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BARLEY ROTATION TRIALS AT TEL HADYA AND BREDA STATIONS

A Summary of Biological Yield Data, 1981-87

ICARDA

Barley Rotation Trials at Tel Hadya and Breda Stations

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A Summary of Biological Yield Data, 1981-87

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INTRODUCTION

The rainfed agricultural systems of northern Syria form a continuous transition: from predominantly wheat, grain legume and tree-crop cultivation in wetter areas, through a drier zone of barley cropping, to the nomadic grazing lands of the dry steppe. Along this transition, with increasing dryness, there is a progressive decrease in the number of arable crops that can safely be grown and a progressive increase in the importance of small ruminants, sheep and goats. Below about 300 mm mean annual rainfall, little wheat is grown, and barley is almost the only arable crop. The dominant farming enterprise here is sheep production, and the purpose of the barley cropping is to provide sheep feed: green-grazing in the spring, stubble after harvest and stored straw and grain as part of the supplementary feed during the winter.

This barley zone is now under serious pressure. The last thirty years have seen a marked increase in human settlement and in sheep numbers; and the widespread use of tractors has enabled more land to be ploughed. As a result, much natural grazing, on hill-slopes and at the edge of the steppe, has been lost. The effect has been to increase both the risk of environmental degradation and the dependence of the sheep on the barley. Signs of water erosion are everywhere, and the wide expanses of cultivated land without trees or other windbreaks are dangerously exposed to the wind. At the same time, the increased demand for barley is encouraging farmers to abandon their customary barley-fallow rotation and to grow barley continuously.

The urgency for new and improved farming practices answering the farmers' immediate need of increased and, as far possible, reliable feed supply is clear. However, such practices must be both productive and sustainable, designed to conserve existing resources, particularly the soil and the natural grazing.

One issue, among many, is that of fallow replacement. Increasingly, the meagre grazing provided by the volunteer growth on a fallow is seen as an unprofitable use of land. But to grow barley on the same field every year is to invite a decline in yields. The obvious alternative is some form of rotation; and given the requirement for sheep feed, most ICARDA work has so far concentrated on a barley-forage legume cycle, with vetch, peas or lathyrus as the legume. A barley-pasture legume cycle, probably using annual medicago species, also holds promise, but trials on this have only recently started.

With the forage legumes, positive results have already been achieved in cooperative work with farmers. In the Breda area (mean annual rainfall: 280 mm), three years work has demonstrated that farmers can successfully grow and utilize common vetch (Vicia sativa) and chickling (Lathyrus sativus) in barley-legume rotations; and that both forages, whether harvested as straw and seed or grazed by lactating ewes or lambs, improve economic returns compared with land under a barley-fallow rotation (PFLP, 1986).

In parallel with this work there have been three major on-station, small-plot trials at Tel Hadya and Breda, also looking at fallow replacement. These trials, though lacking the dimension of crop utilization by animals, have the advantage of allowing the testing of more complex combinations of treatments and of providing an opportunity to observe any cumulative effects beyond a single two-year cycle. The purpose of the present report is to summarize the biological yield data from these trials. This is done first in terms of dry-matter production and then, more tentatively, in terms of theoretical sheep-carrying capacity ("sheep equivalents").

EXPERIMENTAL

There are three trials:

	Site	Year of establishment
New Rotation (NR)	Tel Hadya	1982/3
New Rotation (NR)	Breda	1982/3
Old Rotation (OR)	Breda	1980/1

Ignoring in each case the "start-up" year, the present analysis considers data from four years of each NR trial, 1983-87, and from six years of the OR trial, 1981-87. In the NR trials the design comprises three replicates of both phases of an incomplete factorial combination of six two-year rotations and six fertilizer regimes (Table 1a). The OR trial is similar but has only five fertilizer regimes, and the number of combinations is fewer (Table 1b). Other similarities and differences to note between NR and OR trials are:

i) Fertilizer regimes: NR I, III and VI = OR I, III and V, respectively; but the remainder do not correspond.

ii) Four of the six rotations are common. These are barley-barley (B/B), barley-fallow (B/F), barley-vetch (B/V) and barley-peas (B/P). The remainder do not correspond.

iii) The barley variety is Arabic Aswad in NR, Beecher in OR.

Table 1. Rotation trials: definition of treatments

A. NEW ROTATION

No.	Fertilizer regime: N:P2O5 in phase 1	2	Rotation: Phase 1: Phase 2:	A Barley Peas	B Barley P+B	C Barley Vetch	D Barley V+B	E Barley Fallow	F Barley Barley
I	20:60	20:60							19
II	0:0	20:60							22
III	20:60	0:0		1	2	3	4	18	20
IV	20:30	0:30		5	6	7	8		
V	20:0	0:60		9	10	11	12		
VI	0:0	0:0		13	14	15	16	17	21

(Numbers refer to particular treatment combinations of rotation and fertilizer regimes. Fertilizer materials were ammonium nitrate and triple superphosphate. The rate of N fertilizer indicated, 20 kg N/ha, refers to Breda; at Tel Hadya it was 40 kg N/ha. P+B = peas + barley mixture; V+B = vetch + barley mixture. In the 1986/7 season, lathyrus replaced peas.)

B. OLD ROTATION

No.	Fertilizer regime: N:P2O5 in phase 1	2	Rotation: Phase 1: Phase 2:	A Barley Vetch	B Barley Peas	C Barley Lentil	D Barley C'peas	E Barley Fallow	F Barley Barley
I	20:60	20:60							2
II	20:60	0:60		6	11	9	10		
III	20:60	0:0		8				4	
IV	0:0	0:60		7					
V	0:0	0:0		5				3	1

Full legume data for treatments 9, 10 and 11 are not available for all years of the trial, and these treatments are therefore omitted in the yield analysis below.

Management was similar in OR and NR trials. Crops, all (except Beecher barley) local landraces, were drilled at 17.5 cm row-spacing in 6.5 x 12.5 m plots at seed rates (kg/ha): barley, 90; peas, 200; vetch,

150; peas + barley, 185 + 15; vetch + barley, 135 + 15; lathyrus + barley, 135 + 15. All legumes were inoculated with appropriate rhizobia. Fertilizers were drilled with the seed, but at Tel Hadya half the nitrogen was held back and top-dressed at the start of stem extension. Weeds were controlled with herbicides or, in mixed crops and bare fallows, by hand.

Vetch, peas and lathyrus (and their mixtures with barley) were harvested at the hay stage (early pod set) every year and also at maturity in the two most recent years, 1985/6 and 1986/7 in the NR trials. Pure barley crops were harvested at maturity. In all cases, harvest yields were assessed from six 1 m row lengths randomly selected in each plot.

RESULTS

In trials of this type, the real test of a treatment lies in the productivity of the rotation as a whole. However, to understand better what is going on within rotations, it is useful first to look at the yields of the individual components of the rotation. Results are therefore presented here in the following sequence:

1. Barley yields
2. Legume yields
3. Productivity of rotations

1. BARLEY YIELDS

There is no single ideal way to analyse an incomplete factorial design. For present purposes, several different subsets of the data have been analysed separately:

A) Barley in rotations, with and without fertilizer

Fertilizer produced large and significant increases in mean barley yield, in all cases except that of grain following vetch at Tel Hadya (Table 2). These increases tended to be larger:

i) in OR than NR at Breda (which may reflect the longer duration of the trial; the difference in barley variety; or, in the case of barley following barley, the greater frequency of fertilization);

ii) at Breda than Tel Hadya in NR (on a percentage basis but not absolutely);

iii) for straw rather than grain in NR, particularly at Tel Hadya, but not in OR.

Rotation effects were also large and significant:

i) Barley following vetch or fallow generally outyielded barley following barley. On a percentage basis, these differences were always greater in unfertilized treatments, particularly at Tel Hadya.

ii) Effects on grain and straw were similar, except in the NR trial at Tel Hadya, where straw tended to be more responsive to rotation.

iii) Effects on fertilizer response, in NR, differed widely between Tel Hadya and Breda; at Tel Hadya, barley following barley was very much more responsive than barley following vetch or fallow; but at Breda, rotation had little effect on fertilizer response. (These results probably reflect a difference between sites in the balance of need for fertilizer N and P. We would expect different rotations to have different effects on soil nitrogen availability -- with some increase under vetch and fallow but decrease, probably, under continuous barley; but any rotation effects on phosphate would likely be smaller. Similar responses to NP fertilizer in all three rotations at Breda imply that phosphate is the dominant requirement there. The much smaller responses at Tel Hadya in both barley-vetch and barley-fallow rotations suggest that phosphate is less limiting there, while the very large response in continuous barley probably reflects a high requirement for nitrogen.)

Table 2. Three rotations, with and without fertilizer: rotation and fertilizer effects on grain and straw yields of barley, t/ha (four-year means in NR, six-year means in OR)

	Grain		% increase from NP	Straw		% increase from NP
	+NP	Zero		+NP	Zero	
NEW ROTATION						
Tel Hadya:	*			*		
Barley-vetch	2.23	2.05	9	3.55	2.57	38
Barley-fallow	2.86	2.32	23	4.66	3.00	55
Barley-barley	2.19	1.24	77	3.13	1.43	119
SE (±)	0.129			0.187		
% increase over B/B:						
Barley-vetch	2	65		13	80	
Barley-fallow	31	87		49	110	
Breda	ns			ns		
Barley-vetch	1.79	1.04	72	2.60	1.41	84
Barley-fallow	1.99	1.33	50	2.82	1.66	70
Barley-barley	1.37	0.77	78	2.08	1.06	96
SE (±)	0.061			0.068		
% increase over B/B:						
Barley-vetch	31	35		25	33	
Barley-fallow	45	73		36	56	
OLD ROTATION						
Barley-vetch	1.53	0.75	104	2.07	1.07	93
Barley-fallow	1.91	0.94	103	2.76	1.29	114
Barley-barley	1.25	0.48	160	1.72	0.71	142
SE (±)	0.085	0.042		0.136	0.058	
% increase over B/B:						
Barley-vetch	22	56		20	51	
Barley-fallow	53	96		60	82	

Fertilizer and rotation differences in both grain and straw means were statistically significant in all three trials (except for the fertilizer effect on grain production after vetch at Tel Hadya). This table shows significance levels and standard errors for rotation and fertilizer interactions in NR trials (but not in OR, because in that trial fertilizer treatments were not uniform across rotations).

Idenfitication of treatments:

NR - rotations C, E and F x fertilizer regimes III and VI (i.e., treatments 3, 15, 17, 18, 20 and 21 -- see Table 1a), analysed as a factorial, but interaction effects only shown here.

OR - rotations A and E x fertilizer regime III, with F x I; and, separately analysed, A, E and F x V (i.e., treatments 8, 4 and 2 and 5, 3 and 1 -- see Table 1b; n.b. treatment 2 receives fertilizer every year.

iv) Barley following fallow generally outyielded barley following vetch:

- by about 30% (fertilized) and 15% (unfertilized), NR at Tel Hadya,
- by about 10% (fertilized) and 20% (unfertilized), NR at Breda;
- by about 30% (fertilized) and 23% (unfertilized), OR at Breda.

(These figures represent approximate averages over grain and straw.)

The above summary of results over four and six years conceals the fact that, in both the presence and absence of fertilizer, yield differences between rotations were significantly larger in some years than others -- for no immediately apparent reason. The sequence seemed to be random. There was no gradual evolution over time, such as might have resulted from a progressive deterioration of conditions in, say, continuous barley plots. Over the four years common to all trials, 1983-87, the pattern of results was similar between sites, Breda and Tel Hadya, and between barley varieties, Beecher and Arabic Aswad, at Breda, which tends to suggest weather as the likely cause; but no parameter of weather has been found that shows any real relationship to the pattern of results.

Ratios between the annual barley yields in B/F and B/B rotations over six years in the OR show no obvious relationship to total rainfall or rainfall distribution (Table 3). The most distinctive year was 1984/5, when, in both fertilized and unfertilized situations, continuously cropped barley yielded almost as well as barley following fallow or vetch. In that year also, harvest indices were high (around 50 per cent) and the relative response to fertilizer was very large. The ratio of mean dry-matter yields, fertilized:unfertilized, across three rotations was 3.56 in 1984/5 compared with 1.96 $\pm$ 0.36 for the other five years. One feature of that year was the occurrence of severe frosts as late as March. This might well explain the fertilizer effect,

but it is difficult to see how frost could have been responsible for high harvest index and the relative enhancement of the yield of continuously cropped barley in both fertilized and unfertilized situations.

Table 3. Annual ratios of barley yields: (a) grain and straw, B/F:B/B rotations, fertilized and unfertilized, and (b) total dry matter, three rotation means, fertilized:unfertilized; both in relation to (c) amount and distribution of rainfall

	Season					
	81/2	82/3	83/4	84/5	85/6	86/7
A) B/F:B/B						
With fertilizer - grain	1.86	1.44	1.79	1.07	2.18	1.49
straw	1.87	1.33	1.56	1.10	2.69	1.77
No fertilizer - grain	3.06	1.80	2.54	1.15	1.87	1.96
straw	2.86	1.22	1.92	1.16	1.88	1.97
B) Fert:Unfert						
DM in 3 rotations	1.49	2.48	1.92	3.56	2.10	1.82
C) Rainfall						
Season (August-July)	324	285	204	277	218	241
November-April	269	231	196	245	191	218
November-February (I)	214	164	118	199	157	157
March-April (II)	55	67	78	46	34	61
% (II of I)	20.5	29.3	39.9	18.8	17.8	27.9

B) Fertilizer regimes on continuous barley (NR only)

At first sight, the four regimes in this comparison seem to fall into two subgroups. Where fertilizer had not been applied in the current year, yields were markedly lower than where it had been applied (Table 4a); and residual effects were very small, both in the presence and absence of currently applied fertilizer. However, fertilizer regimes II and III are effectively two halves of the same regime, and it is more useful to compare three regimes having different two-year fertilizer

sequences (Table 4b). Depending on site, annual fertilization gave 22–25 per cent more grain and 29–44 per cent more straw than did fertilization in alternate years only; zero fertilization gave 30 per cent less grain and 36–38 per cent less straw.

Table 4. Different fertilizer regimes for continuous barley: four-year means of grain and straw yields, t/ha, in NR trials

Fertilizer regime		Tel Hadya			Breda		
		Grain	Straw	H.I.	Grain	Straw	H.I.
		***	***		***	***	
a) I NP/NP		2.14	3.33	0.391	1.38	2.16	0.390
III NP/0		2.19	3.13	0.412	1.37	2.08	0.397
II 0/NP		1.31	1.50	0.466	0.84	1.25	0.402
VI 0/0		1.24	1.43	0.464	0.77	1.06	0.421
	SE (±)	0.100	0.138		0.048	0.048	
b) I		2.14	3.33		1.38	2.16	
II + III mean		1.75	2.31		1.10	1.67	
VI		1.24	1.43		0.77	1.06	

Treatment identification: Rotation F x fertilizer regimes I, II, III and VI (i.e. treatments 19, 20, 21 and 22 -- see Table 1a)

mixtures of these legumes with barley. In fact, differences between these rotations in their effects on barley yield were small (Table 5). Barley following a legume+barley mixture was less productive than barley following a pure legume but only by 5-8 per cent. Similarly, differences between barley following peas, pure and mixed, and barley following vetch, pure and mixed, were limited to about 5 per cent. At both sites, these mean differences favoured peas, but they derived mainly from one year, 1985/6, when barley yields were higher following a pea crop lost to frost.

Table 5. Barley in rotation with legumes: effects of rotation on mean yields of grain and straw, t/ha, in NR trials

Rotation	Tel Hadya		Breda	
	Grain	Straw	Grain	Straw
	*	**	***	***
Peas	2.37	3.62	1.65	2.38
Peas + barley	2.26	3.24	1.55	2.22
Vetch	2.27	3.34	1.57	2.26
Vetch + barley	2.15	3.16	1.44	2.12
SE (±)	0.051	0.094	0.051	0.032

Discounting the zero fertilizer control, differences due to fertilizer regime were also small (Table 6a). Timing of phosphate application, whether all to barley, all to legumes or half and half, had very little effect on either grain or straw yield. As already noted, this result contrasts strongly with that found for continuous barley under the same fertilizer regime. It also appears to contrast with results from the OR (Table 6b): barley yielded appreciably less well where the phosphate was applied only to the preceding vetch crop. In that case, differences in nitrogen fertilizer regime may have been responsible; but differences in nitrogen fertilization cannot explain the additional response of currently-fertilized barley (20:60) to

Table 6. Barley in rotation with legumes: effect of fertilizer regime on mean yields of grain and straw

Fertilizer regime			(a) New Rotation				(b) Old Rotation	
			Tel Hadya		Breda		Breda	
P to barley	P to legume	N to barley	Grain	Straw	Grain	Straw	Grain	Straw
Yields, t/ha								
			***	***	***	***	***	***
0	0	0	1.93	2.40	1.08	1.41	0.75	1.07
60	0	20	2.36	2.76	1.79	2.62	1.53	2.07
30	30	20	2.43	3.72	1.68	2.51		
0	60	0					1.25	1.49
0	60	20	2.33	3.49	1.66	2.43		
60	60	20					1.68	2.43
		SE (±)	0.051	0.094	0.051	0.032	0.042	0.059
% increase over control								
60	0	20	22	57	66	86	104	93
0	60	20/0	21	45	54	72	67	39

previous phosphate fertilization of the vetch (mean grain and straw increases, 10 and 17 per cent, respectively). This latter effect occurred even in the 1986/7 season (8 and 25 per cent), although the topsoil content of available-P prior to fertilizer application was by then relatively high from the residual effects of fertilizer applied over the preceding six years (7.6 ppm Olsen-P where 60 kg P_2O_5 had been applied biennially).

2. LEGUME YIELDS

Vetch in the OR trial and all legumes (and mixtures) in the NR trials were harvested every year as hay at the early pod-formation stage; but in the NR trials in 1985/6 and 1986/7 additional harvests were taken at crop maturity (hay samples having been taken only from small areas). Peas failed at both sides in 1984/5 and were replaced in the rotation by lathyrus in 1986/7. As a consequence, vetch and pea (hay) data are available together for only three seasons, including 1982/3, the start-up year. However, there are vetch only data for longer periods from the OR trial (6 years) and from the NR trials (4 years). These data and those for the mature-crop yields, 1985-87, are presented and discussed here.

A) Vetch and vetch+barley hay yields

Vetch+barley mixtures outyielded pure vetch, but this was significant only at Breda (Table 7). Mean differences were small: 0.23 t/ha (7%) at Tel Hayda, 0.31 t/ha (15%) at Breda. Response to P fertilizer was greater proportionately at Breda, consistent with a more acute phosphate deficiency at that site; and there were significant differences arising from fertilizer timing (Table 7). Thus OR hay production was increased by a mean of 44 per cent by the residual effects of fertilizer applied to the barley: 62 per cent by phosphate applied direct to the vetch; and by an additional 22 per cent (i.e. to a total of 84 per cent) by fertilizer applied to both barley and vetch. However, as with the barley, there were significant year x fertilizer interactions (Table 8). These show no clear relationship either with time elapsed since the start of the trial or with rainfall, except that the largest and smallest absolute increases from fertilizer use occurred, respectively, in the wettest and driest years.

Table 7. Mean vetch and vetch+barley hay yields (t/ha) in OR trial, 1982-87, and NR trials, 1983-87

			New Rotation		Old Rotation
			Tel Hadya	Breda	Breda
A) Effect of P-fertilizer					
kg P_2O_5/ha applied to					
Barley	Legume		*	***	***
0	0		3.11	1.45	1.49
60	0	(x)	3.51	2.17	2.14
30	30		3.71	2.41	
0	60	(y)	3.73	2.63	2.41
60	60				2.74
		SE (±)	0.153	0.116	0.064
B) Effect of crop mixture					
			ns	*	
Vetch			3.40	2.01	2.20
Vetch + barley			3.63	2.32	-
		SE (±)	0.108	0.082	
Percentage increase over control from fertilizer use		x	13	50	44
		y	20	81	62

Table 8. Annual vetch hay yields, t/ha, in OR trial, in relation to rainfall

Fert. regime	kg P_2O_5 applied to		Year					
	Barley	Legume	81/2	82/3	83/4	84/5	85/6	86/7
V	0	0	1.20	1.46	0.57	2.05	1.78	1.88
IV	0	60	1.91	2.17	0.95	3.79	2.85	2.77
III	60	0	1.84	2.27	0.86	3.08	2.41	2.36
II	60	60	2.02	3.00	1.01	4.67	2.55	3.19
Mean of regimes II, III + IV			1.78	2.48	0.94	3.85	2.60	2.77
Mean increase from P-fert:								
	t/ha		0.58	1.02	0.37	1.80	0.82	0.89
	as %		48	70	65	88	46	47
Rainfall, Nov-April, mm			269	231	196	277	218	241

B) Mature-crop yields

For mature crops, we consider first total dry-matter production and compare values with those from the corresponding hay harvest (Table 9). At the mature stage, in 1985/6, peas and peas+barley significantly outyielded vetch and vetch+barley, by a mean of 36 per cent at Tel Hadya and 27 per cent at Breda. In 1986/7, the analogous comparison showed virtually no difference between lathyrus and vetch, although species mixtures were more productive than pure legumes, by 12 per cent at Tel Hadya and 14 per cent at Breda. Fertilizer effects were not significant in either year at Tel Hadya; but at Breda there was a significant response to the use of phosphate, although differences due to its timing within the rotation were negligible in 1985/6 and small in 1986/7.

Table 9. Legume and legume+barley yields, 1985/6 and 1986/7: comparison of total dry matter, t/ha, at the hay and mature stages

	Tel Hadya			Breda		
	Hay	Mature	% Change	Hay	Mature	% Change
1985/6						
Crop effects:	*	***		**	***	
Peas	3.74	5.06	35.5	2.20	2.71	23.3
Peas + barley	3.49	4.69	34.3	2.28	2.67	17.3
Vetch	3.29	3.54	7.8	1.93	2.00	3.3
Vetch + Barley	3.54	3.62	2.2	2.14	2.24	4.6
Fertilizer effects:	ns	ns		***	***	
III P to barley	3.47	4.01	15.5	2.30	2.63	14.4
IV P, 1/2 & 1/2	3.65	4.23	16.0	2.41	2.52	4.5
V P to legume	3.58	4.35	21.6	2.32	2.59	11.4
VI zero P	3.36	4.33	28.7	1.52	1.89	23.9
SE (±), both factors	0.092	0.123		0.064	0.084	
1986/7						
Crop effects:	***	**		**	***	
Lathyrus	4.54	4.98	9.9	1.74	2.06	18.8
Lathyrus + barley	5.16	5.53	7.1	1.92	2.31	19.9
Vetch	4.54	4.94	8.8	1.89	1.98	4.9
Vetch + barley	4.81	5.57	16.0	2.07	2.30	11.3
Fertilizer effects:	***	ns		***	***	
III P to barley	4.74	5.23	10.3	1.94	2.25	16.2
IV P, 1/2 & 1/2	5.08	5.41	6.5	2.11	2.19	4.2
V P to legume	5.22	5.45	4.5	2.32	2.44	5.1
VI zero P	4.01	4.94	23.3	1.26	1.77	41.0
SE (±), both factors	0.101	0.142		0.063	0.049	

Responses of hay and mature-crop dry matter to experimental treatment showed some differences, and these are examined in terms of percentage increases between the two harvests. Caution is needed. The percentages derive from differences between two samplings, each subject to experimental error. No significance levels can be attached, and only numerically large differences can be regarded as meaningful. On this basis, the following observations appear to be valid:

1. For vetch and lathyrus (and their mixtures with barley), dry-matter accumulation between hay and mature-crop harvests was small: over two sites and two years, 9.5±5.9 per cent. For peas and peas+barley it was much larger, with means of 35 per cent at Tel Hadya and 20 per cent at Breda. While it is impossible to rule out entirely the possibility that the timing of hay harvest (theoretically, early pod formation stage in each crop) and the procedure used have somehow exaggerated the difference between peas and the other two legumes, it is nevertheless clear that in the one year for which we have data, peas were more productive than vetch when allowed to grow to maturity.

2. Crops in unfertilized rotations accumulated proportionately more dry matter between the hay and mature stages than did those in fertilized rotations: means, 29.2±8.2 and 10.9±5.0 per cent, respectively. Again, this may partly be an artefact of the harvesting procedure. It is unlikely that crops were at precisely the same growth stage in all treatments at the time chosen for hay harvest. Fairly generally, phosphate-deficient crops develop more slowly; and at any particular time we might expect an unfertilized plant to be less advanced phenologically (and so have proportionately more of its potential growth still to achieve) than a fertilized plant. The fairly general corollary of this is that fertilizer effects, or at least phosphate effects, are proportionately smallest at maturity. This was particularly clear at Tel Hadya in 1986/7.

Detailed examination of mature crop data is made on the 1986/7 results only (Table 10). One of the most important points to emerge is

the difference between vetch and lathyrus (whether pure or in mixture with barley) in the proportion of total dry matter put into the grain. Although legume dry-matter production was almost identical, lathyrus produced a mean of 300 kg/ha (19%) more grain than vetch at Tel Hadya and 200 kg/ha (39%) more at Breda.

Table 10. Legume and legume+barley crop yields, 1986/7: breakdown of mature-crop dry matter, t/ha, into grain and straw and, for mixtures, into barley and straw contributions

	Tel Hadya					Breda				
	Total grain	Total straw	Legume grain	Legume straw	Legume HI	Total grain	Total straw	Legume grain	Legume straw	Legume HI
Crop:	***	**	***	***		***	***	***	***	
L	2.27	2.72	2.27	2.72	0.454	0.95	1.11	0.95	1.11	0.463
L+B	2.52	3.09	1.53	1.82	0.456	0.89	1.52	0.48	0.85	0.361
V	1.81	3.13	1.81	3.13	0.369	0.59	1.39	0.59	1.39	0.299
V+B	2.07	3.22	1.38	2.32	0.373	0.75	1.54	0.44	1.07	0.290
Fertilizer regime:	ns	***	ns	*		***	***	*	***	
III	2.14	2.97	1.73	2.48	0.412	0.85	1.40	0.65	1.09	0.366
IV	2.15	3.27	1.68	2.64	0.391	0.75	1.44	0.56	1.13	0.324
V	2.20	3.28	1.71	2.63	0.399	0.87	1.62	0.67	1.32	0.335
VI	2.17	2.63	1.86	2.23	0.452	0.71	1.10	0.59	0.89	0.390
SE (±), both factors,	0.062	0.098	0.056	0.097		0.028	0.041	0.026	0.037	

(For mixed-crop treatments, total grain and total straw are for legume and barley combined).

A second point concerns the effect of fertilizer. Lack of any significant fertilizer effect on total dry-matter production at Tel Hadya was noted above. However, when the components of the dry matter are considered separately, it is seen that total straw yield (barley and legume) was significantly influenced by fertilizer; and the same effect

is seen in the legume straw and grain data. It appears that straw yield was sensitive to the presence of fertilizer and the timing of its application, while grain yield was not. And there is evidence of similar trends in the Breda data. At both sites, this effect is seen most clearly in the harvest index values of the legumes.

3. PRODUCTIVITY OF ROTATIONS

With individual crops, it is usual and convenient to report yields on a per hectare basis. With rotations, however, this can be ambiguous, particularly where fallows are involved. For example, in B/F rotations, barley yields per hectare of barley planted are always relatively high, but each year half the area of the whole rotation is unproductive. Per hectare yields from continuous barley (B/B) are generally lower but are obtained each year from the whole area of the rotation. For this reason, each rotation will be considered here to comprise two one-hectare fields, and combined annual production from both fields will be reported (on a yield/2 ha basis).

Not all treatments will be considered. In the NR trials, the number of years of data for peas and for lathyrus is small; and differences between rotations involving pure legumes and those with legume+barley mixtures are small. So the barley-vetch rotation (B/V) will be taken to represent barley-forage legume rotations generally in comparisons with the B/F and B/B rotations. Similarly, to reduce complexity some of the timing regimes for phosphate fertilizer will be omitted.

In the NR trials, under both the zero and the biennial fertilizer regimes (VI and III), the B/V rotation produced more dry matter than the B/B rotation, which in turn produced more than the B/F (Figure 1; Table 11). Site differences, however, were appreciable. Thus the advantage of B/V over the other two rotations was greater in the presence of fertilizer at Breda but in its absence at Tel Hadya. The advantage of B/B over B/F was appreciable at Breda but almost negligible at Tel Hadya. In the OR trial, under the same fertilizer regimes (in this case, V and III), the B/V rotation outyielded B/F; but this trial had no B/B rotation under the biennial fertilizer regime.

Figure 1a. Effect of rotation and fertilizer regime (Table 1b) on total dry-matter production over six years in the OR trial at Breda

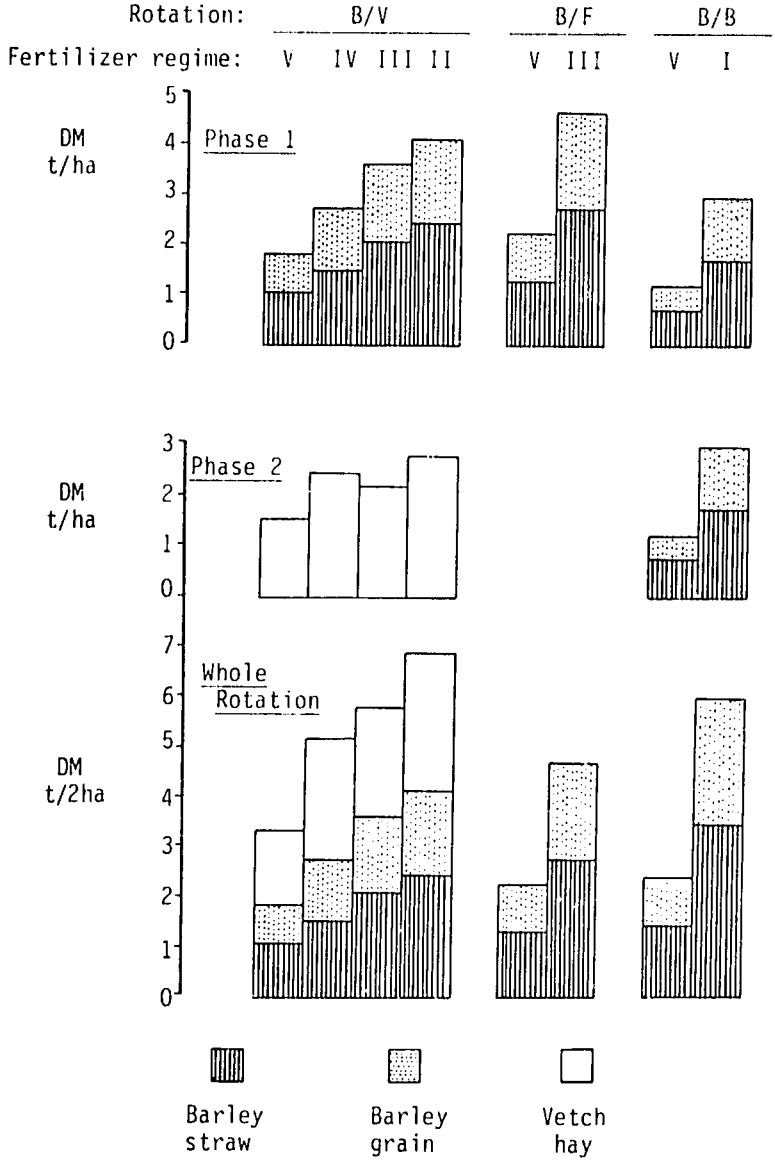

Figure 1b. Effect of rotation and fertilizer regime (Table 1a) on mean total dry matter production over four years in NR trials at Tel Hadya and Breda

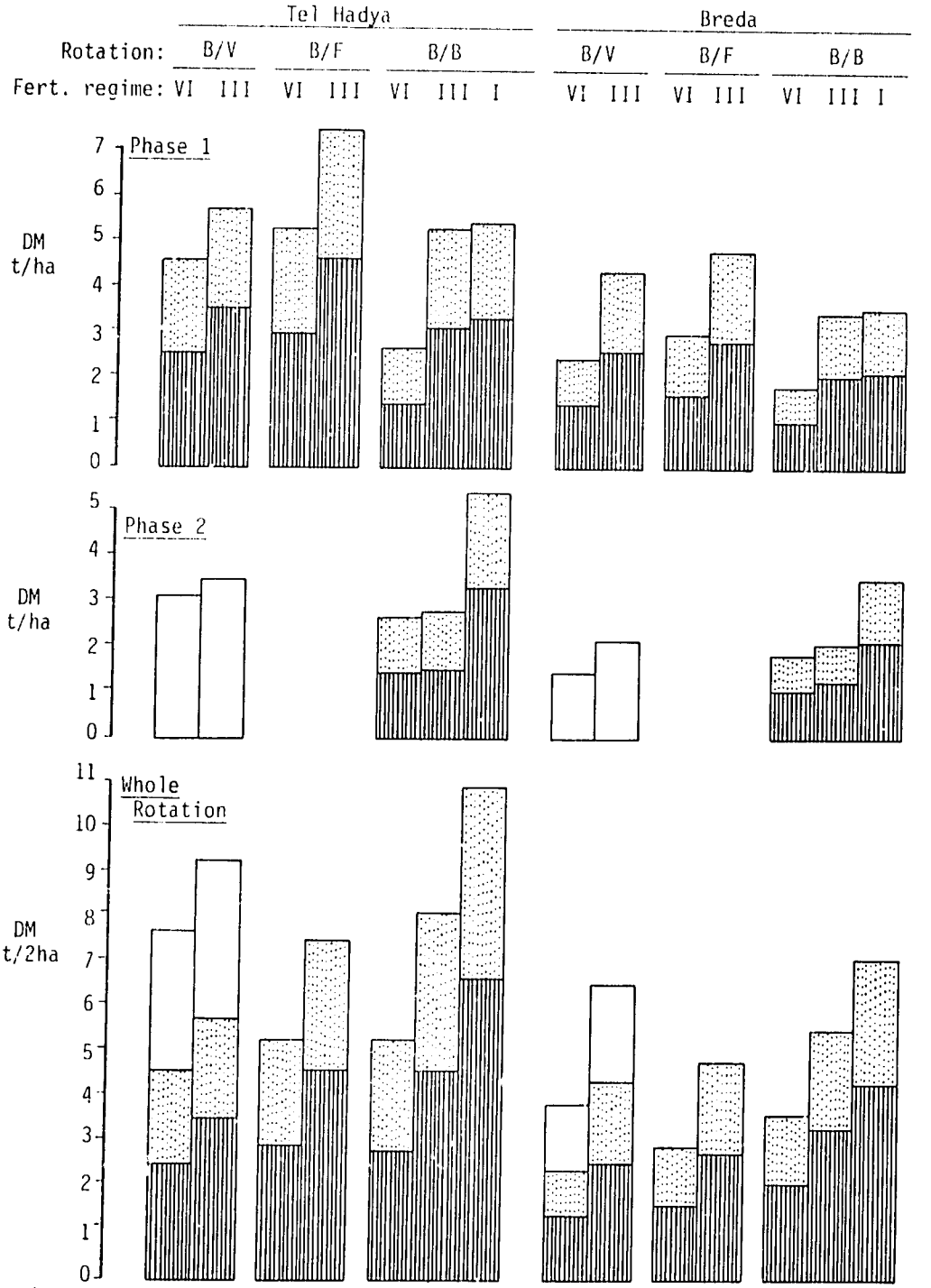

Table 11. Summary of differences between pairs of rotations in mean dry-matter yield, expressed as t/2 ha and percentages of the yield of the second rotation

	B/V relative to B/F		B/V relative to B/B		B/B relative to B/F	
	- Fert.	+ Fert.	- Fert.	+ Fert.	- Fert.	+ Fert.
Tel Hadya:						
NR	+ 2.41 (45%)	+ 1.77 (24%)	+ 2.39 (45%)	+ 1.16 (14%)	+ 0.02 (0%)	+ 0.61 (8%)
Breda:						
NR	+ 0.91 (30%)	+ 1.75 (36%)	+ 0.24 (7%)	+ 1.02 (18%)	+ 0.67 (22%)	+ 0.73 (15%)
OR	+ 1.07 (48%)	+ 1.07 (23%)				

In all three trials, the productivity of the biennially fertilized B/V rotation was exceeded by that of the annually fertilized B/B (regime I in both NR and OR) (Table 12). However, in the OR trial there was also an annually fertilized B/V rotation (regime II): vetch, receiving 60 kg P_2O_5/ha, in rotation with N:P-fertilized barley. And this rotation outyielded the annually fertilized B/B rotation by 0.90 t/2 ha (15%).

Table 12. Yield comparisons of annually fertilized B/B rotations with annually and biennially fertilized B/V rotations (total dry matter, t/2ha)

		B/V rotations		B/B rotations		
Fertilizer:		Biennial	Annual	Annual	Difference	%
Tel Hadya:	NR	9.29		10.94	1.65	18
Breda:	NR	6.56		7.08	0.52	8
	OR	5.74		5.95	0.21	4
			6.85	5.95	0.90	15

Table 13. Effect of rotation and fertilizer regime on the variability of dry-matter production in the OR trial over six years

Fertilizer regime	Rotation		
	B/V	B/F	B/B
V. No fertilizer:			
Mean yield, t/2 ha	3.31	2.24	2.38
s.d. (±)	0.651	0.778	0.375
c.v. (%)	19.6	34.8	15.8
III. Biennial, N:P to barley only:			
Mean yield, t/2 ha	5.74	4.67	
s.d. (±)	1.603	0.886	
c.v. (%)	27.9	19.0	
II. Annual, N:P to barley, P to vetch:			
Mean yield, t/2 ha	6.85		5.95
s.d. (±)	2.100		2.069
c.v. (%)	30.7		34.8

The above figures, all of 4-year or 6-year means, conceal annual differences, and it is pertinent to question the effect of rotation and fertilization on the annual variability of production. The six-year run of OR data is sufficiently long to attempt an answer (Table 13). In all three rotations, fertilizer increased both yield and the absolute variability of yield (i.e. in t/2 ha). In rotations cropped annually (B/V and B/B), the coefficient of variation of yield was also substantially increased by fertilizer; but where a crop was taken only biennially (B/F), fertilizer substantially decreased the coefficient of variation.

SHEEP FEED VALUES

Comparison of rotations simply in terms of total dry-matter production, though biologically interesting, is not very satisfactory from an agronomic point of view, still less from a nutritional or economic point of view. One tonne of dry matter has a different agricultural value,

depending on whether it is grain, straw or legume hay. The comparison should be made on an equivalent value basis.

There are two ways this can be done. One is to adopt a purely economic approach and use cash as the basis of comparison: cost the inputs, price the products and do the necessary arithmetic. In fact, it is not as simple as that. Costs and prices are subject to both short and long-term fluctuations, and hard decisions have to be taken about which values to put into the calculation. Moreover, as with all on-station trials, it is difficult to cost in real farm terms the research-level management the trial has received. With the present trials, there is also the point that, although much buying and selling occurs, most farmers within the barley-livestock system do not grow crops primarily for sale but rather to feed their animals; and the market price for those crops at harvest, say, does not necessarily match their actual value to the farmer later as feed.

The other approach is to use feed value or "nutrient yield" as the basis for comparison, leading on to comparisons of rotations in terms of theoretical animal-carrying capacity. One complication is that feed can be used to provide energy or to provide protein or various combinations of both. The energy value of the feed, ME (metabolizable energy), and its crude protein content (CP) can each be related to the annual needs of a standard Awassi ewe (= "sheep equivalent"). To do this certain values and conversion factors must be assumed; and those used here are taken from Thomson (personal communication): metabolizable energy values of 11.5, 5.5 and 9.0 MJ/kg and crude protein percentages of 10, 3.5 and 10% for barley grain, barley straw and legume hay, respectively; and sheep equivalents of 4.2 GJ of metabolizable energy and 42 kg crude protein (i.e. to feed one ewe for a year).

Nutrient yield values for B/V, B/F and B/B rotations, with and without fertilizer, are derived from NR crop data for Tel Hadya and Breda in Table 14. The following points emerge:

1. Calculations based on CP give generally lower values for sheep equivalents per ha than those based on ME. The difference is

smaller for the B/V rotation (9%) than for the B/F and B/B rotations (23% each) because of the high protein contribution from the vetch hay.

2. Fertilizer generally increased sheep equivalents per ha. Where NP fertilizer was applied biennially, these increases, averaged across the 3 rotations, were approximately 30% at Tel Hadya and 57% at Breda (ME and CP giving similar figures).

3. Differences between rotations were quite large. In both the unfertilized and the biennially fertilized situations, B/F gave the lowest sheep equivalent values. Averaged over sites and methods of calculation, the B/B values were 9% and 13% higher (unfertilized and fertilized, respectively) and the B/V values 57% and 46% higher.

4. Annual fertilization raised the sheep equivalent values of the B/B rotation to approximately the same levels as those of the biennially fertilized B/V rotation (CP values slightly lower, ME values slightly higher).

These findings must be regarded cautiously. The use of assumed, constant factors to calculate ME and CP disregards the possibility of treatment and seasonal effects on the nutritional values of the crops concerned. It is highly likely that: (i) rotations and fertilizer use will each have affected the CP content and possibly also the ME values of both barley components; and (ii) the lower volume of material produced in dry years was, weight for weight, more nutritious. Nevertheless, the broad pattern of the results is surely substantially correct: that the output of feed and, therefore, sheep per ha can be substantially increased, either by replacing fallow with vetch or (more dangerously) with more barley. It can also be greatly increased by the use of fertilizer. Sheep equivalent values in annually fertilized B/B or biennially fertilized B/V rotations exceeded those in unfertilized B/F rotations by about 100 per cent at Tel Hadya and 130 per cent at Breda.

Table 14. Derivation of nutrient yield values (sheep/ha) from crop yield data in seven fertilizer x rotation treatments in the NR trials at Tel Hadya and Breda

Rotation:	B/V		B/Γ		B/B		
Fertilizer:	-	+	-	+	-	+	++
Treatment No.:	15	3	17	18	21	20	19
TEL HADYA							
DM, t/2 ha:							
Barley grain	2.05	2.33	2.32	2.86	2.48	3.50	4.28
Barley straw	2.57	3.55	3.00	4.66	2.86	4.63	6.66
Legume hay	3.11	3.51	-	-	-	-	-
ME, GJ/2 ha:							
Barley grain	23.6	25.6	26.7	32.9	28.5	40.3	49.2
Barley straw	14.1	19.5	16.5	25.6	15.7	25.5	36.6
Legume hay	28.0	31.6	-	-	-	-	-
Total	65.7	76.7	43.2	58.5	44.2	65.8	85.8
CP, kg/2 ha:							
Barley grain	205	223	232	286	248	350	428
Barley straw	90	124	105	163	100	162	233
Legume hay	311	351	-	-	-	-	-
Total	606	698	337	449	348	512	661
BREDA							
DM, t/2 ha:							
Barley grain	1.04	1.79	1.33	1.99	1.54	2.21	2.76
Barley straw	1.41	2.60	1.66	2.82	2.12	3.33	4.32
Legume hay	1.45	2.17	-	-	-	-	-
ME, GJ/2 ha:							
Barley grain	12.0	20.6	15.3	22.9	17.7	25.4	31.7
Barley straw	7.8	14.3	9.1	15.5	11.7	18.3	23.8
Legume hay	13.1	19.5	-	-	-	-	-
Total	32.9	54.4	24.4	38.4	29.4	43.7	55.5
CP, kg/2 ha:							
Barley grain	104	179	133	199	154	221	276
Barley straw	49	91	58	99	74	117	151
Legume hay	145	217	-	-	-	-	-
Total	298	487	191	298	228	338	427
SHEEP EQUIVALENTS PER HECTARE							
Tel Hadya - ME calc.	7.8	9.1	5.1	7.0	5.3	7.8	10.2
- CP calc.	7.2	8.3	4.0	5.3	4.1	6.1	7.9
Breda - ME calc.	3.9	6.5	2.9	4.6	3.5	5.2	6.6
- CP calc.	3.5	5.8	2.3	3.5	2.7	4.0	5.1

DISCUSSION

This paper has attempted to summarize the yield data from three complex rotation trials, and at the end of such a summary it is desirable to be able to state conclusions and indicate their practical consequences. However, in the present case, there are constraints on the drawing of any too firm conclusions. These arise, first, from the time-scale of long-term rotation trials, and, secondly, from the uncertain relevance of small-plot trials to economics and practical agriculture.

Yield sustainability and yield stability are now recognized as issues of fundamental importance in agriculture everywhere but particularly in fragile environments. A major purpose of long-term trials is to observe the effects of repeated sequences of cropping, fertilization and particular systems of management on the pattern of productivity over time and, as far as possible, elucidate the mechanisms involved. Measured against these objectives, the present four- and six-year data sets have limited utility. We can say little as yet about sustainability. One rotation has perhaps initially proved to be more productive than another, but whether such a difference will be maintained over future cycles of the rotations cannot be predicted. So far, no trends of rising or falling yields have been clearly identified. Expectations that yields would fall with time in the continuous barley rotation have not yet been fulfilled. In fact, annually fertilized continuous barley has been one of the most productive treatments. Moreover, recent soil analyses have suggested that amounts of organic matter are higher in soils that are cropped annually (including continuous barley) than in soils under traditional and, supposedly, more conservative barley-fallow rotation (Jones and Matar, 1988).

Stability, however, is another matter. Large within-treatment differences have been observed from one year to the next, attributable to weather differences. That was, of course, to be expected. But there has also been considerable annual variation among between-treatment differences: two treatments may yield similarly in some years but show wide divergence in others. As yet, the time sequences are too short to allow interpretation of these phenomena, but it is likely that they

involve both differential responses to current conditions (particularly crop x fertilizer x weather interactions) and residual and cumulative effects from previous years. These include effects on fertility status -- build-up of soil available-P in some treatments has already been reported (Jones & Matar, 1988) -- and on stored soil water. (Data on soil water balances in certain treatments of the OR trial are currently being summarized.)

Such phenomena are reflected in the coefficients of variation reported above (Table 13). We observe, though cannot yet explain, an increase in yield stability from fertilizer use in a B/F rotation but a decrease in B/B and B/V rotations. At this stage, we can conclude only that innovations with a proven short-term yield benefit, e.g. fertilizer or fallow replacement, may exact a price in terms of greater year to year variability. For practical farming, the eventual question is: where does the balance of advantage lie between increased production and increased variability of that production? And the answer will usually be determined as much by economics as by agronomy.

However, the data presented here came from small-plot research-station trials. As such, they are economically neutral. One option is to try to confer economic meaning on them by drawing up balance sheets based on the market costs and prices of their inputs and outputs. As already indicated, this is not particularly easy. Nor is it necessarily the first priority. On-station trials are essentially investigations of crop-environment relationships, and assessment of their results should be primarily in physical and biological terms. In the end, and after due consideration of on-farm trial results also, we have to select the best economic options for practical farming situations; but that can be done more soundly if the underlying biological and physical mechanisms have first been understood. This is particularly true if we are looking to take account of stability and sustainability issues.

Nevertheless, when one is comparing experimental treatments that give rise to several different products (grain, straw, hay, etc.) in variable proportions, some way of equating their values is essential. "Feed

value" provides a particularly appropriate one for crops grown in a livestock-orientated system; but four caveats need to be made in respect of the "sheep equivalent" method used here. First, accuracy and reliability would be improved by analysis of plant samples. The use of standard values for metabolizable energy and crude protein content may favour or disfavour certain treatments. Secondly, recalculation in terms of sheep equivalents does not necessarily make research-station results any more applicable to real farm situations than does recalculation in terms of cash values. The nutritional needs of sheep, unlike the prices of grain, straw and hay, may be assumed to be constant, but the basic data upon which the calculations are based remain, to a degree, removed from the real farm situation. Thus, thirdly, the biological findings, whether in terms of crop yields or potential sheep yields, must at some stage be critically assessed in terms of management practicability and economic potential. That is not attempted here; and, for the present, conclusions are limited to those represented in the following summary of results.

A fourth and final point concerns the mode of utilization of forage legumes and legume/barley mixtures. When the present trials were started, harvesting as hay was assumed to be the best option, and until recently the measurements made on the crop reflected this. However, Dr. Euan Thomson considered that farmers with small holdings would be unlikely to adopt the practice of making hay and prefer to utilize forages either as green grazing or as mature crops. This seriously undermines the practical relevance of the calculations made above in terms of hay yields. The forage crops in the NR trials are now being grown to maturity, and in time it will be possible to compare the barley-forage rotation with the other rotations, using legume grain and straw yield data. On present evidence, it seems likely that this will increase the relative advantage of that rotation in terms of mean annual productivity but perhaps at the cost of greater inter-annual variability.

SUMMARY OF RESULTS

1. Consistently, though with wide variation in actual degree from year to year (from 10% to nearly 200%), a barley crop following vetch or fallow outyielded one following a previous barley crop; and barley following fallow outyielded barley following vetch (means: 10-30%). This was true for both fertilized and unfertilized situations; but on a percentage basis (though not always in absolute terms), differences between rotations tended to be greater in the absence of fertilizer.

2. In B/B rotations receiving NP fertilizer biennially, there is very little yield response in the non-fertilizer year to any residues of previous fertilization; but in B/V rotations, barley clearly responds to phosphate applied to the previous vetch crop. The difference appears to arise from differences in nitrogen availability. The response of barley, particularly when in B/B rotation, to fertilizer P (current or residual), is strongly dependent on the availability of nitrogen.

3. No great advantage (but also no deleterious effect) has been observed to result from using legume+barley mixtures instead of pure legumes in barley/legume rotations. Higher productivity (of hay) from vetch+barley compared with pure vetch (7% at Tel Hadya, 15% at Breda) was partly offset by yield reductions in the following barley crops (5% at Tel Hadya, 7% at Breda).

4. In terms of the total dry-matter production from whole rotations and of the sheep equivalents per ha derived from them, under any given fertilizer regime:

   - the B/V rotation in all cases outyielded the B/F rotation;
   - the B/B rotation in all cases outyielded the B/F rotation (although differences were either small or negligible where there was no fertilization);
   - the B/V rotation in all cases outyielded the B/B rotation.

5. The total productivity of all rotations was much increased by fertilizer. For instance, in the OR trial, increases over zero fertilizer control were:

	B/V	B/F	B/B
From biennial fertilizer	73%	108%	-
From annual fertilizer	107%	-	150%

However, in continuously-cropped rotations (B/V and B/B), these increases were accompanied by large increases in variability (cv's rising from 15-20% to 30-35%), whereas in the B/F rotation there was a decrease (from 35 to 19%).

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