 1969 did not differ from the one in 1964 but, between 1969 and 1973, it increased considerably. When in combination with N4P0R0, the $CaCl_2$-K concentration exceeded that in N4P4R0, probably due to smaller K uptake with P0. The field variability in $CaCl_2$ soluble K can be assessed by comparing between the curves of the two N4P0K2 replicates (Fig. 60).

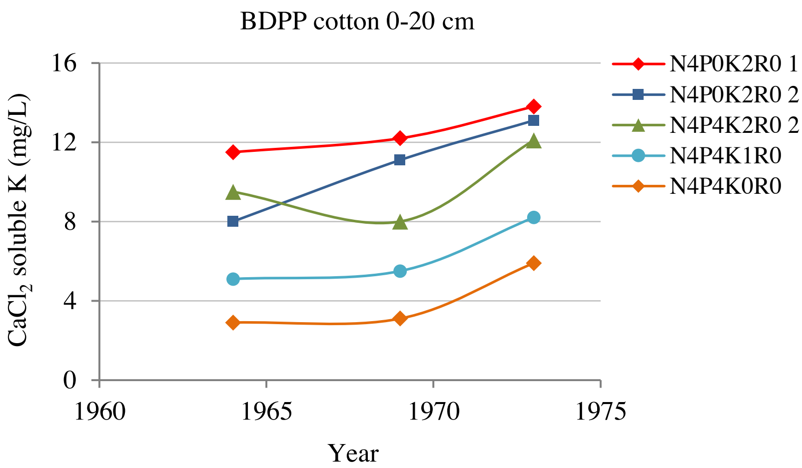

Fig. 60. Treatments and time effect on $CaCl_2$ soluble K concentration in soil. The symbol R0 indicates no manure application. Numbers 1 and 2 beside the treatment label show the replicate number (the default replicate was 1). In 1973 and 1974, no K fertilizer was added to field.

3.5.2 Wheat

The potassium fertilization had no effect or even reduced wheat grain yield. This occurred in 1966 and 1970, in combination with N4P4 and N0P0 (Fig. 61). The lack of response agreed with the fact that wheat yield did not increase when the $CaCl_2$ soluble K concentration in the soil increased from 4-5 to 15-17 mg K/L (Fig. 62). Moreover, in 1970, the yield even declined when the $CaCl_2$ soluble K concentration exceeded ~10 mg K/L.

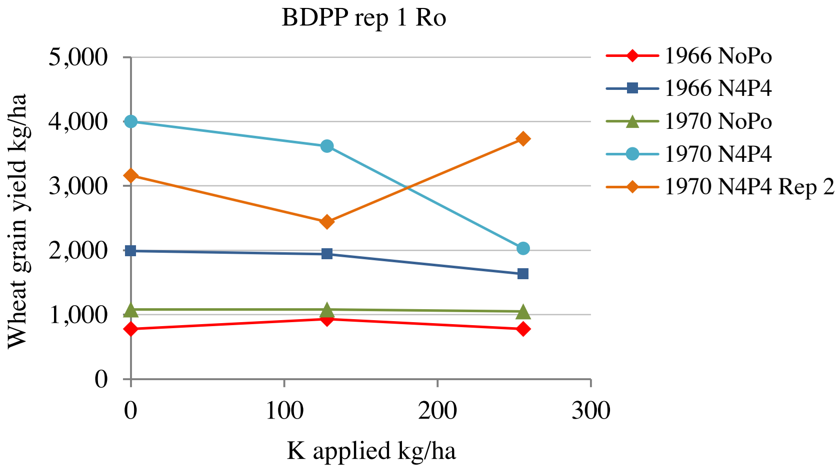

Fig. 61. Annual K application rate effects on wheat grain yield in treatments N4P4 and N0P0 in the years 1966 and 1970.

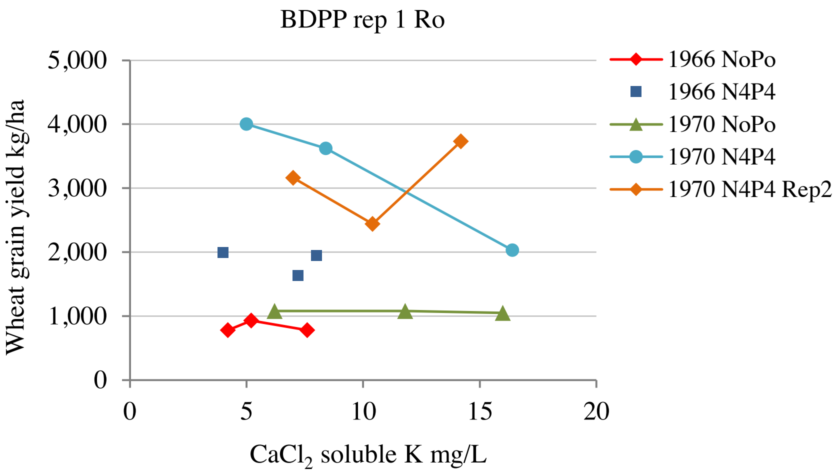

Fig. 62. Soil available K (in $CaCl_2$) effect on wheat grain yield in treatments N4P4 and N0P4 in 1966 and 1970.

The 10 mg K/L threshold was surpassed in the 1970 season when the annual K application rate was raised from 130 to 260 kg K ha^{-1} Y^{-1} (Fig. 63). The number of K fertilizations needed to surpass this threshold was nine (1961-1970). After five fertilizations (1966), the obtained K concentration was 9±1 mg/L.

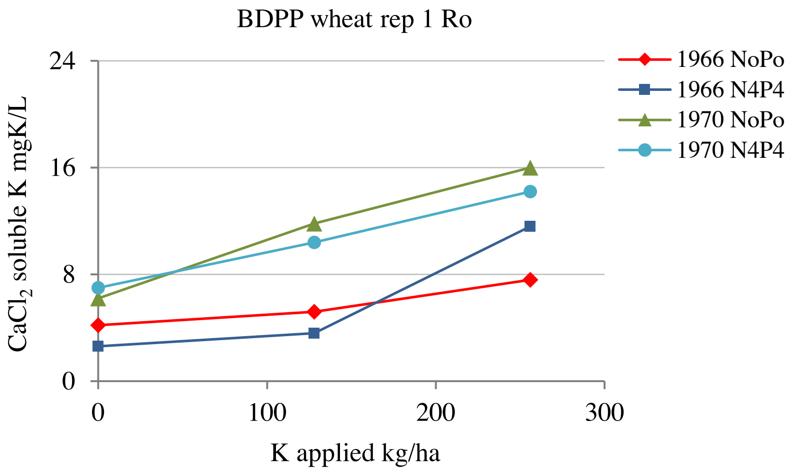

Fig. 63. Annual K application rates effects on the $CaCl_2$ soluble K concentration in soil in treatments N4P4 and N0P0 in 1966 and 1970. In these years the crop was wheat.

3.6 Long-term manure effects

Organic manure (dairy, R1) was applied in 1963, 1968, 1972, 1981, and 1993. Green manure (R2) was grown in 1964 and 1969. From 1976 onwards, treatment R3 was converted to allow evaluating the residual value of P and K in soil. To serve this purpose, it did not receive any more green manure and P and K fertilizers.

3.6.1 Cotton

The effect of manure (R1) on cotton yield is evaluated relative to treatments N0P0K0R0 and N4P4K0R0 (Fig. 64). Between 1963 and 1973, dairy manure considerably increased raw cotton yield in comparison with N0P0K0R0 but later on, until 1981, it had no advantage over it. The reason was that between 1972 and 1981 no manure was added to the soil. The benefit of the 1981 manure application was expressed shortly after the application and two years later (Fig. 64). The green manure had no impact on yield. In the high N, P fertilization treatments, the dairy manure had no beneficial impact on yield except in 1969 where it slightly improved it. The R2 treatment N0P0K0R2 decreased cotton yield relative to the un-manured control treatment N0P0K0R0 (Fig. 64). Treatment N4P4K0R2 also reduced yield relative to N4P4K0R0 but only after 1979.

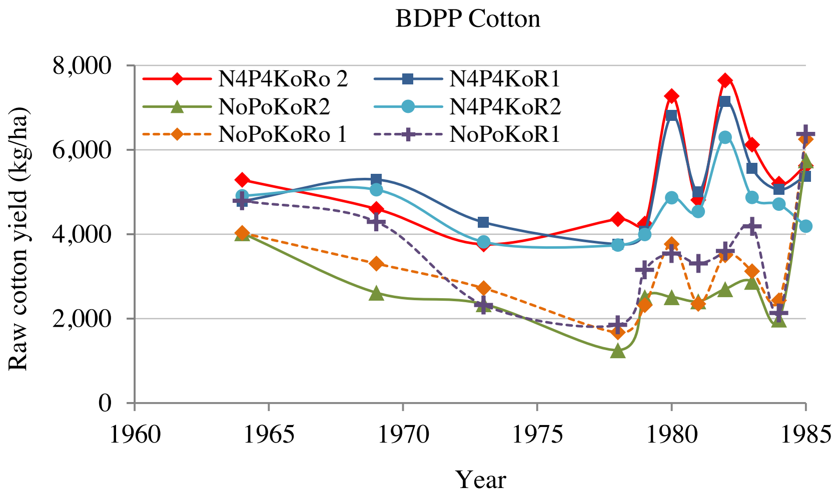

Fig. 64. Manure application (R0, R1, R2) effects on cotton raw yield as function of time and NPK treatment. Dairy manure (R1) was applied in 1963, 1968, 1972 and 1981. In 1973 and 1974, no fertilizer was applied. In 1976 treatment, R2 was converted to study residual effects of P and K in soil after 15 years of fertilization, consequently the supply of P, K and green manure was stopped. Numbers 1 or 2 near labels show the replicate number (default = 1).

3.6.2 Wheat

The effect of manure was tested in association with treatments N0P0K0R0 and N4P4K0 (Fig. 65). In the latter case, dairy manure (R1) and green manure (R2) had no meaningful beneficiary effect on yield along the wheat growing period. In N0P0K0R0, manure had no impact until 1970 but in 1975, after two years (1973 and 1974) of zero fertilization, dairy manure had a clear beneficial effect on yield. Green manure was unable to increase yield. This beneficial effect of dairy manure surfaced again in the season of 1987/8, when P and K fertilizers were omitted. Halting the green manure and P and K fertilization since 1976 in treatment R2 had no adverse effect on wheat grain yield until the end of the experiment (Fig. 65).

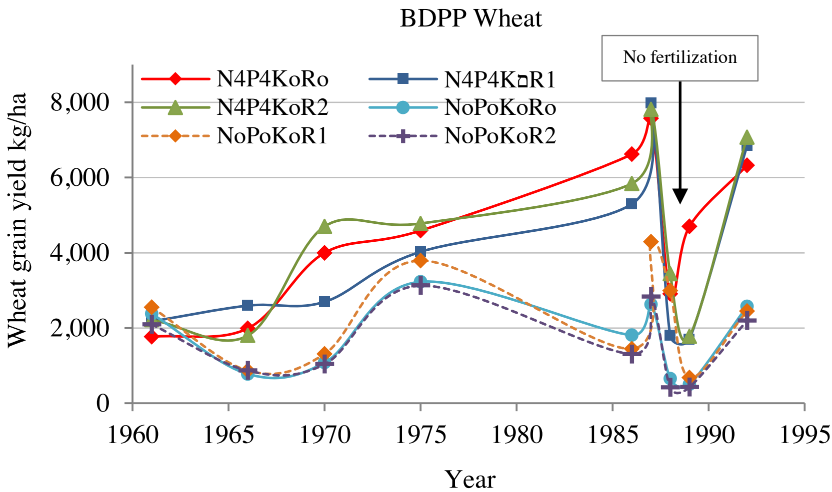

Fig. 65. Manure application (R0, R1, R2) effects on wheat grain yield as function of time and NPK treatment. Dairy manure (R1) was applied in 1963, 1968, 1972 and 1981. In 1973 and 1974, no fertilizer was applied. In 1976, treatment R2 was converted to study the residual effect of P and K in soil after 15 years of fertilization and consequently P, K and green manure were not applied any more in this treatment.

3.7 Nutrients and salts distribution in soil

Deep (12 m) soil sampling was done in 1987 after 26 years of crops growing. The EC_e and e ion profiles were presented in the "1987 wheat report" in results (Figs. 37, 38, 39). The fertilization treatments had a significant effect on soil EC (in saturation extract, EC_e) and its distribution with depth (Fig. 37). The lowest EC_e levels (~0.4-0.7 dS/m) were found in the low fertility ($N_0P_0K_0$) treatment. Much higher values were detected in fertile treatments, up to 2.7 dS/m in treatment $N_3P_4K_0$ at a depth of 10-12m. The high EC_e levels detected in high N and P addition levels could stem from two reasons: (i) direct contribution of solutes by the fertilizers [$(NH_4)_2SO_4$, KCl and K_2SO_4 that substituted KCl several times]. (ii) the effect of fertilization on the water consumption by plants. The $H_2PO_4^-$ had negligible effect on EC_e due to its strong retention by the soil. The added NH_4^+ was transformed quickly into NO_3, which was leached into deep soil layers forming concentration profiles according to the N-application level (Fig. 38A). The sulfate anions accumulated in the top 3-4 m with very little leaching below it (Fig. 38B). The Cl^- profile (Fig. 37) resembled the EC_e profiles in soil. The biggest Cl^- concentration peaks were found at a depth of 10-12m (27 mmol/L) in treatments N3P4K0 and N2P2K0 (called N4P5K1 and N3P3K1 in the excel files). In treatments N0 or P0 no peaks were observed, indicating that the anion was leached below 12m. The deeper leaching stemmed from the fact that plants in the deficient N and P treatments transpired less, and more water was available for leaching in comparison with the well-nourished, bigger plants. The difference in Cl^- and ammonium supply *per se* should not affect the soil depth at which salt peaks occur, only the concentration values around the peak. A similar conclusion based on the same data was obtained by Feigin and Halevy (1995). Those authors estimated that the amount of Cl^- that was added via the irrigation water (17,000 kg/ha until August 1987) was much larger than the amount added in KCl (2,230 and 4,460 kg Cl/ha in treatments K1 and K2 [=K2 and K3 in the Excel files]). The Cl^- mass balance in soil (eq. [1]) over the period of 1961 to 1987 must take into account its initial and final quantities in the 12 m deep soil profile (S_F and S_o, kg Cl/ha), the uptake by plants (U, kg Cl/ha), the cumulative application (A, irrigation+ fertilizers, kg Cl/ha) and the amount leached beyond the 12m horizon (L, kg Cl/ha):

$$L = A - (S_F - S_o) - U \qquad [1]$$

Assigning subscripts h and l for high and low fertilization levels (N3P4K0 and N0P0K0R0, respectively), and subtracting the obtained eq. [1] in the two treatments from each other yields:

$$L_h - L_l = (A_h - A_l) + (S_{Fl} - S_{Fh}) - (U_h - U_l) \qquad [2]$$

Since both treatments did not receive K (K0), $A_h = A_l$. The S_{Fl} and S_{Fh} were estimated by integrating the pertinent Cl^- profiles in Fig. 37 (11,290 and 35,740 kg Cl^-/ha, respectively). The U was estimated from the cumulative DM yield multiplied by a representative Cl^- concentration in it. Feigin and Halevy (1995) estimated the mean annual DM yield in the two treatments as 4,880 and 10,660 kg DM/ha. The representative %Cl in plant was estimated from the review of Xu *et al*. (2000) to be 1±0.5%. By assuming 1% Cl over 26 years (1961-1987), and the above mentioned annual DM yields, U_h and U_l of 2,772 and 1,269 kg Cl/ha are obtained. Inserting these values in [2] gives $L_h - L_l = -25{,}953$, meaning that Cl^- leaching below 12 m in treatment N0P0K0R0 exceeded the leaching in treatment N3P4K0 by 25.9 tonnes Cl/ha over 26 years.

The effect of treatments on water soluble Ca^{2+} distribution in soil (Fig. 39a) is via the differential superphosphate fertilization rates. It can be seen that in treatments P4 and P2 the Ca accumulated in the 1-3 m deep soil layer, while in treatment P0 the profile is uniform with soil depth. It is noted that in treatment N4P4K2 the $CaCO_3$ concentration in soil also had a peak at a depth of 1-3m (Fig. 40), which indicates that Ca added as $Ca(H_2PO_4)_2$ and $CaSO_4$ in superphosphate precipitated as $CaCO_3$.

The effect of treatments on K^+ concentration in soil is unclear (Fig. 39b) except a distinct K accumulation in the top 0.5 m soil layer in the K2 treatments. Deeper in the soil, K exchange and fixation and release from illite masked treatment effects.

3.8 Changes in soil properties

3.8.1 Changes in mineralogy and $CaCO_3$

Sandler *et al.* (2009) reported that there was an increase in the soil smectite content between 1961 and 1993 and decline in illite, particularly in meagerly K fertilized field plots. The release of illite-fixed K^+ was induced by low K^+ concentration in soil solution stemming from high demand for K by the growing plants. However, the observed alteration in mineralogy was evaluated by Sandler *et al.* to be of small practical importance.

The $CaCO_3$ content in the 0-20 cm soil layer increased gradually in representative treatments from 1960 to 1979, and then declined at approximately the same rate from 1980 to 1993 (Fig. 66). At any time, the difference in soil $CaCO_3$ concentration between replicates exceeded the difference between treatments; therefore the governing mechanism (ammonium sulfate level and its impact on soil pH via nitrification and NH_4 uptake by roots) could not be verified.

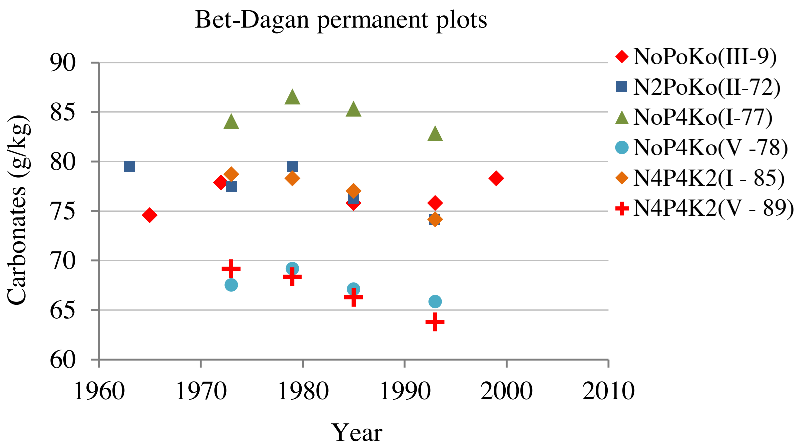

Fig. 66. Carbonates (g $CaCO_3$/kg soil) content in soil (0-20 cm) as function of time, treatment and replicate (source: Fine, P., unpublished data, personal communication, 2014).

3.8.2 Changes in soil organic matter

The treatments and time effects on soil organic nitrogen (SON) are summarized in Table 23.

Table 23. The soil organic N (SON, % of dry soil in the 0-20 cm layer) in representative treatments at the beginning (1963) and end (1993) of the Bet Dagan experiment. Analyses were performed by Soil N Analyzer. The soil organic C (SOC) and organic matter (SOM) contents (both as % of dry soil) were not analyzed and can be estimated from the equations: SOC = SON x 10 and SOM = SOC / 0.58 (Nelson and Sommers, 1996). Note that in the Excel files and Figures the N0P0K0 treatment is called N1P1K1; N4P2K2 is called N5P3K3; and so on.

Treatment	Year	Rep1		Rep2		Average	
		R1[1]	R2[1]	R1	R2	R1	R2
		- - - - - - - - - - - - - Soil organic N (%) - - - - - - - - - - - - -					
N0P0K0	1963	0.065	0.062	0.062	0.066	0.064	0.064
N0P0K0	1993	0.068	0.071	0.072	0.074	0.070	0.073
N2P2K0	1993	0.078	0.090	0.075	0.081	0.077	0.086
N3P4K0	1993	0.084	0.086	0.079	0.088	0.082	0.087
N4P0K2	1993	0.079	0.079	0.086	0.086	0.083	0.083
N4P2K2	1993	0.076	0.083	0.084	0.090	0.080	0.087

Note: [1]R1 = no manure addition; R2 = dairy manure addition. Note that soil samples were taken prior to the 1993 manure application.

The manure effect (R2 vs. R1) on %SON was clear, showing in all treatments a higher %SON (1993) in treatment R2 than in R1. The difference was negligible in treatment N0P0K0 and maximal in N2P2K0 (0.086 vs. 0.077%). In treatment N2P2K0, %SON increased from 0.064 in 1963 to 0.086% in 1993 (~500 kg N/ha in 32 years).

Enhanced N, P fertilization (N0P0K0 to N2P2K0 to N3P4K0) increased the %SON from 0.07 to 0.08 and 0.08%N, respectively, in R1, and from 0.07 to 0.09 and 0.09%N in R2. The maximum increase in %SON between 1963 and 1993 was obtained in treatment N3P4K0R2 (from 0.064 to 0.087%).

The specific K effect can be assessed by comparing treatments N4P2K2 and N3P4K0. The comparison shows negligible K effect on %SON.

The effect of P alone can be assessed by comparing treatments N4P0K2 vs. N4P2K2. The observed difference in %SON was negligible with or without manure application.

The results prove that fertilization can increase %SON in soil by combined application of N, P, and K fertilizers, whereas application of one element only is ineffective if the other two are growth limiting factors.

Hadas *et al.* (1990) and Bar-Yosef and Kafkafi (1972) evaluated the soil organic matter (SOM) status in soil at various points along the BDPP experiment (Table 24). The data indicate that %SOM of all treatments did not change meaningfully between 1963 and 1983 (1.3-1.5%) but between 1983 and 1990 it increased to 1.4-1.6%. The initial organic C:N ratio in soil was 8-10 and in 1983 it elevated to 10-11. The SON in 1983 was 0.067 in the control treatment N1P1K1 and 0.081% in treatment N3P5K3.

Table 24. The soil organic matter (SOM) and soil organic N (SON) contents in soil (both as % of dry weight, 0-20 cm) as a function of time in the Bet Dagan experiment. The effect of treatments on %SOM was unclear therefore the mean of all treatments is presented.

Treatment	Sampling	SOM (%)	Comments	Reference
All	1963	1.3-to-1.5	Initial; organic C/N ratio 8-to-10	Kafkafi *et al.* (1968)[a]
All	1968	1.2-to-1.45[b]	% SON in tr. N1P1 (control) and N3P5 = 0.06 and 0.072, respectively.	Bar-Yosef and Kafkafi (1972)[b]
All	1983	1.3-to-1.4	C/N ratio 10-to-11; % SON in tr. N1P1K1 (control) and N3P5K3 = 0.067 and 0.081, respectively.	Hadas *et al.* (1986)[a]
All	1990	1.4-to-1.6		Hadas *et al.* (1990)[a]

Note: [a]Hadas *et al.* (1990). [b]In Bar-Yosef and Kafkafi (1972) only SON (kg/ha, 0-20 cm) is reported. To obtain %SON in soil a bulk density of 1.25 kg dry soil/L was used; to estimate %SOM from %SON a C/N ratio of 10 was used and SOM = 2 x SOC (Nelson and Sommers, 1996).

The quantity of dairy manure added until 1963 was 30 m^3/ha (approximately equal to 30 t/ha), until 1968 70 m^3/ha, and until 1983 150 m^3/ha (four manure applications). The organic matter content in the manure was 24% of the dry weight, and the moisture content was 50%. If these quantities were mixed in the upper 20 cm soil layer (2,500 tonnes soil/ha) without decomposition, they should have theoretically increased the %SOM by 0.14, 0.34, and 0.72%, respectively. The fact that these additions in %SOM in 1968 and 1983 were not obtained, and %SOM remained steady over time, indicate that the dairy manure decomposition rate under field conditions was ~900 kg OM $ha^{-1}y^{-1}$ over the period 1963-1983, or ~60 kg organic-N $ha^{-1}y^{-1}$ (%N in the dairy manure was 1.55%).

Bar-Yosef and Kafkafi (1972) published data allowing estimation of the first order ammonium nitrification rate constant (K_N) in the studied treatments ($dC/dt = K_N C$). The calculated K_N (units d^{-1}), pertinent to laboratory incubation conditions, showed meaningless differences between treatments, and varied between 0.025 and 0.023 d^{-1}.

3.8.3 Changes in physical properties

The long-term effects of fertilization treatments on tensile strength and water stability of the soil structure were studied by Hadas *et al*. (1990). They compared treated plots (all R0) with control plots in 1987 (after 26 years of experimentation). Their main conclusions were as follows: 1. There was no significant differences in bulk density of a given aggregate size class between the fertilization treatments, except for the largest class (15.0-25.4 mm), in which N0P4K2 was distinctly denser than the others, especially when compared with that of N4P0K2, which had the lowest density. 2. There were no differences between treatments in the mean aggregate diameter within the classes. 3. The aggregates' tensile strength declined as their size increased. The largest aggregates (size class 20.0-25.4 mm) of treatment N0P4K2 were found to be far weaker than the others. 4. The weighted median aggregate diameter (WMAV) values for dry-sieving show differences between the treatments from larger to smaller WMAV in the following order: Control> N4P0K2> N4P4K2> N0P4K2, whereas for wet-sieving there were no differences. 5. Addition of superphosphate fertilizer increases the structural stability to water, whereas N addition or no fertilization at all diminishes the stability. The authors concluded that long-term, heavy fertilizer application to clayey soil, may affect and stabilize the size of its largest structural units at air-dryness; however, when the soil is moistened these bonds disappear and the structure deteriorates to its basic level of micro-aggregates which are not affected by fertilization.

3.9 Residual effects of P and K fertilizers and effect of green vs. dairy manure

At the end of 1976 treatment R2 (green manure) was modified to allow evaluating P- and K-fertilizer residual effects on crop yield and P, K concentration in soil (Table 25). The R2 plots ceased receiving the green manure and P and K fertilizers, but continued to get the original N doses. Comparison between R1 and R2 until 1976 allows evaluating dairy vs. green manures, and comparing R0 and R2 after 1976 allows estimating the effectiveness of P and K that were applied regularly until 1976.

Table 25. The impact of residue P and K fertilizers on yield, and comparison between green and dairy manure effects in representative N, P, K treatments on yield. The residual effect was obtained by stopping P and K fertilizer and green manure supply to R2 plots after 1976 and comparing results with corresponding R0 treatments. The presented data was obtained from the "annual crop reports".

Treatment	Cotton 1973	Cotton 1980	Cotton 1985	Canola 1991
	Raw cotton and canola yield in treatment R0 kg/ha			
N0P0K0	2720	3768	3125	1890
N0P4K0	2220	3768	3375	2840
N4P0K0	4040	6492	4813	2630
N4P4K0	3040	6492	5875	1420
N4P4K2	4940	5312	5313	2290
	Normalized yield R1/R0 (R1 = dairy manure)			
N0P0K0	0.85	0.94	1.28	0.79
N0P4K0	1.65	1.07	1.15	1.02
N4P0K0	1.05	0.91	1.04	0.86
N4P4K0	1.41	1.05	0.96	1.56
N4P4K2	1.00	1.07	1.48	0.78
	Normalized yield R2/R0 (R2 = green manure)			
N0P0K0	0.86	0.67	1.02	0.69
N0P4K0	1.51	0.67	1.11	0.96
N4P0K0	1.11	0.75	0.88	0.65
N4P4K0	1.26	0.75	1.06	0.80
N4P4K2	0.95	0.98	1.22	0.68

In 1973 (before interrupting the R2 treatment) addition of dairy manure increased the cotton yield in treatments N0P4K0 and N4P4K0 (R1/R0>1), but not in N0P0K0, N4P0K0 and N4P4K2. The green manure also had a yield enhancement effect in 1973, although it was smaller than dairy manure (R1/R0> R2/R0). In 1980 and 1991 (after interrupting R2), the cotton and canola yields in all NPK treatments were lower in the new R2 treatments than in the corresponding R0 NPK treatments (R2/R0<1). In 1985, the impact of stopping PK fertilization (new R2) was weaker (R2/R0 ~1), probably because in this year pre-seeding rainfall was very low (Appendix 1) and water limited plant growth. In treatment R1, the effect of adding dairy manure on yield declined in 1980, 1985 and 1991 in comparison with the beneficial effect in 1973 (R1/R0 around 1 in most NPK treatments). The effect of NPK treatments on the response to manuring was inconclusive.

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Appendices

Appendix 1. Maximum and minimum air temperature (ºC) at the Bet Dagan permanent plot experiment (1964-1993).
To visit the file press control and click: BD temp over time.xlsx.

Appendix 2. Rainfall at the Bet Dagan permanent plot experiment during the experiment.
To visit the file press control and click: BD rain over time.xlsx.

Appendix 3. Evaporation from class a pan at the Bet Dagan permanent plot experiment (1964-1993).
To visit the file press control and click: BD pan over time.xlsx.

Appendix 4. The P adsorption isotherm to Bet Dagan soil.
To see the isotherm control and click: sssaj72a.pdf (p. 785).

Part II: The Gilat Permanent Plot Experiment

5 Introduction

5.1 The original objectives of the Gilat long-term fertilization experiment were:

a) To measure yields of various field crops rotation system on irrigated deep loess soil as affected by long-term cumulative application of various combinations of nitrogen fertilizer and organic manure.

b) To investigate the effect of cumulative fertilizer application on the pattern of available nutrients in the soil, their accumulation or depletion.

c) To estimate the role of soil organic matter in plant nutrition and its long-term balance in soil.

d) To create a wide spectrum of plots with known fertilization history that will serve for calibrating soil tests.

5.2 Design

Two factors were investigated:

a) Four levels of nitrogen fertilizer, labeled: N0, N1, N2, N3 (in the attached Excel files they were labeled as N1, N2, N3, N4)

b) Three organic manure treatments labeled M0 (no organic manure), M1 (dairy manure 30 t/ha), M2 (dairy manure 90 t/ha) and R (city refuse compost 30 t/ha) (In the attached Excel files they are labeled M1, M2, M3, R, respectively).

Each treatment was replicated 6 times. Altogether there were 4 x 4 x 6 (= 96) field plots, each 16 m long and 6 m wide. A plot comprised 3 beds. The plots arrangement in the field is described in Fig. 67.

5.3 Data presentation in the Excel files

The Gilat original annual reports (1961-1994) could not be recovered and only the treatment means (of replicates) were available to us. The available data was compiled in Excel files one year per file. Each file contains all the data obtained per cropping season (e.g. yield, % elements in leaves; NPK soil tests, etc.). Altogether this report contains 39 Excel files, corresponding to the number of studied crop-seasons. The Excel file names begin by GLPP followed by the year, e.g., GLPP1961.xlsx, GLPP1962.xlsx, …, GLPP1993.xlsx. Each file entail 16

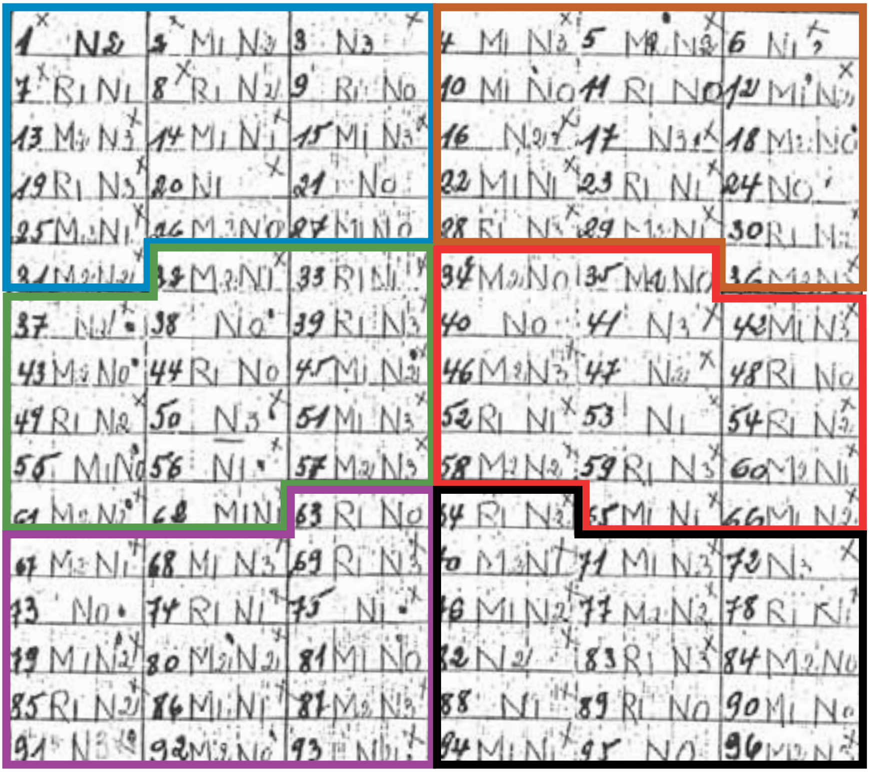


Fig. 67. The field plots arrangement (identified by number and treatment) in the Gilat long-term experiment (photo of the original handwritten plan). Blocks 1-to-6 are marked by color lines: blue = block 1; brown = 2; green = 3; red = 4; purple = 5; black = 6. Note that in text and Excel files the symbols N0, N1, N2, and N3 were replaced by N1, N2, N3, and N4, respectively.

rows each showing data of one treatment, defined by its N and M levels. The 16 rows are followed by additional 8 rows showing the main treatments (N and M) means. Each variable occupies one column so that all the variables are shown side by side. The format of the Excel files is identical to that in the Bet Dagan report (Part I).

5.4 Soil characteristics

The experiment was carried out at the Gilat Experiment Station in Israel (35ºE, 30ºN). The soil is loessial (Calcic Haploxeralf/Typic Haplargid/Calcixerollic Xerochrept) with main properties summarized in Table 26. The soil bulk density increased from 1.25 kg/L in the top 20 cm to 1.60 kg/L at a depth of 400 cm. The soil water contents at air dryness and field capacity were 3.5 and 23% v/v, respectively. To obtain an estimate of the soil organic matter content (%) the soil organic carbon (Org C in Table 26) should be multiplied by a factor of 1.7. The soil mineralization factor = 2% per year (Feigin and Sagiv, 1990), meaning that the annual mineralization (*g mineral N* m^{-2} Y^{1} *in the 0-20 cm soil layer*) = soil organic N (*% soil weight, Org N*) x 0.2 (*m*) x soil bulk density (*kg/L*)] x mineralization factor (0.02 Y^{1}) x 10^4.

Table 26. Some soil properties of the Gilat soil[1].

Layer	Hori-zon	pH	EC 1:1	$CaCO_3$	Clay	Silt	Sand Fine	Sand Coarse	Org C	Org N
cm			*dSm*$^{-1}$	%	%	%	%	%	%	%
0-25	Ap	8.2	1.2	18.6	16.5	33.2	46.3	4.0	0.70	0.075
25-40	B1	8.2	0.9	28.0	22.0	39.9	35.4	2.7	0.77	0.078
40-80	B2	8.3	0.7	28.9	23.0	43.2	30.4	3.4	0.73	0.075
80-120	B3	8.3	0.6	21.1	25.9	38.9	30.6	4.6	0.67	0.084

Note: [1]The data in the table (except EC) was derived from Feigin and Hidesh (1969). The untreated soil mineralization potential at field capacity conditions is 1.5% of the soil organic N per year (0-20 cm soil layer), which is equivalent to ~30 kg N $ha^{-1}Y^{-1}$ (Feigin and Sagiv, 1988). The soil volumetric water content at air dryness and field capacity are 3.5% and 23%, respectively.

The mineral composition of the soil is quartz (45-60%), clay minerals + micas (10-20%), plagioclase (10%), K-feldspare (10%) and calcite (10%) (Sandler *et al.*, 2009). The major clay mineral is illite-smectite (montmorillonite). The soil chemical composition is 61% SiO_2, 7% Al_2O_3, 3% Fe_2O_3, 11% CaO, 1.7% MgO and 1.2% K_2O. All the above mentioned results were very similar (within the range of analytical error) in the 0-20 and 20-40 cm soil layers. The cation exchange capacity (CEC) of the soil is 9.7 – 10.9 $mmol_c$/100 g, the range covering the time and treatments span of the experiment. Calcium (Ca) and potassium (K) constitute ~50% and ~15% of the CEC, respectively. The source of all these results is Sandler *et al*. (2009).

5.5 Manure characteristics and application dates

The chemical composition of the dairy manure and city refuse composts are given in Table 27. The manures were applied to the field according to treatments before planting the following crops: sugarbeet (1961), potato (1963, as pellets), cotton (1967, as pellets), celery (1972), cucumber (1976), sweet corn (1978), potato (1979), cucumber (1984, as pellets), bell pepper (1986 as pellets), Chinese cabbage (1992), carrot (1994).

Table 27. Chemical composition of the manures (results are expressed as % of dry weight except water content which is % fresh weight)[1].

Year	H_2O	Organic matter[2]		Total N	Total P	Total K	C/N	
		Dry digest	Wet digest				Dry	Wet
				Dairy manure				
1961	52	36	25	1.6	0.64	2.51	13	9.1
1963	51	35	23	1.5	-	-	13	8.8
1967	47	53	26	1.5	-	-	20	9.7
1977	55	41	-	-	0.52	-	-	-
1979	47	22	-	-	-	-	-	-
1984[2]	19	54	-	2.6	1.37	2.46	-	-
1986[2]	9	52	-	2.3	1.56	2.81	-	-
				City refuse compost[4]				
1961	28	51	45	1.2	0.21	0.48	25	21.8
1963	30	48	46	1.5	-	-	19	18.0
1967	35	40	22	1.45	-	-	16	8.9
1977	24	48	-	-	0.52	-	-	-
1979	36	68	-	-	-	-	-	-
1984[3]	29	55	-	1.33	0.41	0.50	-	-
1986[3]	32	61	-	1.24	0.30	0.56	-	-

Note: [1]Source: Feigin *et al.* 1974. [2]Dry digest is by ignition at 550ºC in furnace; wet digest is by potassium dichromate ($K_2Cr_2O_7$). [3]In 1984 and 1986 the manure was added as pellets (produced by Shacham, Israel). [4]Contains 4%±2 unidentified solids.

5.6 Climate

The time averaged monthly mean air temperatures in January to December were 11, 13, 16, 21, 24, 29, 32, 32, 29, 25, 18 and 13oC, respectively. The rainfall and class A pan evaporation data for specific years is given in the crop report Excel files.

5.7 Irrigation and P, K fertilization

All treatments received identical superphosphate and KCl doses applied by broadcast before seeding. The doses are specified in the crop report Excel files. Irrigation was aimed to replenish class A pan evaporation multiplied by a time dependent crop coefficient. The precise irrigation rates appear in the crop report Excel files. Until 1984, irrigation was by sprinklers (7 days interval) and N was applied as ammonium sulfate $(NH_4)_2SO_4$ before planting followed by two top dressings. Since 1985, the plots were irrigated by two L/h drippers (1 m between laterals, 2 emitters per m along lines) twice a week. Nitrogen (N) was applied through the water as ammonium nitrate (NH_4NO_3). The average sodium (Na) and Chloride (Cl) concentrations in the irrigation water were 7.0 and 7.5 mM, respectively (162 and 263 g m^{-3}, respectively).

5.8 Yield measurements and soil and plant analyses

The yield of 15 m row length of two centered rows was cut and measured for fresh and dry weight. Plant tissue was analyzed by digesting dry (60ºC) ground tissue sample with H_2S0_4 + H_2O_2 for N, P, K, Na determination and with $HN0_3$ + $HClO_4$ for S analysis. N, P and S were determined by auto-analyzer, K and Na by flame photometer and Cl by chloridometer.

Soil samples were dried at 40ºC and ground to pass through a 2 mm sieve. Soil tests included ionic composition of different soil extracts and soil Kjeldahl N.

5.9 List of tested crops

The list of studied crops and plant and soil variables is summarized in Table 28.

Table 28. List of tested crops and plant and soil variables in the Gilat experiment (1961-1994).

Year	Crop	Excel file name	Seeding date	Harvest date	Variable (and number)		Comment
					Plant	Soil	
1961	Sugar-beet	GLPP1961	11/10/61	10/6/62	Beets yld; total DM	-	Fertilized & manured;
1962	Corn	GLPP1962	19/7/62	17/10/62	Fresh silage yld; total DM	-	Fertilized;
1963	Onion	GLPP1963	6/1/63	5/5/63	Fresh yld; Total DM	Soil org N; soil OM; available P, K; EC pH	Fertilized
1963	Potato	GLPP1963a	25/6/63	15/12/63	Tuber yld ; total DM	-	Fertilized& manured, partial data
1964	Barley	GLPP1964	5/1/64	24/5/64	Grain yld ; total DM	-	Not fertilized not manured; partial data
1965	Sugar-beet	GLPP1965	6/10/64	13/6/65	Beets yld; total DM; sugar yld	Soil org N; soil OM; available P; EC pH	Fertilized; partial data
1966	Onion	GLPP1966	2/1/66	13/5/66	Onion yld; total DM	-	Fertilized;
1966	Setaria	GLPP1966a	5/6/66	28/7/66	Estimated fresh and DM yield	-	Not fertilized not manured; partial data
1967	Cotton	GLPP1967	9/4/67	1/10/67	Cotton yield; total DM	Soil org N	Fertilized& manured; partial yld data
1968	Onion	GLPP1968	1/12/67	27/5/68	Onion yld; Total DM	-	Fertilized
1969	Tomato	GLPP1969	9/4/69	20/8/69	Fruit yld; total DM	Soil org N; mineralization rate;	Not fertilized not manured; partial data
1970	Lettuce	GLPP1970	5/11/69	5/2/70	Untrimmed head yield; total DM	-	Fertilized; partial data
1970	Broccoli	GLPP1970a	3/8/70	25/12/70	Fresh yld; total DM; % NPK in DM over time	Mineral N in 0-30, 30-60 cm over time	Fertilized; partial data Feigin and Shakib, 1971
1971	Beans	GLPP1971	12/4/71	21/6/71	Fresh yld; total DM	-	Fertilized; partial data Feigin *et al.* 19 73

Year	Crop	Excel file name	Seeding date	Harvest date	Variable (and number)		Comment
					Plant	Soil	
1972	Celery	GLPP1972	12/10/72	18/2/73	Fresh yld; total DM	-	Fertilized & manured; partial data
1973	Fallow	GLPP1973	-	-	-	-	Not fertilized not manured
1974	Potato	GLPP1974	20/2/74	5/7/74	Tubers yld; total DM	-	Fertilized; partial data
1975	Onion	GLPP1975	16/10/74	24/4/75	Fresh yld; total DM	-	Fertilized; partial data
1976	Cucumber	GLPP1976	5/4/76	30/5/76	Fresh yld; total DM	Soil org N	Fertilized & manured; partial yld data
1976	Bell pepper	GLPP1976a	9/7/76	12/12/76	Fresh yld; total DM	-	Fertilized; partial data
1977	Fallow	GLPP1977	-	-	-	-	Not fertilized not manured
1978	Sweet corn	GLPP1978	4/4/78	3/7/78	Fresh cob yld; total DM	-	Fertilized & manured; partial data, Feigin *et al.* 1980
1979	Lettuce	GLPP1979	7/11/78	15/2/79	Fresh yld (not trimmed); total DM	-	Fertilized; partial data
1979	Potato	GLPP1979a	20/8/79	31/12/79	Tuber yld; total DM	-	Fertilized & manured; partial data
1980	Chinese cabbage	GLPP1980	21/10/80	20/2/81	Fresh yld; total DM	-	Fertilized; partial data
1981	Proce-ssing tomato	GLPP1981	14/4/81	28/7/41	Fruit yld; total DM	-	Fertilized; partial data
1982	Wheat	GLPP1982	15/11/81	15/6/82	Grain yld; total DM	-	Not fertilized not manured; partial data
1983	Wheat	GLPP1983	15/11/82	14/6/83	Grain yld; total DM	-	Not fertilized, not manured

Year	Crop	Excel file name	Seeding date	Harvest date	Variable (and number)		Comment
					Plant	Soil	
1984	Cucumber	GLPP1984	30/4/84	27/7/84	Fruit yld; total DM	-	Irrigation switched to drip. Fertilized & manured; partial data
1985	Cucumber	GLPP1985	15/4/85	25/7/85	Fruit yld; total DM	-	Fertilized; partial data
1986	Bell pepper	GLPP1986	1/5/86	1/10/86	fruit yld; total DM	-	Fertilized & manured; estimated fruit yld and total DM, Sagiv *et al.* 1987
1987	Musk-melon	GLPP1987	1/4/87	10/8/87	Fruit yld; total DM; % DM; % NPK in plant;	Org N, NO_3, NH_4, available P and K; mineralization under field conditions	Fertilized; partial results. Feigin and Sagiv, 1988
1988	Musk-melon	GLPP1988	27/3/88	11/7/88	Fruit yld; total DM	-	Fertilized; partial data
1989	Fallow	GLPP1989	-	-	-	-	Not fertilized, not manured
1990	Rape	GLPP1990			Seed yld; total DM	-	Fertilized; partial data
1991	Chinese cabbage	GLPP1991	30/10/90	9/1/91	Fresh yld; head wt; total DM; DM vs time; % NPK vs time	Available NO_3, NH_4, P, K 0-20, 20-40 cm	Fertilized, Feigin *et al.* 1991
1992	Chinese cabbage	GLPP1992	30/10/91	10/1/92	Fresh yld, total DM	-	Fertilized & manured, partial data
1993	Carrot	GLPP1993	20/10/92	18/4/93	Carrot yld, total DM	Deep (0-420 cm) soil sampling	Fertilized; partial data; The crop was incorp-orated in soil, Sagiv *et al.* 1994
1994	Carrot	GLPP1994	11/10/ 93	5/4/94	Fresh yld; head wt; total DM; DM vs time; % NPK vs time	Available NO_3, NH_4, P, K 0-20, 20-40 cm	Fertilized & manured, Sagiv *et al.* 1995

6 Results

6.1 The annual crop reports

The annual reports can be identified by the execution year which appears in the file name after the prefix GLPP (to distinguish from the Bet Dagan reports prefixed BDPP) (e.g. GLPP1961.xls). The annual report includes two rain parameters: ann (cell A1), which is the entire-year rainfall (1/1 to 31/12), and rain mm (cell D1), which is rainfall between planting and harvest. Since the annual report Excel files are too big to be inserted in the text, they are stored in a pre-assigned folder and retrieved from the text by clicking (with control button pressed) the blue hyperlinks in the body of the text.

6.1.1 The 1961 season (sugarbeet)

The 1961 report can be viewed by clicking: GLPP1961. The measured variables were sugarbeet fresh beets yield and total dry matter (DM) production (beets + leaves). The beet yield response to mineral N, subject to manure (M) level, is presented in Fig. 68. Mineral-N application exceeding 180 kg/ha had negligible effect on yield and the strongest response was obtained when elevating the N dose from 0 to 90 kg N/ha. When no mineral N was added as fertilizer, the beet yield declined in the order 90 t/ha dairy manure > 30 t/ha dairy manure > 30 t/ha city refuse compost = no manure added. The data indicate that 90 tonnes/ha of dairy manure without N fertilization had the same effect on fresh beet yield as ~100 kg fertilizer-N/ha without manuring, and 30 tonnes dairy manure/ha was equivalent to ~50 kg N/ha.

The DM yield data is presented in Table 29. Elevating dairy manure levels increased nearly linearly the crop DM production even at the highest N dose (maximum increase of ~20% relative to control); city refuse compost (R) enhanced DM yield more than dairy manure level M1. The impact of M2 vs. M0 on the DM yield was similar under zero and maximum N input, indicating that the organic amendment contributed not only N but also additional nutrients or compounds improving soil aggregation.

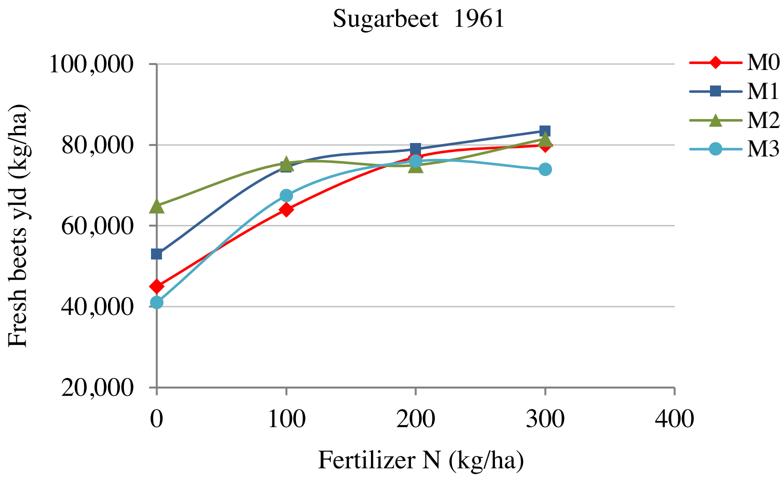


Fig. 68. Fresh sugarbeet yield as function of N fertilizer application rate in relation to four manure treatments: N0 manure (M0), 30 tonnes dairy manure/ha (M1), 90 tonnes dairy manure/ha (M2), and 30 tonnes city refuse compost/ha (M3, later designated as R3).

Table 29. Effects of manure level (M0, M1, M2 all dairy manure) and type (M1 vs. city refuse compost, R) on total dry matter (DM) production by sugarbeet (1961). The application rates of M0, M1, M2 and R are given in the GLPP1961.xlsx report. No statistics are presented as data of treatment replicates were not available.

Treatment	Sugarbeet				
	N		M		Total DM
	Level	*kg N/ha*	*Level*	*Type*	*kg/ha*
M0N3	4	300	1	M0	9,280
M1N3	4	300	2	M1	9,640
M2N3	4	300	3	M2	11,280
RN3	4	300	4	R	11,400
M0N0	1	0	1	M0	8.000
M2N0	1	0	3	M2	10,230

6.1.2 The 1962 season (silage corn)

The 1962 report can be viewed by clicking: GLPP1962. The total DM-yield as a function of N fertilizer and manure levels (the latter applied before the previous crop) is presented in Fig. 69. No statistics are provided as there was no record of replicates yield. The response in DM weight to N was limited to the range 0 to 100 kg N/ha; further increase to 200 and 300 kg/ha was ineffective. The manure had a positive impact on yield only in the 0 and 100 kg fertilizer N/ha treatments. City refuse compost (R) did not differ from null manure application (M0), and 90 t/ha dairy manure (M2) gave higher DM yield than 30 t/ha (M1), but only in the zero N fertilization treatment.

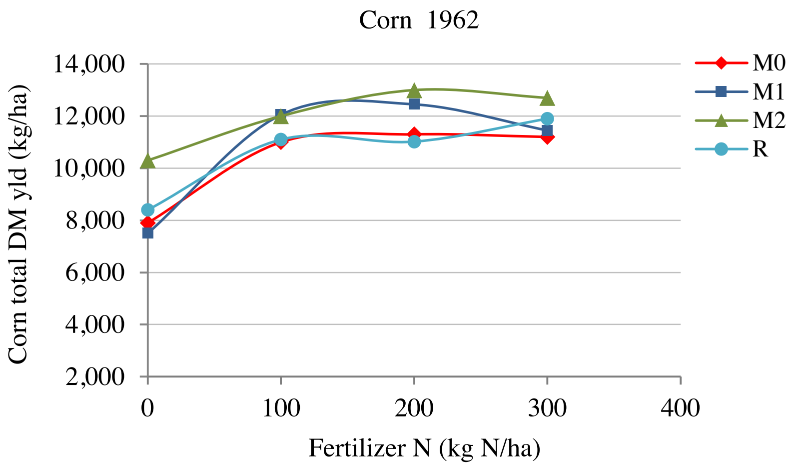


Fig. 69. Silage corn total dry matter (DM) yield as a function of N fertilizer application rate under four manure treatments: no manure (M0), 30 tonnes dairy manure/ha (M1), 90 tonnes dairy manure/ha (M2), and 30 tonnes city refuse compost/ha (R).

The fresh silage corn yield was available as a function of manure level only at 300 and zero fertilizer N application rates (Table 30). The greatest response in yield was obtained in treatment M1 vs. M0 at N level of 300 kg N/ha.

Table 30. Effects of manure (M) level (M0, M1, M2) and type (M1 vs. R) on the fresh weight of silage corn at two levels of N (1962). The manure was applied last year. No statistics are presented as replicate data was unavailable.

Treatment	Silage corn				
	N		M		Fresh yield
	Level	*kg N/ha*	*Level*	*Type*	*kg/ha*
M0N3	4	300	1	M0	36,220
M1N3	4	300	2	M1	56,300
M2N3	4	300	3	M2	59,400
RN3	4	300	4	R	61,000
M0N0	1	0	1	M0	26,330
M2N0	1	0	3	M2	49,900

6.1.3 The 1963 season (onion and potato)

Onion

The 1963 onion report can be viewed by clicking: GLPP1963. The available data for this crop is summarized in Table 31. Even though three years elapsed since organic materials were applied, their impact was still pronounced, albeit weaker than in previous years.

Table 31. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on the fresh weight of onions in 1963 and the total dry matter (DM) production. The application rates of M0, M1, M2 and R (added in 1961) are specified in the 1961 crop report Table. No statistics are presented as individual plot data was unavailable.

Treatment	Onion					
	N		M		Fresh yield	Total DM
	Level	*kg N/ha*	*Level*	*Symbol*	------ *kg/ha* ------	
M0N3	4	240	1	M0	34,800	5,400
M1N3	4	240	2	M1	38,000	5,800
M2N3	4	240	3	M2	44,000	5,900
RN3	4	240	4	R	37,400	5,300
M0N0	1	0	1	M0	17,100	2,100
M2N0	1	0	3	M2	28,000	5,100

Potato

The 1963 potato report can be viewed by clicking: GLPP1963a. The available data for this crop is summarized in Table 32. Manure level (M0, M1 and M2) and city refuse compost (R vs. M1) had no effect on tuber yield or total DM production when applied in combination with 240 kg N/ha. When in combination with null N addition, M2 increased the yield by 20-25% relative to M0. Application of 240 vs. zero kg N/ha, in combination with manure level M2, increased slightly the tuber yield (<10%) but meaningfully (~30%) the plant total DM weight (M2N0 vs. M2N3).

Table 32. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on the potato tuber yield in 1962 and total dry matter (DM) produced. The application rates of M0, M1, M2 and R (added prior to potato planting) are specified in the potato report Table. No statistics are presented as individual plots data were unavailable.

Treatment	Potato					
	N		M		Total DM	Tuber yield
	Level	*kg N/ha*	*Level*	*Type*	- - - - - - *kg/ha* - - - - - -	
M0N3	4	240	1	M0	8,000	38,000
M1N3	4	240	2	M1	6,800	39,000
M2N3	4	240	3	M2	7,000	39,000
RN3	4	240	4	R	7,200	38,500
M0N0	1	0	1	M0	5,390	25,500
M2N0	1	0	3	M2	6,500	30,000

6.1.4 The 1964 season (barley)

The 1964 barley report can be viewed by clicking: GLPP1964. In this season no N and K fertilizers and no manures were applied. The yield and total DM responses to the N and manure residues were clear but weak (Table 33).

Table 33. One year manure and N-fertilizer residual effect on barley grain yield (1964) and on total dry matter (DM) production. No statistics is presented as replicates data were unavailable.

Treatment	Barley					
	N		M		Total DM	Grain yield
	Level	*kg N/ha*	*Level*	*Type*	- - - - - - *kg/ha*	- - - - - -
M0N3	4	240	1	M0	7,600	2,650
M1N3	4	240	2	M1	8,550	3,000
M2N3	4	240	3	M2	9,000	3,150
RN3	4	240	4	R	8,200	2,850
M0N0	1	0	1	M0	2,000	1,000
M2N0	1	0	3	M2	6,750	2,350

6.1.5 The 1965 season (sugarbeet)

The 1965 sugarbeet report can be viewed by clicking: GLPP1965. In the four organic amendment treatments, a response in beet yield to N was obtained when increasing the dose from 0 to 100 kg N/ha. Further increase to 200 or 300 kg N/ha reduced yield (Fig. 70). The effect of manure level on yield was apparent only at null N fertilization, following the order M2>M1>M0. The yield in the city refuse compost treatment (M3 in Fig. 70) was comparable to the yield in treatment M1. Notably, the yield in the control treatment (M0N0) declined since 1961 from 40,000 kg/ha to ~25,000 kg/ha in 1965.

The sugarbeet DM yield is presented in Table 34. At zero N addition, the DM weight in treatments M0 and M2 was 8 and 10.2 t/ha, respectively, whereas at 300 kg N/ha it was 9.3 and 11.3 t/ha, respectively. City refuse compost (R) gave ~18% higher DM yield than treatment M1.

Results of soil tests three months before harvest are summarized in the aforementioned 1965 crop report. They show effects of manuring on soil organic N (Kjeldhal N, SON): at null N application (N0), the SON in treatments M0, M1, M2, and R was 407, 499, 720 and 494 mg N/kg soil, respectively. At 300 kg N/ha (N3) the SON was 503, 554, 685 and 590 mg N/kg, respectively. The SON in N1 and N2 was between N0 and N3. Other results show that the manure mean pH and NaHCO3 extractable P in treatments N0, N1, N2 and N3 were 8.1, 8.1, 8.0, 8.05 and 49, 44, 40 and 40 mg P/kg soil, respectively.

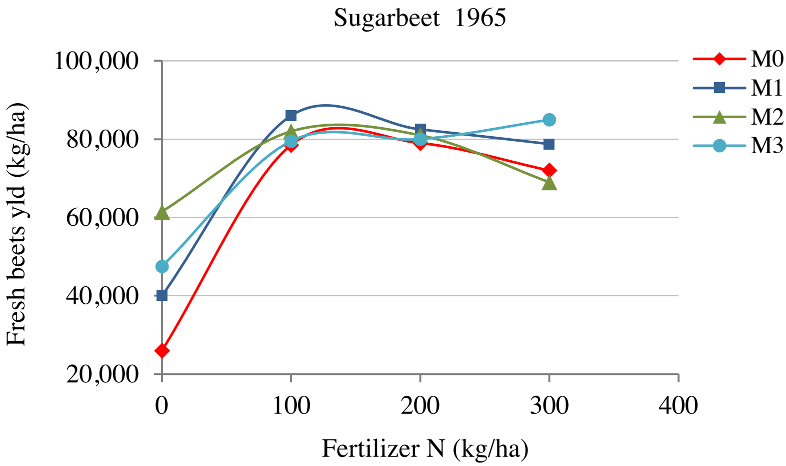


Fig. 70. Fresh sugarbeet beet yield as function of N fertilizer application rate and four manure treatments: no manure (M0), 30 tonnes dairy manure/ha (M1), 90 tonnes dairy manure/ha (M2), and 30 tonnes city refuse compost/ha (M3). The manure was applied in 1963 (before potato planting).

Table 34. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on the total dry matter (DM) of sugarbeet in 1965. The manure was applied in 1963. No statistics are presented as replicate data was unavailable.

Treatment	Sugarbeet				
	N		M		Total DM
	Level	*kg N/ha*	*Level*	*Type*	*kg/ha*
M0N3	4	300	1	M0	9,280
M1N3	4	300	2	M1	9,640
M2N3	4	300	3	M2	11,280
RN3	4	300	4	R	11,400
M0N0	1	0	1	M0	8,000
M2N0	1	0	3	M2	10,230

6.1.6 The 1966 season (onion and setaria)

Onion

The 1966 onion report can be viewed by clicking: GLPP1966. The fresh onion yield responded positively to N-fertilizer addition from 0 to 160 kg N/ha, whereas increases to 240 kg N/ha tended to reduce yield (Fig. 71). Even though no manure was added since 1963, a very pronounced yield increase was obtained at each N-fertilizer level due to elevating M (M2>M1>M0). The response in onion DM yield to manuring at N3 was negligible (Table 35) but at N0, the yield in treatments M0 and M2 was 1,510 and 3,200 kg/ha, respectively. At manure level M3, the DM yield at N additions 0 and 240 kg N/ha was 3,200 and 3,700 kg/ha.

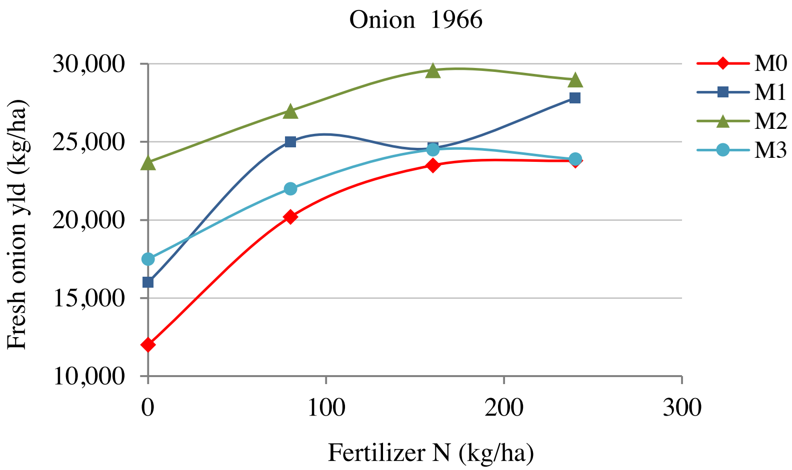


Fig. 71. Fresh onion yield as function of N fertilizer application rate under four manure treatments: N0 manure (M0), 30 tonnes dairy manure/ha (M1), 90 tonnes dairy manure/ha (M2), and 30 tonnes city refuse compost/ha (M3). Last manure application: 1963.

Table 35. Effect of manure levels (M0, M1, M2) and type (M1 vs. R) on total dry matter (DM) of onion in 1966. The manure was applied last time in 1963. No statistics are attached as replicate data were unavailable.

Treatment	Onion				
	N		M		Total DM
	Level	*kg N/ha*	*Level*	*Type*	*kg/ha*
M0N3	4	240	1	M0	3,600
M1N3	4	240	2	M1	3,500
M2N3	4	240	3	M2	3,700
RN3	4	240	4	R	3,500
M0N0	1	0	1	M0	1,510
M2N0	1	0	3	M2	3,200

Setaria

During June and July 1966 setaria was grown without addition of N fertilizer or manure. To see the available irrigation details and yield results click: GLPP1966a. Since the yield results are dubious they are not discussed.

6.1.7 The 1967 season (cotton)

The 1967 cotton report can be viewed by clicking: GLPP1967. Compatible with previous year results, application of manure at N0 was more effective than at N3. In N0, the lint yield in treatments M0N0 and M2N0 were 550 and 3,750 kg/ha, while in treatments M0N3 and M2N3 they were 4,020 and 5,000 kg/ha (Table 36). A fertilizer N dose of 240 kg/ha increased the lint yield in manured M2 plots from 3,750 to 5,000 kg/ha (M2N0 vs. M2N3, Table 36). City refuse compost (R) gave lint yields similar to dairy manure (RN3, M1N3). The response in total DM weight to N and M was similar to the response in lint yield.

Table 36. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on the lint yield and total dry matter (DM) of cotton in 1967. The manure was applied before planting. No statistics are presented as individual plot data were unavailable.

Treatment	Cotton					
	N		M		Lint yield	Total DM
	Level	*kg N/ha*	*Level*	*Type*	----- *kg/ha* -----	
M0N3	4	240	1	M0	4,020	10,900
M1N3	4	240	2	M1	4,750	12,350
M2N3	4	240	3	M2	5,000	13,000
RN3	4	240	4	R	4,550	11,830
M0N0	1	0	1	M0	550	1,430
M2N0	1	0	3	M2	3,750	9,750

6.1.8 The 1968 season (onion)

The 1968 onion report can be viewed by clicking: GLPP1968. Except in dairy manure level M2, the response in fresh yield to fertilizer N was bell-shaped with a peak between 80 and 160 kg N/ha. At M2, the yield in levels 160 and 240 kg N/ha was practically the same (Fig. 72). The response to organic manure was strongest at null fertilizer addition. The fresh yields in 1968 considerably exceeded the yields in 1966. At 240 kg N/ha, no advantage in DM yield was obtained due to manure application (Table 37). At manure level M2, the application of 240 kg N/ha gave the same DM yield as the null N application, compatible with the bell-shaped fresh yield response to N.

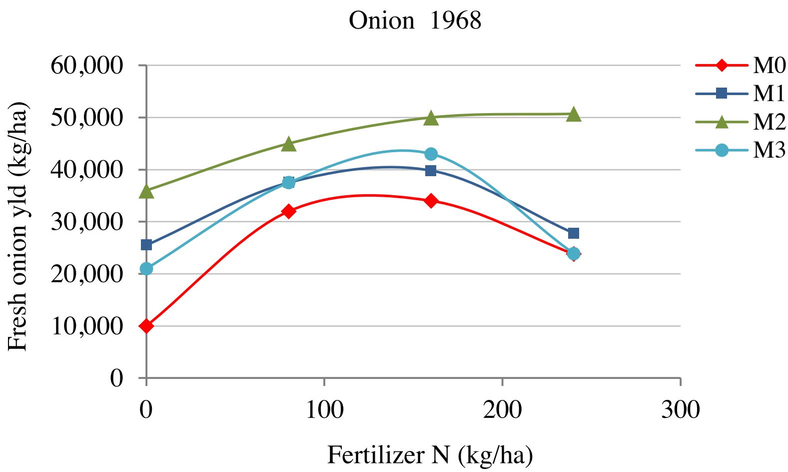


Fig. 72. Fresh onion yield as function of N fertilizer application rate under four manure treatments: no manure (M0), 30 tonnes dairy manure/ha (M1), 90 tonnes dairy manure/ha (M2), and 30 tonnes city refuse compost/ha (M3). Last time the manure was applied was 1967 (before cotton seeding).

Table 37. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on onion total dry matter (DM) production in 1968. The manure was applied in 1967 prior to cotton planting. No statistics are presented as individual plot data was unavailable.

Treatment	Onion				
	N		M		Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	*kg/ha*
M0N3	4	240	1	M0	7,600
M1N3	4	240	2	M1	6,200
M2N3	4	240	3	M2	6,100
RN3	4	240	4	R	6,800
M0N0	1	0	1	M0	1,450
M2N0	1	0	3	M2	6,400

6.1.9 The 1969 season (processing tomato)

The 1969 processing tomato report can be viewed by clicking: GLPP1969. The crop was neither fertilized by N and P nor manured. The impact of manure treatments on fresh tomato yield was negligible in plots that previously received the highest N rate, but in treatment N0 the yield in manure levels M0 and M2 was 67,520 and 80,000 kg/ha, respectively (Table 38).

Table 38. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on processing tomato fresh fruit and total dry matter (DM) yields (1969). The manure was applied in 1967 prior to cotton planting. No statistics are presented as replicate data were unavailable.

Treatment	Processing tomato					
	N		M		Fresh fruit yield	Total DM weight
	Level	*kg N/ha*	*Level*	*Type*	- - - - - - - - *kg/ha*	- - - - - - - -
M0N3	4	0	1	M0	75,760	5,710
M1N3	4	0	2	M1	73,100	5,700
M2N3	4	0	3	M2	75,800	7,400
RN3	4	0	4	R	75,800	5,700
M0N0	1	0	1	M0	67,520	4,370
M2N0	1	0	3	M2	80,000	7,400

Soil samples taken from all the tomato plots (0-20 cm) were incubated for 14 days at 30ºC in order to estimate treatment effect on soil organic N (SON) mineralization rate. The SON (Kjeldhal N) on days 0 and 14 are defined as SON_{t0} and SON_{t14}. The original SON results can be found in the "1969 season report". The first order mineralization rate constant K (d^{-1}) was estimated from the equation: $N_t = N_o*(1- e^{(-K\,t)})$, where N_o (mineralizable SON) = $0.2*SON_{t0}$, $N_t = SON_{t14}$ and t = 14 d. The obtained rate constants are summarized in Table 39. In all N fertilizer treatments the SON increased with increasing manure application rate with negligible impact of the mineral N dose. The effect of city refuse compost (R) on SON did not differ from the impact of dairy manure (Table 39). The rate constant K varied between 0.010 (M0N0) and 0.017 d^{-1} (M2N3). There is a partial trend of increase in K as M increased ($K_{M2}>K_{M1}>K_{M0}$) while the mineral N dose seems to have a negligible effect on K.

Table 39. Soil organic N (SON_{t0}) and estimated mineralization rate constants (k, at 30ºC) in studied treatments.

Organic treatment	Fertilizer N treatment				Fertilizer N treatment			
	N0	N1	N2	N3	N0	N1	N2	N3
	SON (Kjeldhal N, mg N/kg soil)				Mineralization rate constant k (d^{-1})			
M0	415	462	418	440	0.0104	0.0133	0.0151	0.0124
M1	505	567	527	537	0.012	0.0155	0.0155	0.0146
M2	593	647	618	633	0.0146	0.0159	0.0137	0.0173
R	558	480	510	515	0.012	0.0155	0.0168	0.0164

6.1.10 The 1970 season (lettuce and broccoli)

Lettuce

The 1970 lettuce report can be viewed by clicking: GLPP1970. Even at the fertilizer N dose of 360 kg N/kg soil the head yield still responded positively to dairy manure that was applied last in 1967 (Table 40). The residual effect of the city refuse compost (R) was weaker than that of dairy manure (RN3 vs. M1N3). At zero fertilizer-N application, the advantage of M2 over M0 was even stronger. The N supply from manure level M2 without fertilizer-N was deficient as addition of 360 kg N/ha as fertilizer increased the untrimmed head yield from 34,000 (treatment M2N0) to 48,000 (M2N3) kg/ha. The response in DM yield to treatments was ambiguous.

Table 40. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on lettuce untrimmed head yield and total dry matter production (DM) (1970). The manure was applied last in 1967 prior to cotton planting. No statistics are presented as replicate data were unavailable.

Treatment	Lettuce					
	N		M		Fresh untrimmed heads yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	- - - - - - - *kg/ha*	- - - - - - -
M0N3	4	360	1	M0	18,640	820
M1N3	4	360	2	M1	42,000	4,900
M2N3	4	360	3	M2	48,000	3,900
RN3	4	360	4	R	29,000	2,700
M0N0	1	0	1	M0	10,000	790
M2N0	1	0	3	M2	34,000	3,500

Broccoli

The 1970 broccoli report can be read in: GLPP1970a. It includes data on four plant samplings along the growing period in which DM and nutrients concentration were determined. It also includes a soil test at seeding. At N level N3 (240 kg N/ha), the fresh yield declined in the order M2> M1> M0 and R was identical to M1 (Table 41, part A). At null N fertilization, the yield in M0 and M2 was 3.6 and 17.5 t/ha, respectively. The higher yield in M2N0 than in M2N3 indicates adverse effect of excess fertilizer-N on broccoli fresh yield. In the case of DM yield, there was a negative response to M level at N3 but, in N0, the DM yield in M2 exceeded the one in M0. The main factor means (Table 41, part B) show that broccoli fresh and DM yields declined in the order N2= N3> N1> N0, and M2= N1> M1.

The effect of fertilizer-N level on % NPK in broccoli leaves and fruit, in combination with manure levels M0 and M2 is presented in Fig. 73. At any N level, except the highest (N3), the % NPK in leaves and fruits was higher in M2 than in M0 (all at harvest). The effect of N level on % N in plant was greatest when increasing it from level N0 to N1. The effect on % P was beneficial only when raising the N level to N2 or N3. No clear effect of N level on % K in broccoli was observed.

Table 41. *Part A:* Effect of manure level (M0, M1, M2) and type (M1 vs. R) on broccoli fresh yield and total dry matter (DM) production (1970). The manure was applied in 1967 prior to cotton planting. No statistics are presented in part a as replicate data were unavailable. *Part B:* Main factor means fresh yield and its statistics, and DM production.

Part A:

Treatment	Broccoli					
	N		M		Fresh yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	240	1	M0	11,920	5,850
M1N3	4	240	2	M1	12,900	4,800
M2N3	4	240	3	M2	14,000	4,800
RN3	4	240	4	R	12,700	4,600
M0N0	1	0	1	M0	3,610	2,330
M2N0	1	0	3	M2	17,500	5,000

Part B:

Main effect		Fresh yield	Total DM yield
		------------- *kg/ha* -------------	
N0	a[1]	5,400	2,100
N1	b	10,640	3,030
N2	c	13,040	5,730
N3	c	12,840	5,285
M0	a	9,410	4,970
M1	a	10,230	4,636
M2	b	11,960	4,765
R	a	10,320	4,760

Note: [1]Different letters beside means of fresh yield indicate significant ($P<0.05$) difference between main treatments.

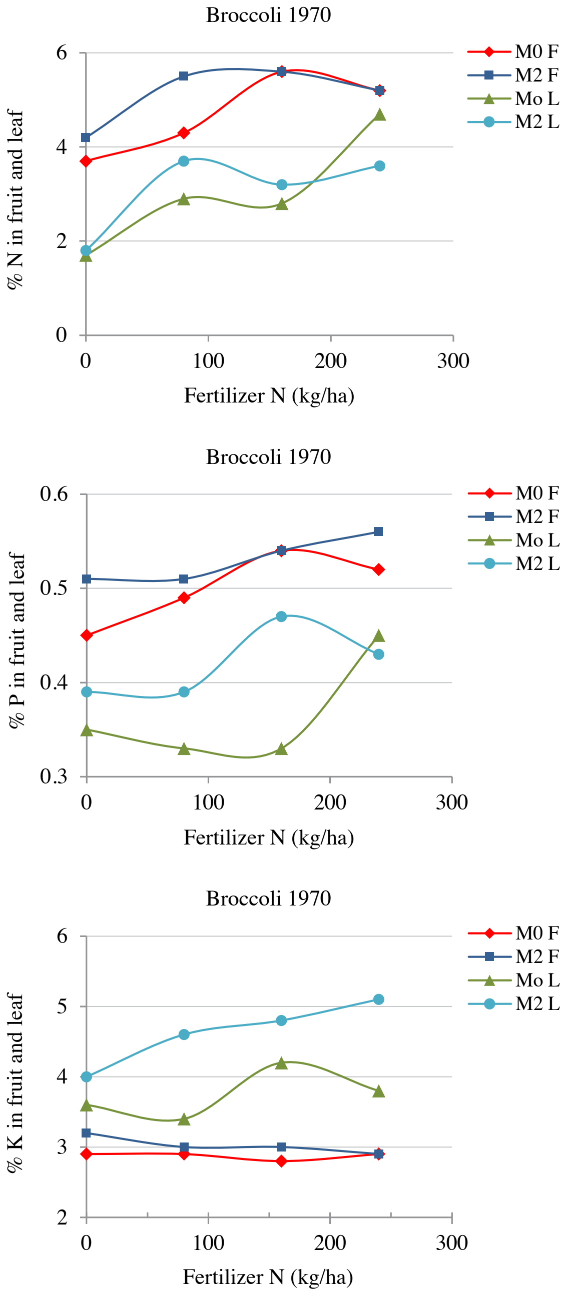


Fig. 73. The NPK concentration in DM of broccoli leaves (L) and florets (F) at harvest as a function of N fertilizer application rate and two dairy manure levels: no manure (M0), and 90 t/ha (M2).

6.1.11 The 1971 season (beans)

The 1971 beans report can be viewed by clicking: GLPP1971. This file includes data of yield, DM produced, temporal nutrients content in plant, and soil mineral N (all derived from Feigin *et al.*, 1973). Fresh and dry yields were unaffected, or declined, by increasing the manure level when in combination with 120 kg fertilizer-N/ha (Table 42). On the other hand, increasing the fertilizer-N from 0 to 120 kg N/ha, in combination with M2, increased the fresh yield from 4,500 to 6,200 kg/ha.

Table 42. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on bean pods fresh yield, fresh canopy weight, and total dry matter (DM) in 1971. The manure was applied last in 1967 prior to cotton planting. No statistics are presented as replicates data were unavailable.

Treatment	Beans						
	N		M		Fresh pods yield	Total DM yield	Fresh canopy
	Level	*kg N/ha*	*Level*	*Type*	- - - - - - - -	*kg/ha*	- - - - - - - -
M0N3	4	120	1	M0	7,940	2,680	12,850
M1N3	4	120	2	M1	6,200	2,980	14,310
M2N3	4	120	3	M2	6,200	2,500	15,120
RN3	4	120	4	R	7,800	2,400	11,490
M0N0	1	0	1	M0	4,420	1,410	6,560
M2N0	1	0	3	M2	4,500	1,500	8,900

6.1.12 The 1972 season (celery)

The 1972 celery report can be viewed by clicking: GLPP1972. Fresh celery yield declined by increasing the manure application rate in combination with 360 kg fertilizer-N/ha (N3, Table 43). However, at N0, elevating M from M0 to M2 increased the fresh yield from 1,500 to 13,000 kg/ha. At manure level M2 increasing the fertilizer-N application rate from 0 to 360 kg N/ha increased the fresh celery yield from 13,000 to 42,000 kg/ha. The response in total DM yield was similar, only it increased at level N3 when the manure level was enhanced from M0 to M1.

Table 43. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on celery fresh yield and total dry matter (DM) produced in 1972. The manure was applied before planting. No statistics are presented as replicate data were unavailable.

Treatment	Celery					
	N		M		Fresh yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	- - - - - - - - *kg/ha*	- - - - - - - -
M0N3	4	360	1	M0	49,250	6,130
M1N3	4	360	2	M1	47,900	6,900
M2N3	4	360	3	M2	42,000	6,400
RN3	4	360	4	R	49,300	5,200
M0N0	1	0	1	M0	1,500	830
M2N0	1	0	3	M2	13,000	1,200

6.1.13 The 1973 season (fallow, uncultivated)

The 1973 report can be viewed by clicking: GLPP1973. This year, the plots remained fallow - not fertilized, not manured, not cultivated and not planted. The file includes the meteorological details for this year.

6.1.14 The 1974 season (potato)

The 1974 potato report can be viewed by clicking: GLPP1974. Tubers yield increased by raising the manure rate from M0 to M1 in combination with 300 kg fertilizer-N/ha but it declined when increasing the level to M2 (Table 44). The fresh yield in the city refuse compost (R) was identical to that in M1. Nitrogen fertilization (300 kg N/ha) in combination with M2 increased the tubers yield from 46,300 (M2N0) to 64,600 (M2N3) kg/ha, respectively. In the control (M0N0), it was 19,100 kg/ha; when the N level was increased N3 (M0N3), the yield jumped to 61,400 kg/ha. The response in DM yield to treatments was similar to that in tuber yields, except that at N3 it increased due to elevating M from M1 to M2.

Table 44. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on potato tubers yield and total dry matter (DM) in 1974. The manure was applied last in 1972 before celery planting. No statistics are presented as replicate data was unavailable.

Treatment	Potato					
	N		M		Tuber yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	300	1	M0	61,400	12,220
M1N3	4	300	2	M1	67,000	12,700
M2N3	4	300	3	M2	64,600	15,600
RN3	4	300	4	R	67,500	14,000
M0N0	1	0	1	M0	19,100	3,310
M2N0	1	0	3	M2	46,300	8,200

6.1.15 The 1975 season (onion)

The 1975 onion report can be viewed by clicking: GLPP1975. Onion fresh and DM yields were meagerly affected by the manure application level (applied last time in 1972) when in combination with 270 kg N/ha (Table 45). Nitrogen fertilization (270 kg N/ha), in combination with M2, increased the fresh yield from 24,300 at N0 (M2N0) to 66,000 (M2N3) kg/ha. The onion yield in the control (M0N0) was 18,600 kg/ha, and in treatment M2N0 24,300 kg/ha. The latter yield increased due to addition of 270 kg N/ha to 66,000 kg/ha (M2N3). The response in DM yield to M and N treatments corresponded nicely to the fresh onion yield results.

Table 45. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on onion yield and total dry matter (DM) in 1974. The manure was applied last in 1972 before celery planting. No statistics are presented as individual plot data were unavailable.

Treatment	Onion					
	N		M		Onion yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	270	1	M0	68,700	8,570
M1N3	4	270	2	M1	70,000	9,700
M2N3	4	270	3	M2	66,000	8,800
RN3	4	270	4	R	74,000	11,000
M0N0	1	0	1	M0	18,600	2,370
M2N0	1	0	3	M2	24,300	4,300

6.1.16 The 1976 season (cucumber and bell pepper)

Cucumber

The 1976 cucumber report can be viewed by clicking: GLPP1976. Manure was applied ~5 months before seeding. The cucumber fresh yield at manure level M1 exceeded the yield at level M0, both under an N fertilization rate of 180 kg/ha; a further increase to M2 reduced the yield (Table 46). The corresponding total DM yield did not decline in M2 in comparison with M1. Nitrogen fertilization of 180 kg N/ha in combination with M2 had a small effect on fruit yield relative to N0 (9,600 kg/ha in M2N0 vs. 8,900 kg/ha in M2N3). The cucumber yield in the control (M0N0) was 2,540 kg/ha. By adding 180 kg N/ha (M0N3), the yield increased to 7,100 kg/ha, while adding 90 tonnes manure per ha (M2N0) it increased to 9,600 kg/ha.

Results of soil tests before seeding reveal that the concentration of total N (Kjeldhal N) was slightly affected by N fertilization under manure treatments M0, M1 and R (Table 47). Under treatment M2, the Kjeldhal N concentration was much lower in treatment N0 (570 mg N/ha) than in treatments N1, N2, N3 (mean of ~770 mg N/kg soil).

The concentration of total N in soil (Table 47) is 9-18% higher than in 1969 (Table 39). The increase was associated with the increasing manure application rate. The lowest total soil N was found in the city refuse compost treatment (R).

Table 46. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on cucumber yield and total dry matter (DM) in 1976. The manure was applied six months before planting. No statistics are presented as individual plot data were unavailable.

Treatment	Cucumber					
	N		M		Fruit yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	180	1	M0	7,100	1,760
M1N3	4	180	2	M1	9,900	2,700
M2N3	4	180	3	M2	8,900	3,200
RN3	4	180	4	R	10,500	2,700
M0N0	1	0	1	M0	2,540	1,760
M2N0	1	0	3	M2	9,600	2,600

Table 47. Total soil N (Kjeldhal N) in studied treatments (1976) before cucumber seeding.

Organic treatment	Fertilizer-N level			
	N0	N1	N2	N3
	Total soil N (Kjeldhal), mg N/kg soil			
M0	470	500	490	490
M1	580	630	560	650
M2	570	780	800	740
R	560	550	500	540

Bell pepper

The 1976 bell pepper report can be viewed by clicking: GLPP1976a. The fruit yield and DM production were higher in treatment M1 than in M0 when in combination with 270 kg N/ha (N3), but fruit yield declined in manure level M2 (Table 48). No such decline was observed in the total DM production. Nitrogen fertilization (N3), in combination with M2, had negligible effect on fruit yield (25,000 kg/ha in M2N0 in comparison with 34,000 in M2N3). The fruit yield in the control (M0N0) was 8,300 kg/ha. Adding 270 kg N/ha (M0N3) enhanced the yield to 35,000 kg/ha while by manuring (M2N0) the yield increased to 9,600 kg/ha.

Table 48. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on bell pepper fresh fruit yield and total dry matter (DM) production in 1976. The manure was applied six months before the preceding cucumber crop was planted. No statistics are presented as replicate data were unavailable.

Treatment	Bell pepper					
	N		M		Fruit yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	*kg/ha*	
M0N3	4	270	1	M0	35,000	4,350
M1N3	4	270	2	M1	42,000	5,300
M2N3	4	270	3	M2	34,000	5,900
RN3	4	270	4	R	46,000	5,200
M0N0	1	0	1	M0	8,300	750
M2N0	1	0	3	M2	25,000	1,300

6.1.17 *The 1977 season (fallow)*

The 1977 report can be viewed by clicking: GLPP1977.

During this year, the field plots stood fallow without cultivation, planting and water and fertilizer application. The file contains the rain and Evp data during the year.

6.1.18 *The 1978 season (sweet corn)*

The 1978 report can be viewed by clicking: GLPP1978. Manure applied six months before seeding increased cob weight and DM production, even when in combination with a N fertilization rate of 360 kg N/ha (see treatments M2, M1, M0 in Table 49). The yield in the control (M0N0) was 2,710 kg/ha. When adding 360 kg N/ha, the yield increased to 20,640 kg/ha (M0N3), while when adding manure it rose to 23,800 kg/ha (M2N0).

Table 49. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on sweet corn cob yield and total dry matter (DM) production in 1978. The manure was applied in Oct 1977. No statistics are presented as replicate data were unavailable.

Treatment	Sweet corn					
	N		M		Cobs yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	- - - - - - - *kg/ha* - - - - - - -	
M0N3	4	360	1	M0	20,640	10,200
M1N3	4	360	2	M1	25,300	10,100
M2N3	4	360	3	M2	28,000	11,500
RN3	4	360	4	R	22,700	10,400
M0N0	1	0	1	M0	2,710	3,020
M2N0	1	0	3	M2	23,800	10,300

6.1.19 *The 1979 season (lettuce and potato)*

Lettuce

The 1979 lettuce report can be viewed by clicking: GLPP1979. Manure that was applied last in late 1977 increased untrimmed lettuce yield, even when in combination with fertilizer-N application of 300 kg N/ha (compare M2, M1, M0 at N3 in Table 50).

Table 50. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on lettuce untrimmed heads yield and total dry matter (DM) production in 1979. The manure was applied in Oct 1977. No statistics are presented as replicate data were unavailable.

Treatment	Lettuce					
	N		M		Heads yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	300	1	M0	18,600	820
M1N3	4	300	2	M1	42,000	4,870
M2N3	4	300	3	M2	48,000	3,920
RN3	4	300	4	R	29,000	2,740
M0N0	1	0	1	M0	10,000	790
M2N0	1	0	3	M2	31,400	3,480

The manure impact on DM production was limited to the transition from M0 to M1. The yield in the control (M0N0) was 10,000 kg/ha. When adding 300 kg N/ha the yield increased to 18,600 kg/ha (M0N3), while adding manure at level M2 increased the yield to 31,400 kg/ha (N0M2). The city refuse compost (R) gave ~30% lower yield than dairy manure at level M1, both combined with N3.

Potato

The 1979 potato report can be viewed by clicking: GLPP1979a. Manure amendment before planting (April 1979) did not increase the potato tuber yield and total DM production when in combination with fertilizer-N application rate of 360 kg N/ha (see treatments M2N3, M1N3, M0N3 in Table 51). The yield in the control (M0N0) was 29,400 kg/ha, which is surprisingly high but supported by the high DM production in this treatment. Increasing the fertilizer-N application to 360 kg/ha (M0N3) increased the tubers yield to 43,400 kg/ha, while adding dairy manure at level M2 (M2N0) reduced yield. A similar response was also obtained in the total DM yield. The tuber yield in the city refuse compost treatment (R) was similar to that in the M1N3 treatment.

Table 51. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on potato tuber yield and total dry matter (DM) production in 1979. The manure was applied 2-3 weeks before planting. No statistics are presented as replicate data were unavailable.

Treatment	Potato					
	N		M		Tubers yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	-------- *kg/ha* --------	
M0N3	4	360	1	M0	43,400	9,960
M1N3	4	360	2	M1	28,000	4,700
M2N3	4	360	3	M2	38,000	5,600
RN3	4	360	4	R	29,600	5,100
M0N0	1	0	1	M0	29,400	7,040
M2N0	1	0	3	M2	25,000	5,000

6.1.20 The 1980 season (Chinese cabbage)

The 1980 report can be viewed by clicking: GLPP1980. Manure that was last applied in April 1979 before the previous crop, in combination with 300 kg fertilizer-N/ha, increased the Chinese cabbage yield and DM production only when moving from M0 to M1 (see M1N3, M0N3, Table 52). At the higher manure level (M2), the yield declined. The yield in the control (M0N0) was 17,300 kg/ha. When adding 300 kg N/ha, the yield increased to 35,100 kg/ha (M0N3,) while when applying manure the yield increased to 52,500 kg/ha (M2N0). A similar response was obtained in total DM yield.

Table 52. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on Chinese cabbage yield and total dry matter (DM) production in 1980. The manure was applied in April 1979. No statistics are presented as replicate data were unavailable.

Treatment	Chinese cabbage					
	N		M		Heads yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	300	1	M0	35,100	4,600
M1N3	4	300	2	M1	51,700	4,900
M2N3	4	300	3	M2	50,000	4,500
RN3	4	300	4	R	51,500	4,300
M0N0	1	0	1	M0	17,300	2,530
M2N0	1	0	3	M2	52,500	4,200

6.1.21 The 1981 season (processing tomato)

The 1981 processing tomato report can be viewed by clicking: GLPP1981. The impact of manure treatments (applied in April 1979) on fresh fruit yield was significant only when shifting from M0 to M1 in combination with 150 kg N/ha (M0N3 to M2N3), and from M0N0 to M2N0 (Table 53). In un-manured plots, addition of 150 kg N/ha increased the yield from 49,000 (M0N0) to 61,600 kg/ha (M0N3). The responses in total DM production were qualitatively similar to the above responses in fresh fruit yield.

Table 53. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on processing tomato yield and total dry matter (DM) production in 1981. The manure was applied in April 1979. No statistics are presented as replicate data were unavailable.

Treatment	Processing tomatoes					
	N		M		Fruit yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	150	1	M0	61,600	3,480
M1N3	4	150	2	M1	73,400	5,700
M2N3	4	150	3	M2	75,800	7,400
RN3	4	150	4	R	74,800	5,700
M0N0	1	0	1	M0	49,000	3,990
M2N0	1	0	3	M2	79,500	7,400

6.1.22 The 1982 season (wheat)

The 1982 wheat report can be viewed by clicking: GLPP1982. The crop was neither fertilized nor manured. The impact of manure treatments at N3 on grain yield and DM production was linear (from 2,950 to 3,500 kg/ha, Table 54). In unmanured plots, the grain yield in treatment M0N0 was a mere 400 kg/ha, while in M0N3 it was 2,950 kg/ha. Addition of manure (M2) at N0 increased the grain yield from 400 (N0M0) to 2,630 kg/ha (M2N0). The response in DM had the same trend.

Table 54. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on wheat grain yield and total dry matter (DM) production in 1982. The plots were neither fertilized nor manured. No statistics are presented as individual plot data were unavailable.

Treatment	Wheat					
	N		M		Grain yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	- - - - - - - *kg/ha* - - - - - - -	
M0N3	4	150	1	M0	2,950	8,400
M1N3	4	150	2	M1	3,320	9,500
M2N3	4	150	3	M2	3,500	10,000
RN3	4	150	4	R	3,180	9,100
M0N0	1	0	1	M0	400	1,100
M2N0	1	0	3	M2	2,630	7,500

6.1.23 The 1983 season (wheat)

The 1983 wheat report can be viewed by clicking: GLPP1983. The crop was neither fertilized nor manured and yield and DM production have not been measured. The file contains the rain and evapotranspiration for this year.

6.1.24 The 1984 season (cucumber grown for seeds)

The 1984 cucumber report can be viewed by clicking: GLPP1984. Manure application before planting (October 1983), in combination with N3, increased the cucumber fruit and total DM yields when shifting from M0 to M1 (M0N3 to M1N3), but a further increase to M2N3 had no effect on these variables (Table 55). The fruit yield in control plots (M0N0) is higher than expected (28,200 kg/ha), particularly when compared with the yield in treatment M0N3 (27,700 kg/ha). Treatment RN3 was inferior to treatment M1N3 in both fruit and total DM yields.

Table 55. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on cucumber for seeds yield and total dry matter (DM) production in 1984. The manure was applied ~5 months before planting. No statistics are presented as replicate data were unavailable.

Treatment	Cucumber for seeds					
	N		M		Fruit yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	180	1	M0	27,700	2,030
M1N3	4	180	2	M1	39,800	2,500
M2N3	4	180	3	M2	39,500	2,500
RN3	4	180	4	R	31,500	1,900
M0N0	1	0	1	M0	28,200	1,840
M2N0	1	0	3	M2	33,000	1,400

6.1.25 The 1985 season (cucumber grown for seeds)

The 1985 cucumber grown for seeds report can be viewed by clicking: GLPP1985. Compatible with the 1984 season, manure application increased the cucumber fruit and total DM yields when shifting from M0N3 to M1N3, while a further increase to M2N3 had no effect on these variables (Table 56). The fruit yield in control plots (M0N0) was 10,100 kg/ha; adding 180 kg N/ha elevated the yield to 15,200 kg/ha (M0N3), while adding manure (M2N0) increased it to 20,500 kg/ha. The total DM yield supports the latter results. Comparison between the 1985 and 1984 results reveals that yield was considerably lower in 1985. This cannot be attributed to the fact that manure was not added in 1985 because the reduction in yield also prevailed in treatment M0N0.

Table 56. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on cucumber for seeds yield and total dry matter (DM) production in 1985. The manure was applied during October 1983. No statistics are presented as replicate data were unavailable.

Treatment	Cucumber for seeds					
	N		M		Fruit yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	180	1	M0	15,200	2,020
M1N3	4	180	2	M1	20,500	2,200
M2N3	4	180	3	M2	20,500	2,100
RN3	4	180	4	R	16,500	1,900
M0N0	1	0	1	M0	10,100	1,390
M2N0	1	0	3	M2	20,500	1,800

6.1.26 The 1986 season (bell pepper)

The 1986 bell pepper report can be viewed by clicking: GLPP1986. The crop was fertilized and manured but yield and DM production have not been determined due to undisclosed reasons.

6.1.27 The 1987 season (musk melon)

The 1987 musk melon report can be viewed by clicking: GLPP1987. Musk melon fresh yield and total DM production increased with increasing manure application levels (M0, M1, M2 last applied in 1983) even in combination with 420 kg fertilizer-N/ha (N3) (Table 57). Contrasting previous results, city refuse compost (RN3) gave higher yields than dairy manure (M1N3 and even M2N3). Nitrogen fertilization (420 kg N/ha), in combination with M2, increased DM yield relative to M2N0 (4,000 kg/ha in M2N3 vs. 3,200 in M2N0), but the fresh fruit yield was identical in these treatments. The fresh fruit yield in the control (M0N0) was 14,380 kg/ha. By adding 420 kg N/ha (M0N3), it increased to 25,750 kg/ha while manuring (M2N0) elevated the fruits weight to 29,200 kg/ha.

In this season, additional plant and soil variables were measured: N, P, K concentration in the DM of leaves and fruits; soil organic N (SON); NH_4-N and NO_3-N in soil; soil P ($NaHCO_3$ extract), and soil-K ($CaCl_2$ 0.01 M extract) all in the 0-20 cm soil layer.

Table 57. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on musk melon yield and total dry matter (DM) in 1987. The manure was applied six month before planting. No statistics are presented as replicate data were unavailable.

Treatment	Musk melon					
	N		M		Fruit yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	420	1	M0	25,750	3,150
M1N3	4	420	2	M1	27,600	3,700
M2N3	4	420	3	M2	29,200	4,000
RN3	4	420	4	R	36,500	4,700
M0N0	1	0	1	M0	14,380	1,920
M2N0	1	0	3	M2	29,200	3,200

The N concentration in plant leaves and fruit are presented in Fig. 74. The P and K concentrations can be found in the aforementioned file GLPP1987. They are not presented herein because they were meagerly and inconsistently affected by the studied treatments, probably because they were supplied adequately to all treatments at equal rate.

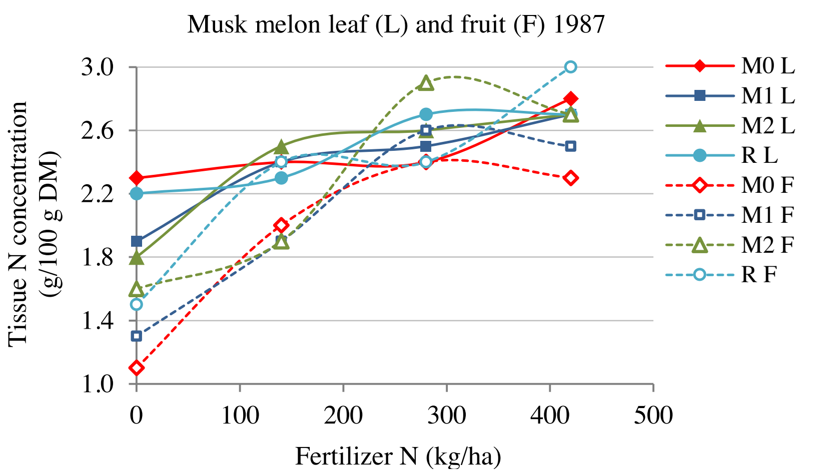


Fig. 74. Organic N concentration in musk melon leaves (L) and fruits (F) in 1987 as function of N rate and organic amendment level (M, R). The manures were last applied in 1983.

The effect of organic amendment on % N was unclear, probably because it was last applied in 1983. The effect of fertilizer-N in both leaves and fruits was significant when the N rate was raised from 0 to 120 kg N/ha. Further increases to 280 kg N/ha increased the % N in fruit but not in leaves.

Soil samples taken from all melon plots were used in an incubation experiment, which was identical to that carried out in 1969 (14 days incubation at 30ºC). The soils were analyzed for soil organic N (SON, Kjeldhal N) at t=0 and 14 (SON_{t0} and SON_{t14}; see data in above mentioned file GLPP1987). The results were used to estimate treatment effects on the mineralization first order rate constant k (d^{-1}) (Table 58).

In all the fertilizer-N treatments, the SON in 1987 increased with elevating manure application rates (M2>M1>M0). In the city refuse compost (R), the SON was ~10% higher than in the comparable M1 treatment. The impact of increasing mineral N dose on SON was weaker than the impact of increasing M level (Table 58). In all the treatments, the SON in 1987 were 10-15% lower than in 1969.

The rate constant k varied between 0.011 (in treatment M1No) and 0.020 d^{-1} (M2N3). There is an inconsistent trend of increase in k as M increases ($k_{M2}>k_{M1}>k_{Mo}$) and the same with N. In most cases, the 1987 k values are very similar to those in 1969.

Table 58. Soil organic N (SON_{t0}) and estimated mineralization 1st order rate constants k (30ºC) in the studied treatments in 1987.

Organic treatment	Fertilizer N treatment							
	N0	N1	N2	N3	N0	N1	N2	N3
	SON (Kjeldhal N, mg N/kg soil)				*Mineralization rate constant k (d^{-1})[a]*			
M0	483	500	524	517	0.0116	0.0159	0.0151	0.0164
M1	551	588	592	667	0.0108	0.0133	0.0142	0.0159
M2	780	825	750	737	0.0120	0.0129	0.0159	0.0201
R	606	641	635	663	0.0142	0.0159	0.0155	0.0177

Note: [a]k (d^{-1}) was estimated from the equation N_t=N0*(1-$e^{(-k\,t)}$), where N0 (mineralizable SON) = 0.2*SON_{t0}; N_t = SON_{t14}, and t = 14 d.

6.1.28 The 1988 season (musk melon)

The 1988 musk melon (second season) report can be accessed by clicking: GLPP1988. The fresh yield and total DM production increased as the manure application level increased (manure was last added last in 1987). This yield increase was obtained even when the fertilizer-N application rate was 270 kg N/ha (Table 59). As in the previous year, RN3 (city refuse compost) gave a higher fruit yield than the corresponding dairy manure treatment M1N3. The range in fruit yield was between 19,760 kg/ha in treatment M0N0 and 58,200 in treatment M2N3; in M2N0 and M0N3 the yields were 47,600 and 34,380 kg/ha.

Table 59. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on musk melon yield and total dry matter (DM) production in 1988. The manure was last applied in 1987. No statistics are presented as replicate data were unavailable.

Treatment	Musk melon					
	N		M		Fruit yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------- *kg/ha* -------	
M0N3	4	270	1	M0	34,380	4,190
M1N3	4	270	2	M1	50,100	5,300
M2N3	4	270	3	M2	58,200	5,900
RN3	4	270	4	R	53,500	6,800
M0N0	1	0	1	M0	19,760	2,260
M2N0	1	0	3	M2	47,600	4,500

6.1.29 The 1989 season (fallow)

In 1989, the plots stood fallow (No planting and No fertilizer or manure application). The report (weather data) can be accessed by clicking: GLPP1989.

6.1.30 The 1990 season (rape)

The 1990 rape report can be accessed by clicking: GLPP1990. Rape seed yield and total DM production increased due to manure application (M2> M1> M0) even though the manure was last added in 1983 and it was associated with a high level of fertilizer-N application (N3) (Table 60). The city refuse compost (RN3) gave the same seed yield as the corresponding dairy manure treatment M1N3. The range in seed yield was between 900 kg/ha in treatment M0N0 and 1750 in treatment M2N3; in M2N0 and M0N3, the yields were 1,300 and 1,500 kg/ha. The total DM yield in the control (M0N0) was 500 kg/ha. Adding N at level N3 (M0N3) enhanced the DM yield to 4,200 kg/ha and adding manure at level M2 (M2N0) increased the DM weight to 3,700 kg/ha. The contribution of R and M1 (at N3 level) to seed yield was the same. It was the same in DM production as well.

Table 60. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on rape seed yield and total dry matter (DM) in 1990. Manure was last applied in 1987. No statistics are presented as replicate data were unavailable.

Treatment	Rape					
	N		M		Yield	Total DM yield
	Level	*kg N/ha*	*Level*	*Type*	------ *kg/ha* ------	
M0N3	4	ua[1]	1	M0	1,500	4,200
M1N3	4	ua	2	M1	1,600	4,800
M2N3	4	ua	3	M2	1,750	5,000
RN3	4	ua	4	R	1,600	4,500
M0N0	1	0	1	M0	900	500
M2N0	1	0	3	M2	1,300	3,700

Note: [1]ua = unavailable

6.1.31 The 1991 season (Chinese cabbage)

The 1991 Chinese cabbage report can be accessed by clicking: GLPP1991. In this season, plants were sampled three times along the growth period and DM production and NPK tissue concentrations were determined. At the end of the experiment, fresh and dry yields were measured. The trimmed (marketable) head weight (g/head) was determined two weeks earlier, when head quality was best. The data presented herein was obtained from Feigin *et al.* (1991).

Yield and dry matter production

The Chinese cabbage fresh yield results are summarized in Table 61. The manure treatments did not have a significant effect on edible yield and head weight. The fertilizer-N levels had a significant effect on these variables only when shifting from N0 to N1. The difference between N1 and higher N levels was insignificant.

Table 61. The effects of manure level (M0, M1, M2) and type (M1 vs. R), and fertilization level (N) on Chinese cabbage yield and head weight (1991). Manure was last applied in 1987. Different letters beside means indicate significant (P<0.05) differences between main treatments.

Organic treatment	Fertilizer N treatment				
	N0	N1	N2	N3	Mean
	------ *Total fresh Chinese cabbage heads yield, t/ha* ------				
Mo	89.4	91.3	107.6	104.7	98.3 a
M1	81.2	110.7	104.9	100.6	100.1 a
M2	99.4	95.2	99.4	90.5	91.5 a
R	87.8	93.0	96.8	105.7	95.8 a
Mean	90.2 b	97.6 b	98.7 a	97.2 a	
	---- *Marketable Chinese cabbage head weight, g/head* ----				
Mo	650	665	756	797	717 b
M1	788	910	862	815	843 b
M2	975	862	851	840	882 b
R	636	738	842	808	768 b
Mean	774 b	793 a	827 a	815 a	

The response in total DM weight to M and N levels (Fig. 75) was insignificant (P>0.05). However, two trends can be pointed out:

1. In treatment R (city refuse compost) the response to fertilizer-N level was nearly linear, while in M1 and M2 it was bell-shaped with a peak between 100 and 200 kg N/ha, and decline at 270 kg N/ha (N3);
2. Under zero fertilization (N0), the yield in treatment M2N0 was two times higher than the yield in treatments M0N0, M1N0 and RN0.

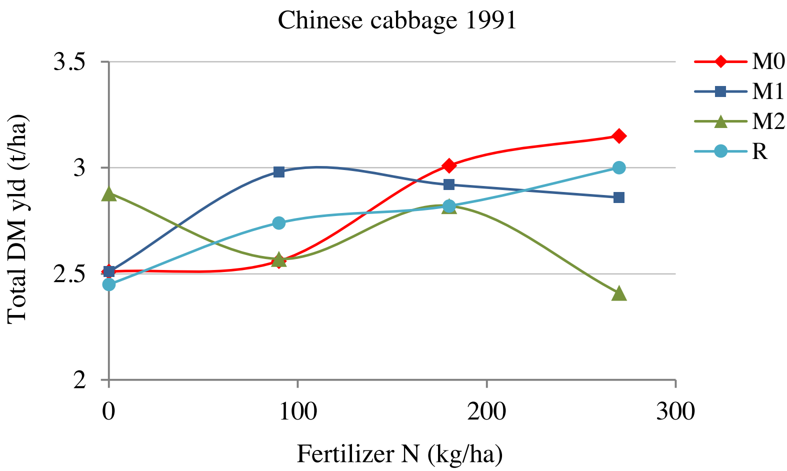


Fig. 75. The total dry matter (DM) produced by Chinese cabbage in 1991 as a function of manure and fertilizer-N treatments. The difference between treatments was insignificant (P>0.05). The manure was last added in 1987.

NPK concentration in heads

The N, P, and K contents in Chinese cabbage at harvest are presented in Table 62. At this stage, the N level (at any manure treatment) had negligible effect on tissue N concentration. However, in two earlier samplings (30 and 47 days after planting (dap), not presented herein but reported in the original file GLPP1991.xlsx), an increase in N (at any M) brought forth, generally, an increase in % N. Increase from M0 to M1 at any N level increased % N, except in level N2 where the low % N seems to be an experimental deviation. In order to obtain high Chinese cabbage yield (e.g. treatment M1N1, Table 61) the % N at 30, 47 and 68 dap should be 2.9-3, 3-3.1 and 3.2-3.4. The % N associated with low yield (e.g. M0N0 or M1N0, Table 61) is <2.7 at 30 dap, <2.9 at 47 dap, and <3.1 % N at 68 dap (time dependent data are not presented herein but can be found in the aforementioned file GLPP1991.xlsx).

The % P in plant increased with time in all treatments and was highest (68 dap) in treatment M2N1 (0.8 % P) and lowest in M0N3 (0.64 % P). To get high yield, the % P at 30, 47 and 68 dap should be 0.47-0.48, 0.62-0.64, and 0.67-0.69 % P, respectively. The % P associated with low yield is <0.46 at 30 dap, 0.49-0.53 at 47 dap, and <0.66 % P at 68 dap.

Table 62. The effect of manure level (M0, M1, M2), type (M1 vs. R), and N fertilization level on N, P and K concentration in Chinese cabbage heads (sampled when heads quality was highest- 6/1/1991). The manure was last applied in 1987. No statistics are presented as replicate data were unavailable.

Organic treatment	Fertilizer N treatment				
	N0	N1	N2	N3	Mean
	- - - - *Canopy (head) N, g N/100 g DM (6/1/91[a] 68 dap)* - - - -				
M0	3.0	3.1	3.4	3.3	3.2
M1	3.3	3.3	3.1	3.6	3.3
M2	3.3	3.2	3.3	3.4	3.3
R	3.4	3.4	3.5	3.2	3.4
Mean	3.3	3.3	3.3	3.4	
	- - - - - - - - - *Canopy (head) P, g P/100g DM* - - - - - - - - -				
M0	0.66	0.66	0.70	0.64	0.67
M1	0.70	0.67	0.70	0.73	0.70
M2	0.71	0.80	0.79	0.78	0.77
R	0.65	0.79	0.64	0.74	0.71
Mean	0.68	0.75	0.71	0.72	
	- - - - - - - - - *Canopy (head) K, g K/100 g DM* - - - - - - - - -				
M0	6.8	6.4	6.8	5.9	6.5
M1	6.7	5.7	6.3	6.3	6.5
M2	6.2	6.4	6.6	6.7	6.5
R	6.6	6.9	6.5	6.7	6.5
Mean	6.6	6.4	6.6	6.4	

Note: [a]There were two more samplings: 30 and 47 dap. The results can be found in the crop report file GLPP1991.

The % K fluctuated with time (not presented) and treatment. The inconsistency is attributed to the fact that K (and P) was fertilized annually at equal K (and P) rates in all treatments, which masked the effect of manuring on their uptake by plants.

The % Na in the canopy (0.86-to-1.4%; data not presented) tended to decrease as the N-fertilization level increased.

DM production as a function of time

The time functions of DM production by Chinese cabbage in representative treatments are depicted in Fig. 76. In treatments M0-N and M1N0, a decline in DM production rate occurred between day 35 and 45, followed by recovery (parts A, B). In treatments M2, the DM production was nearly linear along the entire growth period (part D). An increase in N level had a small beneficial effect on DM production until 45 dap, but later on the DM production rate in M2N3 declined with time (part D). The DM curve of treatment M1N1 that gave highest heads yield was identical to M0N2 (part B) and is therefore not presented.

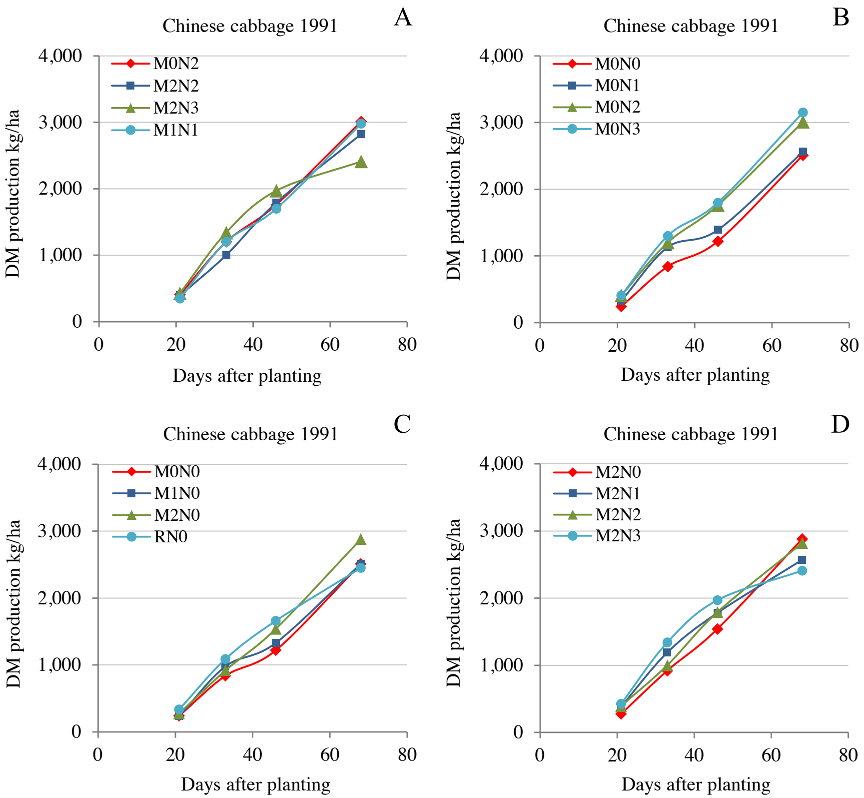


Fig. 76. Treatments effect on Chinese cabbage dry matter (DM) production as function of time (1991). Manure was applied last time in 1987.

Nutrients concentration in soil

The soil was sampled for mineral N and available P and K in the 0-20 and 20-40 cm soil layers before base fertilization (Table 63). Increase in manure and N-fertilizer levels increased, as expected, the NH_4-N and NO_3-N concentration in the top soil (0-20 cm) layer, but not in the 20-40 cm layer. The $NaHCO_3$ extractable P concentration in both soil layers increased as M was raised from M0 to M1 and M2; the effect of N level on available P was negligible. The contribution of treatment R to soil available P was comparable to that of treatment M1. The effect of treatments on available K in soil (estimated by extraction with $NaHCO_3$) was similar to their effect on P. In general, the available N and P concentration in the 0-20 cm was ~2-fold higher than in the 20-40 cm. The $NaHCO_3$ extractable K in the 0-20 cm soil layer was ~30% higher than in the 20-40 cm layer. The higher NO_3-N concentration in the top layer than in the 20-40 cm layer indicates either restricted irrigation (limited leaching) or intensive root activity in the 20-40 cm layer.

Table 63. Available N, P and K in soil (0-20 and 20-40 cm layers) in studied treatments. The soils were sampled 30 days prior to planting (before base fertilization).

Organic treatment	Fertilizer N treatment							
	N0	N1	N2	N3	N0	N1	N2	N3
	Soil NH_4-N, mg N/kg soil 0-20 cm				*Soil NH_4-N, mg N/kg soil 20-40 cm*			
M0	5	5	4	6	5	6	9	5
M1	6	4	5	7	3	4	6	5
M2	5	8	9	9	6	6	6	6
R	6	9	7	7	6	7	6	5
	Soil NO_3-N, mg N/kg soil 0-20 cm				*Soil NO_3-N, mg N/kg soil 20-40 cm*			
M0	4	10	12	14	5	6	6	8
M1	6	7	14	16	3	5	4	6
M2	5	15	22	21	5	5	7	10
R	8	9	16	17	6	4	8	6
	Soil Olsen-P, mg P/kg soil 0-20 cm				*Soil Olsen-P, mg P/kg soil 20-40 cm*			
M0	28	30	30	27	19	18	19	16
M1	49	40	40	42	28	23	25	35
M2	67	61	66	62	42	30	40	33
R	36	39	39	32	28	25	23	24
	Soil $NaHCO_3$, mg K/kg soil 0-20 cm				*Soil $NaHCO_3$, mg K/kg soil 20-40 cm*			
M0	255	230	274	275	192	175	170	170
M1	353	283	300	386	256	210	260	250
M2	405	413	391	424	345	321	321	266
R	265	285	236	266	215	208	181	213

6.1.32 The 1992 season (Chinese cabbage)

The 1992 Chinese cabbage data can be accessed by clicking: GLPP1992. In this season manure and N fertilizer were applied, and plants were sampled for heads yield and DM production. The data is presented in Table 64. The fresh yield data is inconsistent. The DM results declined in the order M0N3> M1N3> M2N3. Under N0, the M2N0 DM yield exceeded that of M0N0 (2,300 vs. 1,360 kg/ha).

Table 64. Effect of manure level (M0, M1, M2) and type (M1 vs. R) on Chinese cabbage yield and total dry matter (DM) in 1992. Manure was applied last time in 1987.

Treatment	Chinese M Cabbage					
	N		M		Heads yield	DM yield
	Level	*kg N/ha*	*Level*	*Type*	------ *kg/ha* ------	
M0N3	4	0	1	M0	67,180	3,010
M1N3	4	90	2	M1	147,000	2,900
M2N3	4	180	3	M2	122,500	2,400
RN3	4	270	4	R	132,400	2,700
M0N0	1	0	1	M0	32,000	1,360
M2N0	1	0	3	M2	107,200	2,300

6.1.33 The 1993 season (carrot)

The 1993 carrot report can be accessed by clicking: GLPP1993. This season the plants were sampled only at the end of the growing season for beet yield, canopy weight and total DM production. The available data is presented in Table 65. At the N3 level, increasing the manure application rate caused a clear increase in yield and DM production (M2N3> M1N3> M0N3). City refuse compost was as effective as dairy manure at level M1. Manure level M2 in combination with zero N fertilization was unable to sustain an economic carrot yield.

Table 65. Effect of manure level (M0, M1, M2) and type (M1 vs. R) and N level (N0 to N3) on carrot yield, total dry matter (DM) and canopy weight in 1993. Manure was applied last time in Oct 1991. *Top part:* comparison between treatments in root yield and total DM production. No statistics is presented here as replicate results were unavailable. *Bottom part:* main treatment effects on root yield and fresh canopy weight, and statistics.

Representative treatments only are presented						
Treatment	Carrot					
	N		M		Root yield	DM yield
	Level	*kg N/ha*	*Level*	*Type*	----- *kg/ha* -----	
M0N3	4	0	1	M0	60,160	8,440
M1N3	4	90	2	M1	73,400	9,800
M2N3	4	180	3	M2	82,800	12,200
RN3	4	270	4	R	68,500	9,600
M0N0	1	0	1	M0	21,760	3,000
M2N0	1	0	3	M2	46,900	6,300

Main treatments effects and statistics				
Main treatment	Total root yield		Fresh canopy wt	
	-------------------- *kg/ha* --------------------			
N0	c[1]	37,560	c	8,170
N1	a	70,070	b	19,350
N2	a	73,380	a	25,670
N3	a	71,210	a	26,060
M0	c	55,600	c	15,950
M1	ab	66,070	ab	20,220
M2	a	69,250	a	23,700
R	b	61,300	b	19,390

Note: [1]Different letters beside means indicate significant (P<0.05) difference between main treatments.

6.1.34 The 1994 season (carrot)

The 1994 carrot report can be retrieved by clicking: GLPP1994. This season plants were sampled 4 times along the growing season for beet yield, total

DM production, and NPK concentrations in beets and canopy. Soil tests were performed on 12 Oct 1993 (1 day after seeding). Plots were fertilized with N and dairy manure and city refuse compost were applied according to treatments. The presented results were copied from Sagiv *et al.* (1995). At the end of this season organic-N was determined in most plots. The C: N ratio was determined too but since it was uniform in all plots (9.9 with standard deviation of 0.05) the results are not presented.

Yield and dry matter production

The fresh yield results, canopy fresh weight and DM production results are summarized in Table 66. The manure treatments increased significantly all abovementioned variables relative to the control (M0N0) but did not differ significantly from each other. The fertilizer-N treatments had a significant effect on those variables subject to the order N2> N1= N3> N0. For more insight the response in total fresh beet yield and total DM weight to M and N treatments is also presented graphically (Fig. 77). The beets yield data show a peak (common to all M treatments) at N dose of 180 kg N/ha. In the DM data the peaks are replaced by flattening of the response curves at this N rate, except treatment M2 which still had a peak at N dose of 90 kg N/ha. Treatment R (city refuse compost) behaved similarly to M1 except one deviating point at N=190 kg/ha.

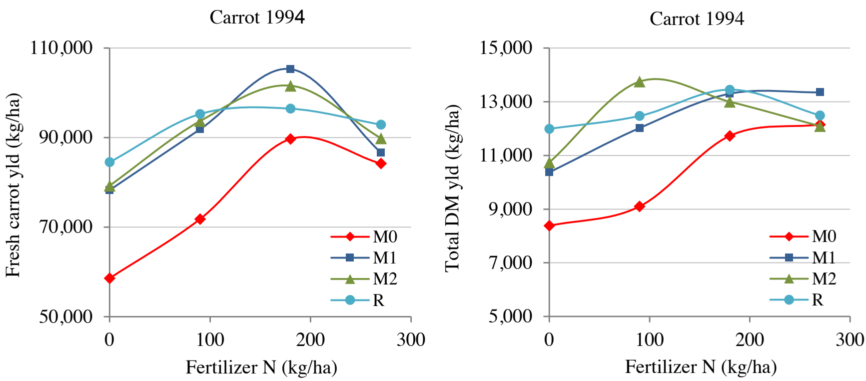


Fig. 77. The fresh carrot beet yield and total dry matter (DM) produced as function of manure and fertilizer-N treatments. For significance statistics see Table 66 (from which the data was taken).

Table 66. The effects of manure level (M0, M1, M2) and type (M1 vs. R), and fertilization dose (N) on carrot total and marketable yields, fresh canopy weight and total DM production (1994). Manure was applied prior to seeding and N was added via the water.

Organic treatment	Fertilizer N treatment				
	N0	N1	N2	N3	Mean
	Total carrot fresh root yield, t/ha				
Mo	58,560	71,780	89,680	84,200	76,500 b[1]
M1	78,260	91,850	105,300	86,630	90,560 a
M2	79,260	93,680	101,600	89,860	97,990 a
R	84,500	95,260	96,460	92,900	90,220 a
Mean	75,150 c	88,070 b	98,260 a	88,400 b	Mean
	Marketable carrot fresh yield, t/ha				
Mo	54,730	67,430	76,900	75,030	68,520 b
M1	70,460	79,480	84,960	74,600	77,460 a
M2	73,730	81,720	81,160	80,160	79,380 a
R	74,000	85,100	75,430	77,900	77,880 a
Mean	68,230 b	78,340 a	79,390 a	78,340 a	
	Carrot total DM, t/ha				
Mo	8,380	9,100	11,730	12,150	10,340 b
M1	10,370	12,020	13,300	13,350	11,710 ab
M2	10,740	13,750	13,000	12,090	12,340 a
R	11,990	12,470	13,450	12,490	12,600 a
Mean	10,350 b	11,760 ab	12,870 a	12,020 a	
	Carrot canopy fresh weight, t/ha				
Mo	7,010	6,930	11,810	10,860	9,150 c
M1	8,730	10,480	13,960	9,500	10,660 bc
M2	7,830	12,600	15,330	9,330	11,210 ab
R	11,530	13,900	13,710	11,610	12,700 a
Mean	8,770 c	10,890 b	13,700 a	10,390 bc	

Note: [1]Different letters beside values indicate significant ($P < 0.05$) difference between main treatments.

NPK concentration in plant

The % N, P, K in carrot canopy 6 weeks before harvest is summarized in Table 67. At this stage the N level (in all manure treatments) had insignificant ($P<0.05$) effect on tissue N concentration. That was also the case in two earlier and one latter crop samplings which are presented only in the Excel report file GLPP1994.xlsx.

Table 67. The effect of manure level (M0, M1, M2), type (M1 vs. R), and N fertilization level on N, P and K concentration in carrot canopy six weeks before harvest. The manure was applied before seeding.

Organic treatment	Fertilizer N treatment				
	N0	N1	N2	N3	Mean
	- - - - - - - - *Canopy (leaf) N, g N/100 g DM (23/2/93)* - - - - - - - -				
Mo	1.8	1.8	2.1	2	1.91 b[1]
M1	2.6	2	2.3	2	2.13 a
M2	2.4	2.3	2.2	2	2.24 a
R	2.1	2.2	2.3	2.4	2.3 a
Mean	2.1 a	2.09 a	2.25 a	2.13 a	
	- - - - - - - - - - - *Canopy (leaf) P, g P/100 g DM* - - - - - - - - - - -				
Mo	0.3	0.26	0.35	0.2	0.29 c
M1	0.45	0.5	0.41	0.23	0.4 a
M2	0.71	0.55	0.42	0.25	0.48 b
R	0.5	0.44	0.41	0.28	0.44 a
Mean	0.48 a	0.44 a	0.4 b	0.24 c	
	- - - - - - - - - - - *Canopy (leaf) K, g N/100 g DM* - - - - - - - - - - -				
Mo	3.3	3.6	4	3.4	3.56 b
M1	4.8	4.8	4.3	3.7	4.41 a
M2	4.3	4.2	4.7	3.2	4.12 a
R	4	3.8	4.2	4	4.68 a
Mean	4.16 a	4.13 a	4.31 a	3.58 a	

Note: [1]Different letters beside means indicate significant ($P<0.05$) difference between main treatments.

Increasing the manure level from M0 to M1 increased the % N in canopy, but treatments M2 and R did not differ from M1. In order to obtain high carrot yield (e.g. treatment M2N2, Table 66) the % N 91, 116, 136 and 177 days after planting (dap) should be 3.5-3.7, 2.3-2.4, 2.2-2.3 and 1.7-1.9%. The % N that is associated with low yield (e.g. M0N0, Table 66) is 2.7-2.8, 2.1-2.4, 1.8, and 1.7-1.8 % N, respectively (the time dependent data is presented only in the Excel file GLPP1994.xlsx).

The % P in canopy 6 weeks before harvest was significantly affected by N and M (Table 67). It increased when M was elevated from M0 to M1 and M2, and decreased when N was raised from N0 (0.48 % P) to N1, N2 and most strongly to N3 (0.24 % P). In general, % P declined with time in all treatments and was highest on day 91 in treatment M2N0 (0.85 % P) and lowest on day 177 in MoN0 (0.22 % P). To get high yield, the % P 91, 116, 136 and 177 days after planting should be 0.5-0.6, 0.4-0.5, 0.4-0.5, and 0.3-0.35 % P, respectively

Main N and manure treatments did not have a significant effect on % K in canopy 6 weeks before harvest, except main treatment M0 that had a significantly lower % K (3.6 vs. the average 4.1%, Table 67). The % K fluctuated with time (not presented) with a general trend of increase until ~120 dap, followed by decline until harvest.

Data on three additional samplings is not presented herein and appear in GLPP1994. The data on NPK concentration in carrot beets is also not presented herein, and can be found in the same file.

DM production as a function of time

The DM time functions are depicted for representative treatments in Fig. 78. The reduced DM production rate between 116 and 136 dap is attributed to low temperatures (mid Feb to mid Mar). The recovery between 136 and 177 dap was strongest in treatment M1N2 (which also gave the highest yield) and weakest in treatment M0N0.

The DM as a function of time in all the studied treatments is presented in Table 68. It can be seen that the delay in DM production between days 116 and 136 is common to all treatments. The recovery rate increased with elevating M and N rates.

Table 68. Total dry matter weight (root + canopy) of carrot plants as a function of time in all studied treatments (M0N0 to M1N2). The four rows (top to bottom) refer to 88, 116, 136 and 180 days after planting.

M0N0	M0N1	M0N2	M0N3	M1N0	M2N0	RN0	M2N1	M2N2	M2N3	M1N2
2,080	3,460	3,310	3,700	2,780	2,700	2,960	3,080	3,550	2,560	3,770
2,970	5,660	6,340	4,440	4,850	5,110	5,040	5,510	5,420	5,060	6,430
3,260	6,330	7,360	5,910	5,650	5,170	4,980	5,260	5,650	6,930	6,420
5,980	9,100	11,730	12,150	10,370	10,740	11,990	13,750	13,000	12,090	13,300

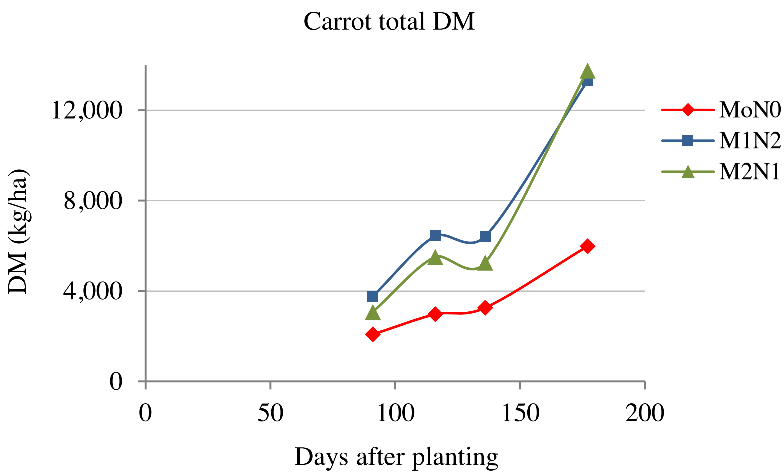


Fig. 78. The total dry matter (DM) weight of carrot plants as a function of time in three representative treatments (M1N2 and M0N0 had maximum and minimum beet yield). Data was derived from Table 43 (1994).

Nutrients concentration in soil

The soil was sampled in the 0-20, 20-40 and 40-60 cm layers one day after seeding. Total (Kjeldhal) N and available P and K were determined only in the 0-20 cm soil layer. The results are summarized in Table 69. Increase in manure and N-fertilizer levels increased, as expected, the NH_4-N and NO_3-N concentration in the top soil layer. In general, the NH_4-N concentration in the 0-20 cm soil layer was ~2-fold higher than in the 20-40 or 40-60 cm layers.

The NO_3-N concentration in soil declined gradually with increasing depth in all treatments. The treatments effect on mineral N concentration in the 20-40 and 40-60 cm soil layers was negligible. Total (Kjeldhal) N in the 0-20 cm soil layer increased from 700 to 830 and 1,160 mg N/kg, respectively, as the manure application level increased from 0 to 30 and 90 t/ha manure; the impact of mineral N on total N in soil was negligible.

The $NaHCO_3$ extractable P concentration in the 0-20 cm soil layers increased as M increased from M0 to M1 and M2; the effect of fertilizer-N on available P was meager. The contribution of treatment R to $NaHCO_3$ extractable P was ~30% smaller than in treatment M1. The effect of treatments on available K in soil (0-20 cm, NaHCO3 extractable K) was similar to the treatment effect on available P.

Table 69. Available N, P, K and total (Kjeldhal) N in the top soil layer (0-20 cm, Part A) and mineral N concentration in the 20-40 and 40-60 cm soil layers (Part B) in studied treatments. The soil was sampled one day after seeding in 1993.

Part A

Organic treatment	Fertilizer N treatment				
	N0	N1	N2	N3	Mean
			Soil NH4-N, mg N/kg soil 0-20 cm		
Mo	6	21	27	11	16
M1	7	15	25	25	18
M2	5	20	15	23	16
R	13	25	12	22	18
Mean	11	20	20	20	
			Soil NO3-N, mg N/kg soil 0-20 cm		
Mo	10	31	29	20	22
M1	20	62	48	53	46
M2	45	50	60	60	54
R	42	30	46	43	40
Mean	29	43	43	44	
			Soil Olsen-P, mg P/kg soil 0-20 cm		
Mo	33	35	39	31	35
M1	60	68	61	62	63
M2	120	127	133	111	122
R	35	44	44	41	41
Mean	63	69	69	62	
			Soil NaHCO3 soluble K, mg K/kg soil 0-20 cm		
Mo	462	487	450	433	458
M1	527	650	517	583	569
M2	690	885	897	800	818
R	495	463	448	540	486
Mean	543	621	578	589	
			Total (Kjeldhal), mg N/kg 0-20 cm soil		
Mo	673	867	726	721	702
M1	838	904	771	819	833
M2	1,123	1,141	1,194	1,166	1,156
R	841	837	871	928	869
Mean	869	892	891	909	

Part B

Organic treatment	Fertilizer N treatment					Fertilizer N treatment				
	N0	N1	N2	N3	Mean	N0	N1	N2	N3	Mean
	Soil NH4-N, mg N/kg soil 20-40 cm					*Soil NH4-N, mg N/kg soil 240-60 cm*				
Mo	4	5	4	5	5	6	4	7	3	5
M1	5	5	6	7	6	5	5	4	3	4
M2	5	7	7	6	6	3	3	3	4	4
R	6	6	4	8	6	3	3	12	3	5
Mean	5	6	5	7		4	4	7	3	
	Soil NO3-N, mg N/kg soil 20-40 cm					*Soil NO3-N, mg N/kg soil 40-60 cm*				
Mo	10	20	16	26	18	14	20	22	24	20
M1	26	32	25	33	32	26	32	20	31	27
M2	44	52	40	47	45	26	32	20	31	31
R	40	24	28	38	33	27	24	22	25	25
Mean	30	32	28	36		24	27	25	27	

Ion distribution in soil (0-420 cm) at the end of the experiment

After the last harvest (September 1994), the soil in selected treatments was sampled to a depth of 420 cm, and major ions were determined in 1:1 soil: water extract. The detailed results can be accessed by control/clicking the following links: for treatment M0N0: GL depth N0 73; M0N3: GL depth N3 17; M2N0: GL depth M2N0 18; M1N3: GL depth M1N3 15 and GL depth M1N3 51; RN3: GL depth RN3 59; M2N3: GL depth M2N3 57.

The main results are depicted in Fig. 79. The nitrate (NO_3) profile in soil was similar in all treatments, but concentration at each depth increased with increasing N application rate. In all treatments, NO_3 concentration in the 80-160 cm soil layer was low, and no clear concentration peaks could be observed in the accumulation zone 180-400 cm. The nitrate amount in the 0-420 cm layer was 8-16% of the mineral N that was added to soil.

Chloride was added in all treatments at the same rate. Consequently, different Cl^- concentration profiles (Fig. 79) could stem only from different leaching patterns, caused by differential transpiration by plants exposed to diverse fertility treatments. Indeed, in fertilized plots (high transpiration, small leaching) Cl^- concentration in the 40-90 and 300-400 cm soil layers was higher than in unfertilized plots (large leaching). This effect was even more pronounced in the EC profiles (Fig. 79), except treatment M2N3 that had unexpectedly low EC values. As in the case of nitrate, no clear peaks were found in the Cl and EC profiles, but unlike nitrate the Cl^- accumulated in the 200-400 cm soil layer.

Sulfate was applied equally to all treatments through the supply water and in superphosphate, and differentially (until 1986) as ammonium sulfate (AS). In plots that were fertilized with AS, the sulfate accumulated in the 200-400 cm soil layer, while in treatment N0 the concentration of SO_4 in the entire soil profile was low (Fig. 79). Below a depth of 200 cm the water soluble SO_4 concentration was tenfold greater than Cl concentration. The similarity between the soil SO_4 and Ca profiles (Fig. 79) indicates that the sulfate concentrations in treatments receiving N3 were controlled by gypsum solubility.

Sodium (Na) application in water and fertilizers was identical in all treatments, while M2 and R added Na to the soil. Overall, the water soluble Na profile was quite similar in all the reported treatments, with largest peaks occurring in treatments RN3 and M2No (Fig. 79). Except at soil depth>300 cm, the experimental sodium adsorption ratio [SAR, $C_{Na}/(C_{Ca}+C_{Mg})^{1/2}$, C in mM] fluctuated around the SAR of the irrigation water (3.1 $mM^{1/2}$) (data not presented). In general, manure-N3 treatments had lower SAR than the rest of the treatments, particularly at depths exceeding 300 cm.

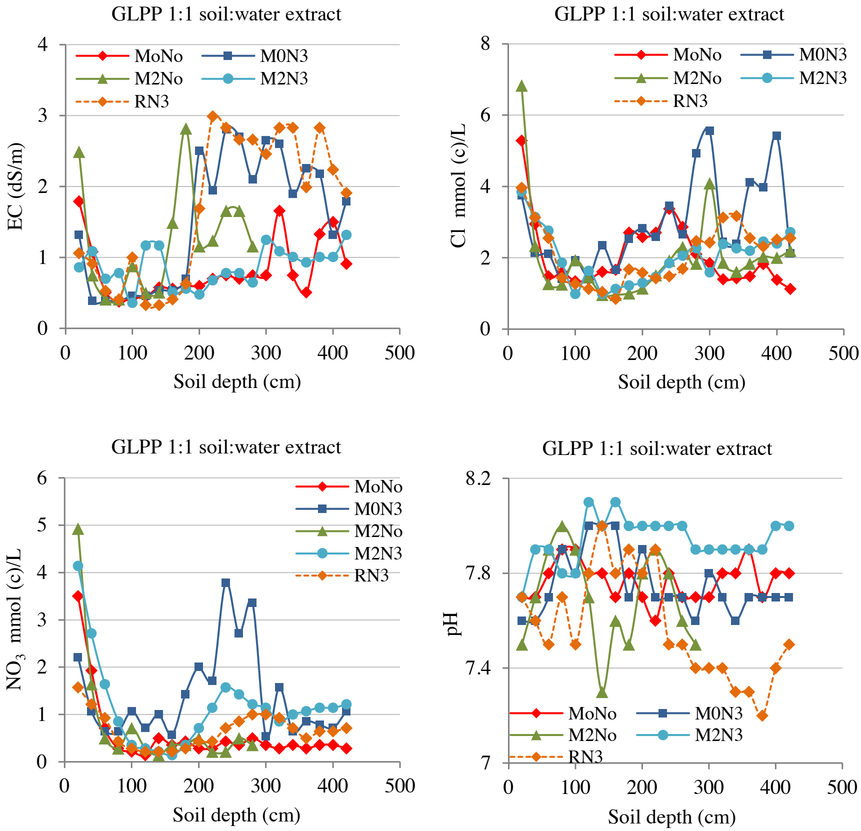
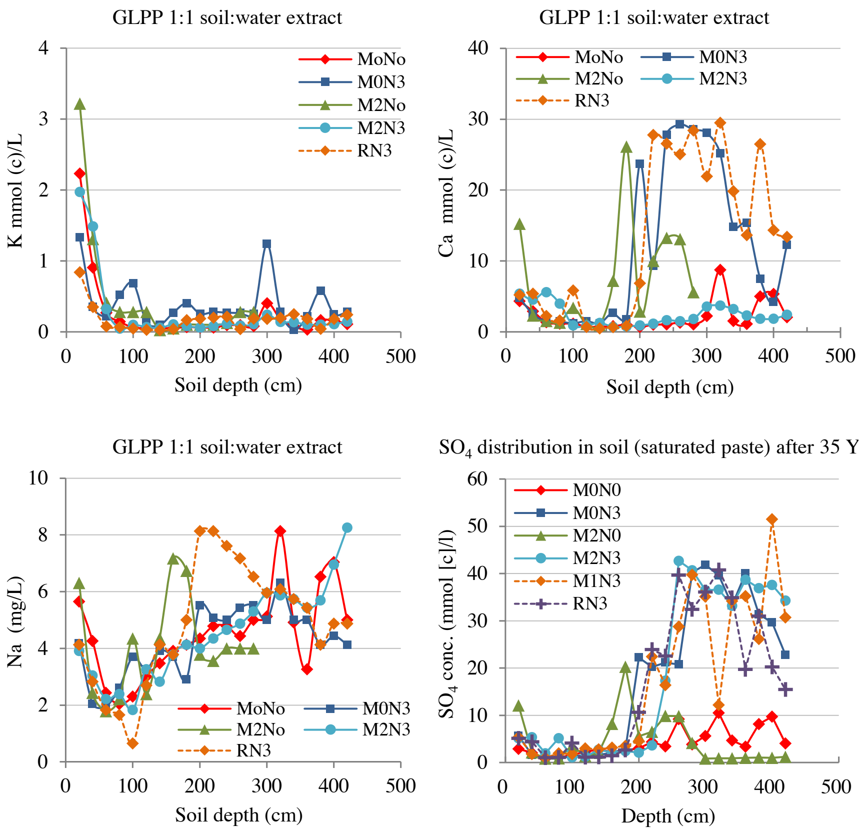


Fig. 79. Distribution of the main ions in the soil profile (0-420 cm) at the end of the experiment (35 years) in representative treatments. 1:1 soil: water extract (except saturated paste in SO_4).

The soil pH profiles were steady with depth with small difference among treatments. Exceptions were treatment RN3 that had lower pH below 200 cm (~7.3 vs. all treatments mean of 7.8) and treatment M2No which resembled in parts of the profile RN3 (Fig. 79).



7 Discussion

7.1 Changes in total (Kjeldhal) N concentration in the 0-20 cm soil layer over time

The amount of organic N added to soil in the manure treatments, and total (Kjeldhal) N found in the top 0-20 cm soil layer, both as function of time (1963-1994), are presented in Table 70. The highlights are summarized in Fig. 80.

Table 70. Added organic N, and total (Kjeldhal) N found in the top soil layer (0-20 cm) as function of time and treatment.

Added N via manure in treatment (mg N/kg soil 0-20 cm): 1st row per year, 2nd row cumulative											
Treatment	1961	1963	1967	1972	1975	1977	1979	1984	1986	1992	1994
Mo	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-
M1	112	112	112	112	112	112	112	112	112	187	112
	112	225	337	450	562	674	787	899	1,012	1,199	1,311
M2	337	337	337	337	337	337	337	337	337	562	337
	337	674	1,012	1,349	1,686	2,023	2,361	2,698	3,035	3,597	3,934
R	119	119	119	119	119	119	119	119	119	199	119
	119	239	358	477	596	716	835	954	1,074	1,272	1,392

	Total N in soil (mg N/kg soil)						
	1963	1965	1967	1969	1976	1987	1994
M0N0	380	407	355	415	480	483	673
M0N1	420	445	415	462	500	500	687
M0N2	420	445	400	418	490	524	726
M0N3	400	503	410	440	500	517	721
M1N0	420	499	420	505	580	551	838
M1N1	440	522	450	567	630	588	904
M1N2	410	509	460	527	560	592	771
M1N3	400	554	470	537		667	819
M2N0	480	720	505	593	570	780	1123
M2N1	480	693	525	647		825	1141
M2N2	490	720	545	618	800	750	1194
M2N3	490	685	560	633	740	737	1166
RN0	390	494	440	558		606	841
RN1	430	549	480	480	550	641	837
RN2	420	557	510	510	500	635	871
RN3	490	590	515	515		663	928
Manure treatments means							
N0	417	534	430	518		605	868.75
N1	442	549	468	556	588	639	892.25
N2	435	557	478	532		625	890.5
N3	445	587	490	551		646	908.5
Fertizer-N treatments means							
M0	405	454	395	434		506	702
M1	417	521	450	534		600	833
M2	485	704	535	623		773	1156
R3	432	544	486	567		636	869

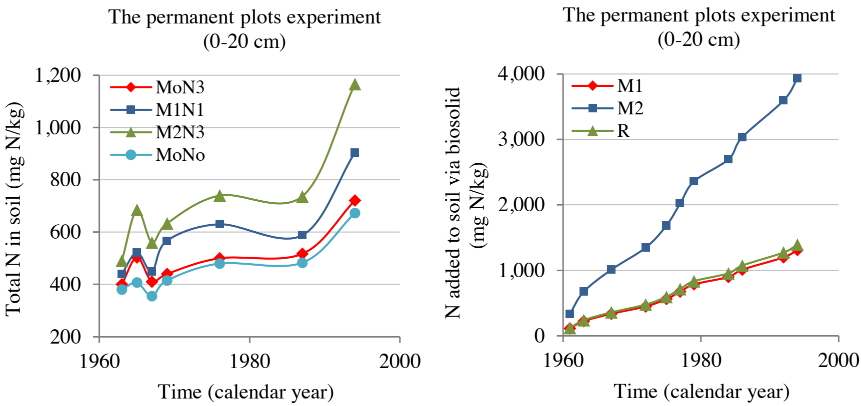


Fig. 80. Added organic N in applied manure, and organic (Kjeldhal) N found in soil (0-20 cm) as a function of time in selected treatments. Data derived from Table 70.

During the 13 years, between 1963 and 1976, the total (Kjeldhal) N concentration in soil increased in all treatments, including M0N0 and M0N3 that did not receive manure. The average accumulation rate (0-20 cm soil layer) in treatments M2N3, M1N1 and M0N0 during this period was 26.1, 16.1 and 3.1 mg N kg^{-1} soil y^{-1}, respectively. The average organic N supply rate in treatments M2N3 and M1N1 was 130 and 50 mg N kg^{-1} soil y^{-1}. The fraction of the added organic-N in treatment M2N3 that was recovered in the 0-20 cm soil test at the end of the experiment is estimated as ([soil organic N]$_{M2N3}$ - [soil organic N] $_{M0N0}$) / [organic N applied] $_{M2N3}$, all in units of [mg N kg^{-1} soil]. The recovered manure N for treatment M2N3 over the period 1963-1976 is 18%, meaning that 82% of the added manure-N was mineralized. The recovered organic-N in treatment M1N1 was found to be 26% (or 74% mineralized).

Between 1976 and 1987, total N in soil in all treatments was steady (Fig. 80) even though the supply of organic-N continued. In 1994, the concentration of total N in soil was much higher than in 1987 in all treatments. Repeating the recovered organic-N calculation for the 1987-1994 time interval gives % recovery of 28% and 30% for treatments M2N3 and M1N1, respectively.

7.2 Ions and water mass balance in soil

The mass balance is described in equation [1] (see Bar-Yosef *et al*., 1991a). Here IL is the ion quantity leached below a certain depth (in our case 420 cm, see later) (g m^{-2}); IA is the cumulative (35 year) ion quantity added to the soil. In the case of nitrogen, it is fertilizer-N plus mineralized-N. IU is the cumulative uptake by plants, and IS the quantity accumulated in the 0-420 cm soil profile (IS_{end} - $IS_{initial}$).

$$IL = IA - IU - IS \qquad [1]$$

To estimate IS in the case of mineral N, the mineralization rate must be known. It was predicted from mineralization of two organic-N pools: (i) soil indigenous organic-N (SON); (ii) manure organic-N (MON). The fraction of the MON pool that was not mineralized within one year was transferred to the SON pool; Also-5% of the N that was consumed by plants returns to the soil as part of the SON pool. The annual mineralization (N_{min}, g m^{-2}) was predicted according to eq. [2] that was derived by best fitting from data of Hadas *et al*. (1979) and Feigin and Sagiv (1990):

$$N_{min} = 0.025\ SON + 0.15\ MON \qquad [2]$$

The water head available for solute leaching (L) was calculated according to:

$$L = I + R - T - E \qquad [3]$$

Here I and R are annual irrigation and rainfall rates, and T and E cumulative transpiration and annual evaporation from the soil, respectively. Evaporation was estimated to be 120 mm/y for all years (Gardner and Hillel, 1962), which amounts to ~50% of the mean annual precipitation at the experiment site. The transpiration (T) is assessed according to Hanks (1974) as:

$$T = T_{max}\ DM/DM_{max} \qquad [4]$$

Here T_{max} is maximum transpiration, estimated as T_{max} = 0.5 EVp (EVp = evaporation from class A pan); DM and DM_{max} are crop DM weight in a certain treatment and in the treatment that gave maximum DM yield in that year. The total DM production in a certain treatment is the sum of annual DM yields over the experiment (Table 71). By inserting the needed (all known) data in eq. [4] the cumulative and year-specific L values were obtained. They are summarized in Table 72.

Table 71. Total dry matter production over the entire experimental period (35-years) of the experiment in representative treatments.

Year	Crop	Treatment					
		M0N0	M0N3	M2N0	M2N3	M1N3	RN3
		Total dry matter (kg/m²)					
1961-1994	All crops	9.58	21.51	19.40	25.25	23.01	23.69

Table 72. The water head available for solute leaching (L) in representative crops and the cumulative L covering the entire (35-years) experiment

Year	Crop	Treatment					
		M0N0	M0N3	M2N0	M2N3	M1N3	RN3
		L[a] (mm)					
1974	Potato	364	225	320	300	308	292
1978	Sweet corn	702	494	492	457	497	489
1981	Processing tomato	687	711	526	526	606	606
1987	Muskmelon	464	304	298	194	233	103
1994	Carrot	469	415	418	388	444	379
		Cumulative L (m)					
1961-1994	All crops	13.68	8.47	9.60	7.28	8.31	7.88

Note: [a]L was calculated according to [4].

In the low-yield treatment M0N0 the cumulative L (1368 cm) was ~60% higher than in treatment M2N3 that gave the maximum yield. The difference in L stemmed from the linear relationship between transpiration and plant DM weight. Differences in L between other treatments were also clear, but they were smaller than in the above mentioned treatments.

7.3 Nitrogen supply minus uptake

The difference between the quantity of mineral-N added to soil (fertilization + mineralization) and N uptake by plants (NAD-NUP) is part of the mass balance [1], but it is worthwhile to evaluate it separately too. In treatment M0N3, the 35 years cumulative NAD-NUP was 542 g N/m² (Table 73). When N3 was supplemented by manure at level M1 (M1N3), or by city refuse compost (RN3) the cumulative NAD-NUP increased to 600 g N/m^2. Treatment M2N0 deserves attention: its 35-years cumulative DM was 19.4 kg/m^2, which is close to the 25.2 kg/m^2 obtained in treatment M2N3 (Table 71). The difference in fresh fruit yield between those treatments was even smaller (not presented). Despite the small difference in yield, the cumulative NAD-NUP in treatment M2N0 was 65 g N/m^2 and in treatment M2N3 665 g N/m^2 (Table 73). In treatment M0N0, the cumulative NAD-NUP was ~0, indicating that the assumption of 2% soil organic-N mineralization per year is reasonable.

Table 73. The difference between mineral-N added$^+$ to soil (NAD) and N uptake (NUP) by representative crops and years, and cumulative differences over the entire (35-years) experiment period.

Year	Crop	Treatment					
		M0N0	M0N3	M2N0	M2N3	M1N3	RN3
		NAD-NUP (g N/m^2)					
1974	Potato	0.2	20.6	5.6	14.4	11.4	9.6
1978	Sweet corn	1.8	27.0	7.8	36.9	29.2	30.9
1981	Processing tomato	-6.2	9.3	-9.4	5.1	8.0	8.2
1987	Muskmelon	0.0	22.5	3.9	25.4	23.9	21.4
1994	Carrot	-8.0	14.3	-7.3	19.5	16.4	12.6
Sum (1961-1994)	All crops	12	542	65	665	605	599

Note: $^+$NAD = Fertilizer N + Manure mineralized N + Soil organic matter mineralized N. Mineralization was calculated according to [3].

In a few cases negative values were obtained, meaning greater mineral-N supply by the soil than predicted. The Experimental NUP values used above in treatments with high yields were in good agreement with data on optimal nutrient uptake rates by field crops in Israel published by Bar-Yosef (1999).

7.4 Mineral- and organic-N in the soil-root volume

Mineral N in soil was determined to a depth of 120 cm four times during the experiment (Table 74) but the original data was unavailable to the authors, and the results as published by Bar-Yosef *et al.* (1999b) are used. The organic-N results, which are used herein, are included in the annual crop reports. The quantity of mineral-N in the 0-120 cm soil layer depended on fertilizer and manure application rates (Table 74). It did not accumulate in soil because, in all cases, L was sufficiently large to leach nitrate beyond the depth of 120 cm. The 35-year average mineral-N quantities in soil in treatments M0N0 and M2N0 were 14 and 26 g N m^{-2}, while in treatments M0N3 and M2N3 the quantities were 22 and 36 g N/m^2, respectively (Table 73).

Table 74. Temporal variations in N quantities (mineral and organic) in soil. Values in parenthesis were predicted according to eq. [2] and related assumptions.

Year[a]	Crop	Treatment					
		M0N0	M0N3	M2N0	M2N3	M1N3	RN3
		------ *Mineral-N[b] (g/m², 0-120 cm)* ------					
1969	Processing tomato	12	22	26	28	25	22
1974	Potato	16	18	24	42	36	38
1978	Sweet corn	17	39	31	51	46	55
1994	Carrot	12	13	35	42	40	35
1961-1994	Mean	14±3	22±7	26±7	36±8	33±9	31±10
		------ *Organic-N (g N/m², 0-40 cm)[c]* ------					
1963	Potato	230 (280)	250 (274)	300 (330)	300 (321)	240 (358)	300 (334)
1967	Cotton	215 (248)	245 (250)	300 (348)	335 (341)	280 (338)	310 (338)
1969	Processing tomato	240	250	335	360	340	340
1976	Pepper	270 (205)	280 (222)	340 (350)	445 (318)	385 (337)	310 (340)
1987	Muskmelon	290 (166)	310 (180)	470 (485)	442 (462)	400 (328)	400 (361)

Note: [a]Since 1986, the plots were irrigated by trickle irrigation and N was applied as NH_4NO_3 via the water. [b]Mineral-N=NH_4 + NO_3; NH_4-N comprised ~10% of mineral-N. [c]Organic-N concentration in soil (0-40 cm) at the beginning of the experiment was 200 g N/m^2.

Organic-N quantity in the 0-40 cm soil layer (no measurements below this depth) increased between 1963 and 1987: in manured plots, the increase was from ~300 to ~430 g organic-N/m^2, while in un-manured treatments it was only ~250 to ~300 g/m^2 (Table 74). The fluctuations with time are explained by the fact that manure was applied every 3-to-5 years, and soil samples were taken regardless of the time after manure application. The experimental organic-N concentration results in Table 74 were accompanied by the predicted values (eq. [3]). The main reason for discrepancies between experimental and predicted results was the larger quantity of plant residue incorporated into the soil than assumed in the model. In treatment M2, the contribution of incorporated plant residue was small relative to manure application therefore the agreement between experimental and predicted data was better than in other treatments. The reference year for predicting organic-N in soil was 1969 (Table 74). The model predicted a decrease in soil organic-N (SMN+MMN) with time in treatment M0, negligible variation with time in treatments M1 and R, and increase with time in treatment M2 (Table 74). The experimental soil organic-N, however, increased in all treatments, including M0.

7.5 Leaching depth

Solutes leaching depth was approximated by assuming that salts were displaced instantaneously by the cumulative water head available for leaching (L) by means of piston flow, resulting in an increase in soil water content from a given initial value (θ_i, 0.12 LL^{-1}) to field capacity (θ_{fc}, 0.23 LL^{-1}). The θ values are assumed to be uniform along the entire soil profile. The leaching depth (h, cm) was estimated as $h = L/ (\theta_{fc} - \theta_i)$ and varied between 66 m in treatment M2N3 and 125 m in treatment M0N0. Assuming convective flow only and hydraulic conductivity K_{fc} of 0.003 cm h^{-1}, solute velocity v (K_{fc}/θ_{fc}) equaled 110 cm y_{-1}. Diffusive flow at θ_{fc} is ~10 cm y^{-1} which gives a total v of 120 cm y^{-1}. For θ_{fc} = 0.26, the calculated v is ~200 cm $year^{-1}$.

7.6 Mineral-N, Cl^- and SO_4^{2-} content and distribution in the soil profile

At the end of the experiment, the soil was sampled to a depth of 420 cm and the main ions were analyzed for their concentration (Fig. 79 and raw data in: GL Ion distribution soil 1993). The ions mass balance over this soil layer was calculated according to eq. [1] by employing the IA, IU and IS data presented in Table 75. In the case of IS, the initial amount in soil was neglected. The calculated quantity of NO_3-N that was leached below 420 cm (IL) in treatment M2N3 was 557 g N m^{-2} (= 16 g N m^{-2} y^{-1}). In treatments RN3 and M1N3, leaching was 430-to-557 g N m^{-2} as compared with only 85-to-176 g N m^{-2} found in the soil at the end of the experiment. In treatments M2N3 and RN3 N leaching was greater than in treatments M0N3 and M1N3 (535 vs. 430 g N m^{-2}) due to the greater mineralization. In treatment M0N0 and M2N0, no nitrate was leached below 420 cm and the balance was negative, indicating that in these treatments neglecting the initial quantity in the soil ($IS_{initial}$) was unjustified.

Table 75. Inorganic ions balance in soil after thirty-five years of experiment.

Element	Treatment					
	M0N0	M0N3	M2N0	M2N3	M1N3	RN3
	- - - - - - - - - - - - *Application* [a] *(g element/m^{-2})* - - - - - - - - - - - -					
N	152	948	407	1,188	1,070	1,081
K	237	237	957	957	477	477
Cl	4,212	4,212	4,692	4,692	4,372	4,372
S	434	1,090	434	1,090	1,090	1,090
Na	2,589	2,589	2,784	2,784	2,654	2,654
	- - - - - - - - - - - - - - *Uptake* [b] *(g element/m^{2})* - - - - - - - - - - - - - -					
N	140	406	343	523	464	482
K	316	693	602	883	680	790
Cl	48	108	97	126	115	118
S	48	108	97	126	115	118
Na	10	21	19	25	23	24
	- - - - - - - - *Application minus uptake (g element/m^{2})* - - - - - - - -					
K	-79	-456	355	74	-203	-313
Na	2,579	2,567	2,765	2,759	2,631	2,630
	Quantity in soil (0-420 cm) at the end of experiment (g element/m^{2})					
Min-N	136	105	66	108	176	85
Cl	482	694	460	469	590	490
S	456	1,995	468	1,234	1,889	1,825
	- - *Quantity leached beyond a depth of 420 cm (g element/m^{2})* - -					
Min-N	-124	437	-2	557	430	514
Cl	3682	3,410	4,135	4,097	3,667	3,764
S	-70	-1013	-131	-270	-914	-853

Note: [a]Application includes fertilizer + manure + water. [b]N, P, K uptake according to plant analyses; other elements according to dry matter multiplied by approximate concentrations in plant (Cl, S 0.5%, Na 0.1%).

The range in Cl^- leaching beyond 420 cm in the various treatments varied between 4,135 g m^{-2} (M2N0) and 3,410 g m^{-2} (M0N3) (Table 75). The leaching increased with added manure due to Cl- presence. The expected effect of transpiration on Cl^- leaching was probably expressed below a depth of 420 cm, as was found in deep soil sampling in the Permanent Plots Experiment at Bet Dagan (Feigin and Halevy, 1995).

Sulfate did not leach beyond 420 cm and the added amounts (as superphosphate and ammonium sulfate, and in manure) accumulated in the 0-420 cm soil layer (Table 75), which is compatible with the sulfate concentration profiles in soil shown in Fig. 79. The quantity of sulfate in the 0-420 cm soil layer exceeded the difference between application and uptake (Table 75), thus negating the assumption that $IS_{initial}$ of sulfate was negligible. From $CaSO_4$ solubility considerations ($K_{sp}=10^{-4.64}$, Lindsay, 1979), the SO_4^{2-} concentration is expected to be between 9.6 and 25 mmol(-) L^{-1}. The higher value is expected if Ca^{2+} concentration is governed by soil $CaCO_3$ (pH 8) and PCO_2 of 3 x 10^{-4} atm. The low concentration is expected in a saturated $CaSO_4$ solution.

Experimental SO_4^{2-} concentrations in the 0-200 cm soil layer were lower (except one point) than the concentration predicted in saturated $CaSO_4$ solution (Fig. 79). The concentrations in the 200-250 cm soil layer in high yield (N3) treatments were governed by $CaSO_4$ solubility in the presence of calcite. In low-yield treatments, the large L leached the sulfate below a depth of 250 cm. In the 250-450 cm soil layer, the SO_4^{-2} concentration in N3 treatments was supersaturated with respect to gypsum solubility in the presence of calcite (Fig. 79), probably due to slow crystallization kinetics in these treatments.

When multiplied by the agricultural area above the coastal aquifer in Israel, the obtained nitrate leaching below 420 cm (potential nitrate pollution) is compatible with observed annual increases in NO_3-N concentration in the aquifer, while Cl^- explains ~75% of the reported annual increases in Cl^- concentration (Wallman, 1992).

7.7 Potassium, sodium and phosphate status in soil

7.7.1 Addition minus uptake over 35 years

Potassium uptake by plants in treatments M0, M1 and R exceeded its addition to the soil (Table 75). Exchangeable and fixed K contributed to the unaccounted-for K. In treatments M2N0 and M2N3, surplus K (355 and 74 g K m^{-2}, respectively) should be found in the soil as K addition exceeded uptake and K mobility in Gilat soil is limited. The soil-K harvesting observed in treatments M0, M1 and R indicates that in order to sustain the soil fertility, K in fields well fertilized by N and P must be added to replace at least the K consumption by the crop.

Sodium accumulation in soil was unaffected by treatments as it was only added via the irrigation water (Table 75), it has limited mobility in soil, and its uptake by plants is negligible in comparison with its addition to soil. Sodium effect on SAR (sodium adsorption ratio) was relatively small (data not presented) due to the high $CaCO_3$ content in the soil.

Phosphorus addition to the soil exceeded its consumption by plants over the 35 years by a margin of 80-to-225 g P m^{-2}, depending on manure treatment (data not presented). The excess P was retained in soil by adsorption, fixation, precipitation and biological reactions (Black, 1968).

7.7.2 Phosphorus and potassium availability in soil

Phosphorus and K fertilizers were applied at identical rates to all treatments, but the manure treatments created differential P and K availability levels in soil. The availability of both P and K was evaluated by a single $NaHCO_3$ extract, as suggested by Bar-Yosef and Akiri (1978), except in 1963 when K was evaluated by the $CaCl_2$ 0.01M (1:7) extract (Table 76). At any manure treatment, the impact of N fertilization dose on P and K availability was small with a trend of decreased P, K concentration at the N level that gave highest crop yield.

The time effect on P availability in soil (0-20 cm) can be best evaluated by considering the manure main factor treatments (Table 76). Treatment M0 (average of the four N treatments) received no manure, but the $NaHCO_3$ extractable P concentration in soil increased from year 1963 (14 mg P/kg) to year 1994 (35 mg P/kg). The source of this P is fixed P and sparingly soluble P compounds that became labile due to cultivation and root activity, and mineralization of soil organic-P.

Treatments M1, M2 and R exhibited a clear increase in available P concentration in soil from 1963 to 1965, but in 1987 the concentrations declined and were lower than in 1965 and even closer to the concentrations prevailing in 1963. This was the result of fewer manure applications between 1979 and 1987 than prior to 1979 (Table 76). In 1991, the available P concentration regained the values that existed in 1965, and in 1994 the concentration steeply increased again thanks to manure application in 1992. The results show that there is only a short-term impact of manure addition on available P in soil, and 3-4 years with no manure supply allows re-equilibration of P in soil according to soil pH and Ca^{2+} activity.

Table 76. Available P and K in soil as function of treatment and time.[a]

Treatment	NaHCO3 extractable P						NaHCO3 extractable K			CaCl2 K (1:7)
	0-20 cm					20-40 cm	0-20 cm		20-40 cm	0-20 cm
	1963	1965	1987	1991	1994	1991	1991	1994	1991	1963
	mg P/kg soil						mg K/kg soil			mg K/L
M0N0	-	-	23	28	33	19	255	462	192	
M0N1	-	-	30	30	35	18	230	487	175	
M0N2	-	-	26	30	39	19	274	450	170	
M0N3	-	-	21	27	31	16	275	433	170	
M1N0	-	-	32	49	60	28	353	527	256	
M1N1	-	-	37	40	68	23	283	650	210	
M1N2	-	-	29	40	61	25	300	517	260	
M1N3	-	-	34	42	62	35	386	583	250	
M2N0	-	-	41	67	120	42	405	690	345	
M2N1	-	-	34	61	127	30	413	885	321	
M2N2	-	-	43	66	133	40	391	897	321	
M2N3	-	-	39	62	111	33	424	800	266	
RN0	-	-	29	36	35	28	265	495	215	
RN1	-	-	32	39	44	25	285	463	208	
RN2	-	-	23	39	44	23	236	448	181	
RN3	-	-	26	32	41	24	266	540	213	

	Main factor means									
N0	25	49	31	45	63	30	320	543	176	23
N1	24	44	33	38	69	24	300	621	244	25
N2	24	40	30	42	69	27	300	578	318	27
N3	21	40	30	41	62	27	337	589	204	24
M0	14	20	25	29	35	18	258	458	248	21
M1	25	41	33	42	63	28	333	569	225	27
M2	37	88	39	64	122	37	408	818	232	29
R	18	24	27	37	41	25	263	486	237	22
Manure dose (t/ha) added in **1961, 63, 67, 72, 76, 78, 79, 84, 86, 92, 1994**										
M0			0							
M1			30							
M2			90							
R			30							

Note: [a]The source data for this table is found in GL soil P K by time.

At any time, the available P and K concentrations in soil increased in the order M2> M1> R> M0. That was also the order in the case of $CaCl_2$ soluble K (1963). In 1991, available P and K were determined in both the 0-20 and 20-40 cm soil layers (Table 76). The concentration in the deeper soil layer varied between ~50 and ~75% of that in the top soil layer.

The crop response to available P and K concentration in soil could be evaluated three times along the experiment (in 1987, 1991 and 1994). The response to P is depicted in Fig. 81. In 1987, the range of $NaHCO_3$ extractable P concentration in the 0-20 cm soil layer was ~20-to-~45 mg P/kg soil and it increased with increasing manure dose per application. In 1991, the range was ~30-to-~65 mg P/kg, and in 1994 ~30-to-~130 mg P/kg. For comparison, we can estimate the theoretical maximum increase in soil P concentration due to application of 30 t/ha, which is the dose per application in treatment M1. In the dairy manure (50% water and 0.6% P in dry matter, Table 27), this dose increases the P concentration by ~35 mg P/kg soil in the 0-20 cm soil layer. Two manure additions between 1991 and 1994 can explain the observed increase in available P concentration in this treatment (from ~38 mg P/kg in 1991 to ~70 in 1994 and bearing in mind that the $NaHCO_3$ extract does not dissolve the entire adsorbed P in the soil). The effect of N at each manure level on available P concentration was significant in 1987 and negligible later on. Despite the difference in P tissue concentration between the three crops, the threshold $NaHCO_3$-P concentration above which no increase in tissue P was obtained was 25-30 mg P/kg soil (Fig. 81). This was also the threshold in the relationship between crop edible yield and available P concentration in the soil (Fig. 81). The straight lines crossing the abscissa show the expected response to soil available P when it is the growth limiting factor of the crop.

The crop response to soil available K is presented in Fig. 82. In 1987, the threshold concentration of $CaCl_2$ soluble K was 8 mg K/L, and this value was exceeded even in the un-manured treatment M0. The available K concentration in soil in 1991 and 1994 was evaluated by the $NaHCO_3$ 0.5M extract that was used to estimate available P in soil (Bar-Yosef and Akiri, 1978). The obtained concentration spread in 1991 was between ~220 and ~420 mg K/kg soil, the values increasing with increasing manure application rates. In 1994, the spread was ~410-to-~900 mg K/kg soil. To assess this increase, the K found in 30 tonnes of dairy manure and mixed in the 0-20 cm soil layer of 1 ha (treatment M1) can increase the soil K concentration by up to 150 mg K/kg (Table 76). It is interesting to note that in treatment M0, in which K uptake exceeded fertilizer-K application and organic matter has not been added, the soil K concentration still increased with time. A reasonable explanation is that fixed K was released to

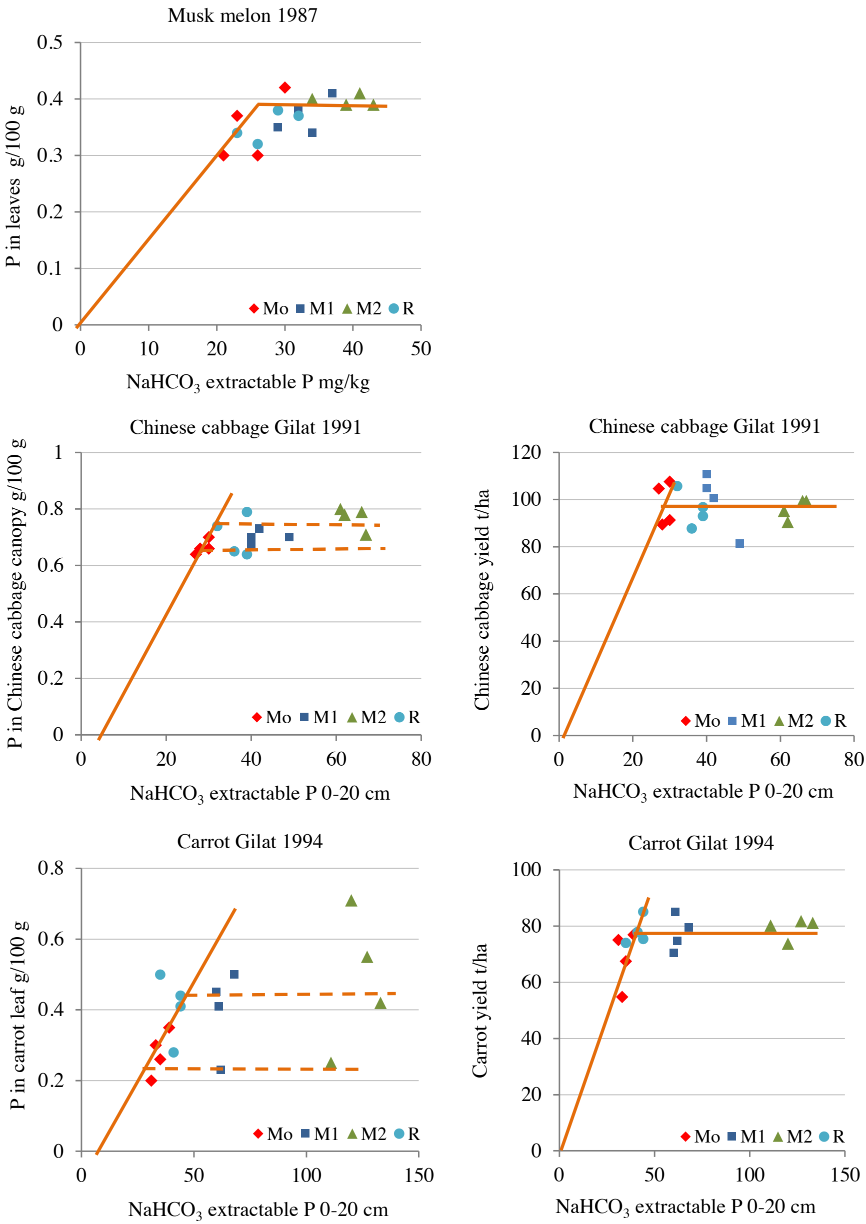


Fig. 81. Crop yield and % P in leaves response to available P in soil three crops.

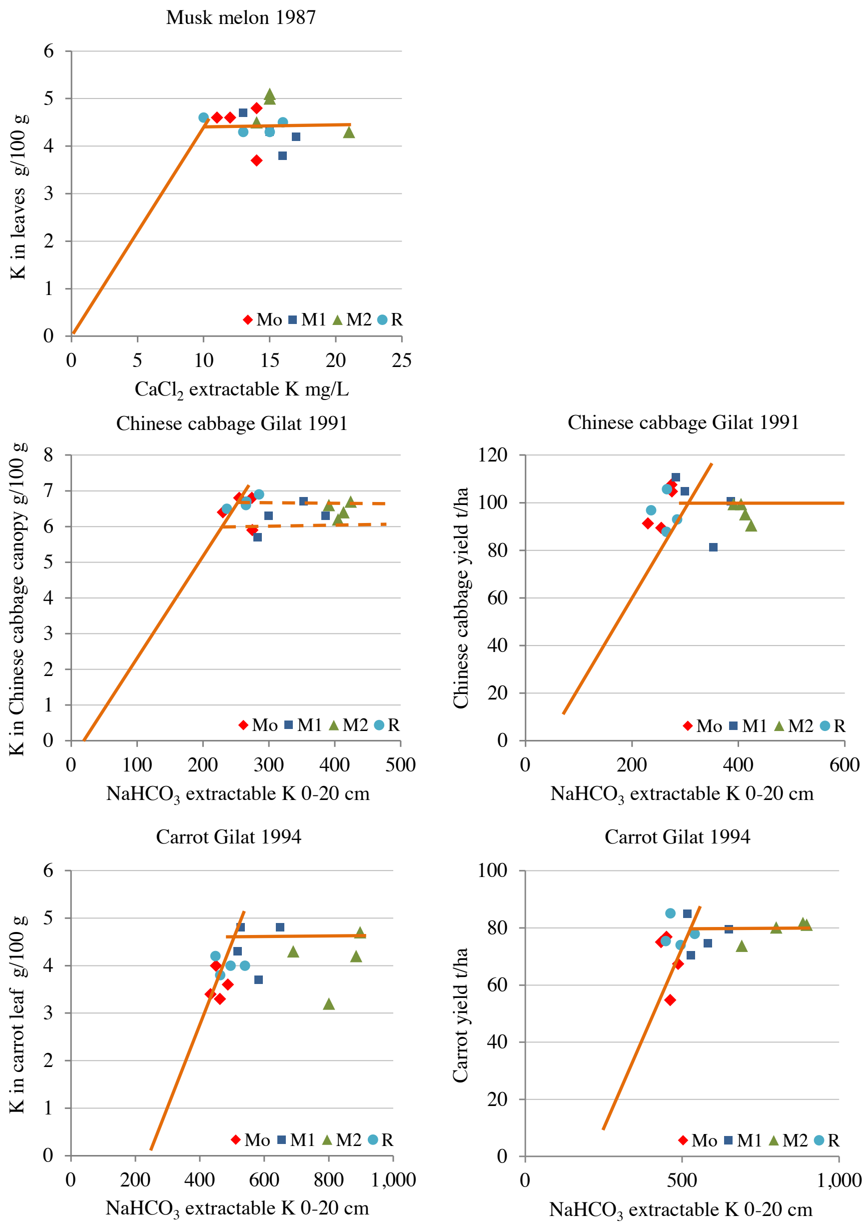


Fig. 82. Crop yield, and % K in leaves response to available K in soil. The response in %K in leaves in 1987 is to $CaCl_2$ soluble K.

the soil solution in response to the depletion of K by the plants. In Chinese cabbage (1991), the threshold $NaHCO_3$-K concentration in both yield and % K in leaves was ~200 mg K/kg, while in carrot (1994) it was ~500 mg K/kg (~1.2 mmol(c)/100 g soil).

7.8 Changes in soil mineralogy

Sandler *et al*. (2009) studied the soil mineralogy in Gilat's experimental plots in soil specimens that were sampled along the experiment and stored in covered plastic containers in the warehouse (annual temperatures varying between ~10 and ~40ºC in winter and summer). They found that the continuous cropping reduced calcite concentration in soil, but the practical impact of this finding was small.

The long-term fertilization had a slight impact on the soil's mineralogical composition. High manure and fertilization rates caused a small decline in soil illite due to K consumption by plants and a subsequent increase in soil smectite.

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