Barley based rotations in a typical Mediterranean agroecosystem: crop production trends and soil quality

Ryan J., Masri S., Pala M., Bounejmate M.

in

Zdruli P. (ed.), Steduto P. (ed.), Kapur S. (ed.).
7. International meeting on Soils with Mediterranean Type of Climate (selected papers)

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 50

2002
pages 287-296

CHAPTER III

SOIL QUALITY INDICATORS IN MEDITERRANEAN ENVIRONMENTS

BARLEY-BASED ROTATIONS IN A TYPICAL MEDITERRANEAN AGROECOSYSTEM: CROP PRODUCTION TRENDS AND SOIL QUALITY

J. RYAN, S. MASRI, M. PALA AND M. BOUNEJMATE (deceased)

Natural Resource Management Program, International Center for Agricultural Research in the Dry Areas (ICARDA), P.O. Box 5466, Aleppo, Syria

Introduction

From the advent of settled communities and civilisations many thousands of years ago, agriculture the process of producing food has continuously evolved and changed to meet the challenge of sustaining the earth's growing population. It was characterised by adapting crops to specific environments, colonisation of new lands for cultivation, and in the last century harnessing of mechanical power. While agriculture in developed industrial countries is now highly efficient and productive, and involves only a small percentage of the population, agriculture in developing countries is still traditional, with low inputs and low outputs, and is frequently constrained by climate, especially drought.

The broad area of North Africa West Asia (WANA), primarily representing Mediterranean agroecosystems, is still one of the world's major food-deficit areas, despite being the centre of origin of many of major crops, especially cereals and legumes, and the area where settled agriculture and modern civilisation began.

The major constraint to crop production is insufficient rainfall and soil moisture (Kassam, 1981). The region's climate is typically Mediterranean, with cold wet winters and warm to hot arid summers (Cooper and Gregory, 1987). Rainfall is highly variable in time and space, but generally ranges from 100 to 600 mm/yr, being higher in some high-elevation areas and lower in the vast area of steppe merging into desert. Cropping is only possible in the cooler winter season (Keatinge *et al.,* 1985), and yields are directly dependent on seasonal rainfall. In the lower end of the rainfall spectrum (i.e., < 300 mm) complete crop failure due to drought is a common occurrence. Even in more favorable areas and years (300500 mm) terminal drought invariably occurs in April/May prior to harvest.

Cropping systems in the Mediterranean zone center around cereals, with barley (*Hordeum vulgare* L) being dominant in the drier areas (< 300 mm) and bread wheat (*Triticum aestivum* L.) and durum wheat (*T. durum* var *durum*) in the wetter areas (Cooper *et al.,* 1987). Food legumes such as lentil (*Lens culinaris*), chickpea (*Cicer arietinum*), faba bean (*Vicia faba* L.), pea (*Pisum sativum*) and forage legumes such as vetch (*Vicia sativa*) and medic (*Medicago sativa*) are grown in rotation with cereals. Small ruminants (sheep and goats) are an integral part of the farming system, feeding on the harvested straw and grazing the stubble.

Fallow was a traditional approach to conserving soil moisture and ensuring a reasonable crop yield once in two years. However, with land-use pressure fallow has all but disappeared except in very dry (< 250 mm) areas (Harris, 1995) and are being replaced by continuous cereal cropping. Such a practice is biologically and economically unsustainable (Jones and Singh, 2000). The approach developed by the International Center for Agricultural Research in the Dry Areas (ICARDA) and by various national agricultural research systems in the WANA region was to identify through long-term rotation trials alternative and more attractive cropping options (Ryan and Abdel Monem, 1998).

Early research at ICARDA (Cocks and Thomson, 1988; Osman *et al.,* 1990) and in Cyprus (Papastylianou, 1993) had demonstrated the viability of legumes for fallow replacement. Given the fact that much of the dryland area of Syria is mainly a barley-livestock system, various studies focused on improving output through rotations, grazing management, and fertilisation. Field trials at various sites in northeastern Syria, with rainfall ranging from 149 to 451 mm per growing season, clearly showed the value of nitrogen (N) and phosphorus (P) fertilisation for increasing barley yields (Wahbi *et al.,* 1993).

In a typically barley-growing area (280 mm/yr), a multi-year trial showed that barley yielded most after fallow and more after legumes than barley alone, but on the basis of total production over the 2-year cycle, barleyvetch yielded most biomass (Jones and Singh, 1995), bearing in mind that a cereal crop is produced in the fallow system once every 2 years. Other studies showed that legumes could contribute some N to the succeeding barley crop (Keatinge *et al.,* 1988) as well as increase water-use efficiency (Harris, 1994).

Similar long-term studies with wheat at Tel Hadya, ICARDA's main station (330 mm/yr on average) had demonstrated the value of vetch and medics in the rotation, particularly in terms of total biomass yield per cycle and the accumulation of N derived from fixation for the benefit of the cereal crop (Harris *et al.,* 1995). The increases in both total and mineral N were paralleled by increasing soil organic matter, both total, labile, and biomass forms (Ryan, 1988).

While many long-term rotation trials were initiated in the 1980s, each had a specific focus, but many had overlapping elements. However, only one such trial was primarily based on sheep grazing management within the context of acceptable rotations. The initial phase of the trial, described in detail by White *et al.,* (1994), involved wheat.

The trial was later transformed to a barley-based one as it was considered that this was more appropriate to this transition zone, and as a relatively similar trial already existed for wheat. Thus, by way of background, some key features of this initial phase are described. The broad objectives of the trial were to answer a number of questions which cropping system is most productive and economical in the long run? As legumes fix N, how will this affect fertiliser N needs of cereals? What are the benefits of legumes for soil quality, especially for the organic matter?

Initial wheat rotation

The trial, established in 1985/86 on a deep (2 m) clay soil or Calcixerert (Ryan *et al.,* 1997) involved durum wheat in rotation: with 1) medic pasture grazed at low, medium, and high intensities (or 4,7,10 sheep/ha); 2) common vetch; 3) lentil, 4) watermelon (*Citrullus vulgaris*), and 5) clean fallow.

Each rotation was in triplicate and distributed in three separate blocks. Nitrogen was applied to the cereal phase at 0 and 40 to 90 kg ha^{-1} (depending on the year) and P as a blanket treatment. Both cereal and alternative rotation phases were present each year. The rainfall was generally below average for the 6 years, with only one year (423 mm) above average (330 mm) and the others ranging from as low as 216 mm in 1989/90 to 308 mm in 1986/87.

Early Observations

Though this phase continued for only 6 years to 1991/92, some significant trends were in evidence (White *et al.,* 1994):

- Yields were highest in the fallow rotation (one crop in two years only), followed by medic, vetch, and lentil;
- Nitrogen increased total cereal biomass, but not grain yield;
- Fertilisation with N did not increase soil N but did increased organic matter;
- There was no effect of total soil N on wheat response to N fertiliser;
- Calculated nutrient outputs were higher than inputs;
- Medic pastures increased soil organic matter (1020%) and total soil N from 550 ppm in 1985 to 750 ppm (due to root biomass and leaf-fall from medics, and biological N fixation);
- Lentil, a short-growing crop, which is pulled from the roots in harvesting, had no effect on either organic matter or N;
- In the fallow/wheat rotation, total organic matter declined (14%) but N remained constant;
- Stocking rates had no differential effect on soil properties;
- Yields from continuous wheat decreased with time;
- Cereal yields after medic were reduced due to a depletion effect of medic on soil moisture.

Barley rotation

Following a re-examination of the trial in the light of results obtained, and considering the greater adaptability of barley to the prevailing drought conditions, it was decided to modify the trial to replace wheat with barley. Other changes included an expansion of vetch rotation management to include grazing, cutting for hay, and being left for seed production. The watermelon rotation (essentially fallow) was dropped, while the continuous barley, fallow, lentil, and grazed medic rotations were retained. In addition, vetch treatments were expanded to consider all possible options: grazing, hay and seed production. This time N was held constant at 60 kg/ha in addition to the non-fertilised control.

Another major modification in the modified barley trial was the use of intensive soil analyses to monitor soil moisture and temperature and to assess changes in total, labile, and biomass fractions of N and C on a yearly basis and, in some years, within the season.

Yield Observations

Data for 3 years are presented to illustrate yield trends for both grain and straw in relation to the rotations with and without N (Table 1). The data reflect and are consistent with observations on yield from the initial wheat phase. However, this time there was a consistent response to N as most years in the barley rotation had generally higher rainfall than in the wheat rotation. In all cases, regardless of the year and the rotation, yields were consistently higher with added fertiliser N. As anticipated, yield levels were related to seasonal rainfall.

Table 1. Yield data from the rotations.

Rainfall (mm)	Year	Barley +N	Barley -N	Fallow +N	Fallow -N	Medic +N	Medic -N	Vetch +N	Vetch -N
		t/ha							
		GRAIN							
416	97/98	1.4	0.3	3.0	1.8	2.6	1.8	3.1	2.6
311	98/99	1.3	0.9	2.5	1.5	2.5	1.9	2.8	2.1
249	99/00	0.9	0.8	2.7	1.9	1.3	1.4	1.7	1.9
Mean		1.2	0.7	2.8	1.7	2.1	1.7	2.6	2.2
		STRAW							
416	97/98	1.3	0.3	3.0	1.8	2.6	1.8	3.1	2.6
311	98/99	0.6	0.3	3.2	1.7	3.3	2.3	3.5	2.3
249	99/00	0.8	0.1	2.4	1.6	1.2	1.2	1.5	1.5
Mean		0.9	0.4	2.9	1.7	2.4	1.8	2.7	2.1

Of major interest was the rotation effect. Again, as observed in the initial wheat phase and in other parallel trials, continuous cereal cropping yielded least in terms of grain and straw; without N, yields were considerably less than a ton and in most cases not even justifying harvesting. While fallow cereal yields were higher, they were only marginally better than those with the medic and vetch rotation. On average, cereal yields after vetch were higher than those after medic. As the discrepancy between the N fertilised and non-fertilised treatments was less in the two legume rotations than in the fallow one, this clearly indicates the residual condition of the legumes to the N supply for the following cereal crop.

Soil Properties

The major soil properties, especially organic matter and total N were differentially influenced by the different rotations (Table 2). Organic matter was, on average, highest with the forage legume rotation, intermediate for fallow, and least for the continuous barley rotation. Within any rotation, the addition of N to the cereal phase increased organic matter levels, especially for continuous barley and fallow.

Total N values followed the same patterns as organic matter. For example, the N values for the non-fertilised treatment were 561, 624, 741, and 752 ppm for the continuous barley, fallow, vetch, and medic rotations, respectively. Values for the fertilised treatments were consistently higher.

Table 2. Organic matter, total and mineral N in surface (020 cm) samples.

Parameters	Barley		Fallow		Medic		Vetch	
	+N	-N	+N	-N	+N	-N	+N	-N
	---%-------------------------------------							
Organic Matter	1.01	0.86	1.18	1.02	1.25	1.23	1.26	1.18
	---%-------------------------------------							
Total N	629	561	714	624	761	752	753	741
Mineral N	4.0	3.6	5.0	4.5	3.7	4.8	4.6	4.2

These data again are consistent with the two legumes, medic and vetch, supplying N to the soil through biological N fixation. Mineral N (ammonium and nitrate) values were relatively small (< 5 ppm) compared to total N values and showed no consistent differences either between rotations or with N fertilisation. Labile N is that fraction of total N (mainly organic) that is potentially mineralisable and thus related to the soil N supply. Not surprisingly, this fraction corresponds with trends for total N, again with clear differences between rotations (Figure 1) and reflecting the effect of N fertilisation (except the vetch rotation where the lack of added N is compensated by N fixation by the vetch crop).

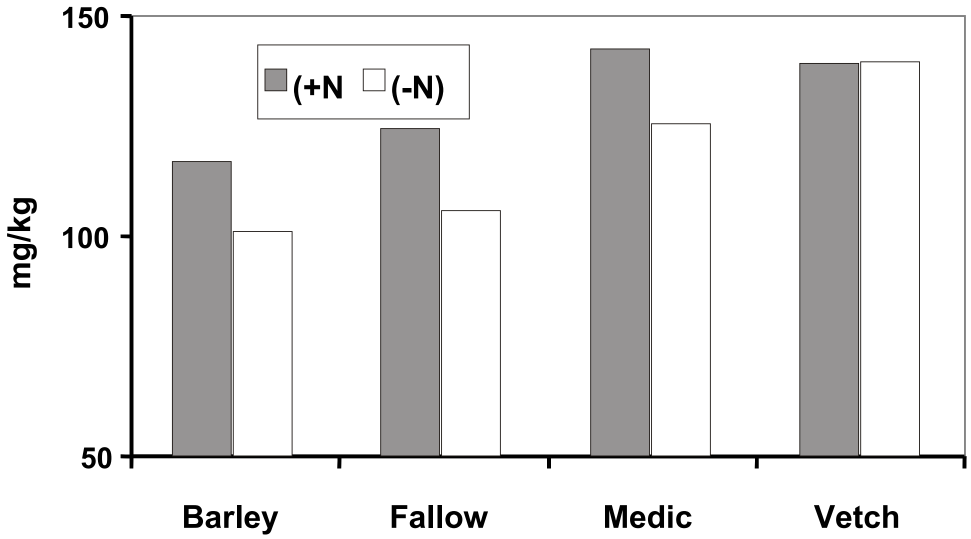

Figure 1. Labile nitrogen in soil samples from fertilised and non-fertilised rotations in the 1999/00 cropping season.

Within-Season Changes

Mineral N values within the growing season could be expected to change with time, mainly due to mineralisation, a process that converts some of the organic N pool to ammonium (and then nitrified to nitrate). In essence, it adds to the pool of plant available N and is controlled by two main factors, temperature and moisture.

As soil moisture is generally adequate for mineralisation in the late fall and early spring, temperature is the dominant influence on both, mineralisation and plant growth. Significant mineralisation can be expected to occur where soil temperature is at least 10°C. Idealised temperature regimes throughout the season are depicted (Figure 2).

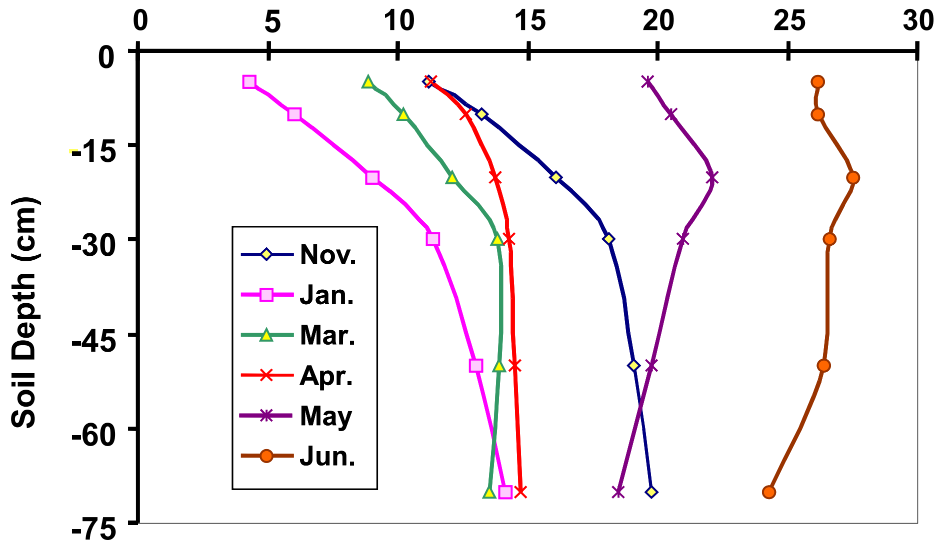

Figure 2. Minimum profile soil temperatures throughout the 1998/99 cropping season**.**

In the sampled rotations, the influence of mineralisation was not very evident, largely because the values from the periodic analyses are net mineral N values, reflecting N added to the available N pool by mineralisation and N taken from the pool as uptake by the growing crop. Nevertheless, it is apparent (Table 3) that net values increased from March onwards, particularly in the case of continuous barley and fallow. In retrospect, mineralisation could be more reliably measured in bare non-cropped plots and with an exchange resins, those eliminating the uptake and immobilisation factors.

Table 3. Soil mineral N changes within season.

Month	Barley		Fallow		Medic		Vetch
	+N	-N	+N	-N	+N	-N	+N
	ppm						
Jan	5.1	3.7	4.6	3.2	5.2	4.5	5.6
Feb	4.4	4.6	3.9	4.0	5.2	5.5	5.4
Mar	13.9	4.2	4.6	4.7	6.0	6.7	4.2
Apr	9.4	3.4	7.5	5.6	4.7	4.6	4.1
July	9.5	4.6	8.7	7.1	8.0	6.2	6.1
Mean	8.5	4.1	5.9	4.9	5.8	5.5	5.1

Yearly Trends

Since the beginning of the trial, differences in organic matter levels (Figure 3) and total N (Figure 4) were evident. Continuous barley was consistently lowest, followed by fallow, with the medic and vetch rotations relatively similar and higher. Notwithstanding the variability between years, which is largely due to sampling variability and also to a seasonal effect, some trends are obvious. A trend for increasing values from 1985 to 1995 is evident for both parameters. Subsequently, a plateau or equilibrium seems to appear. The apparent decrease after 1995 may be an artifact, reflecting differences in sampling, as post 1995 sampling was done by a different technical support staff. The seemingly stable values from 1995 onwards suggest that little further change is likely to occur.

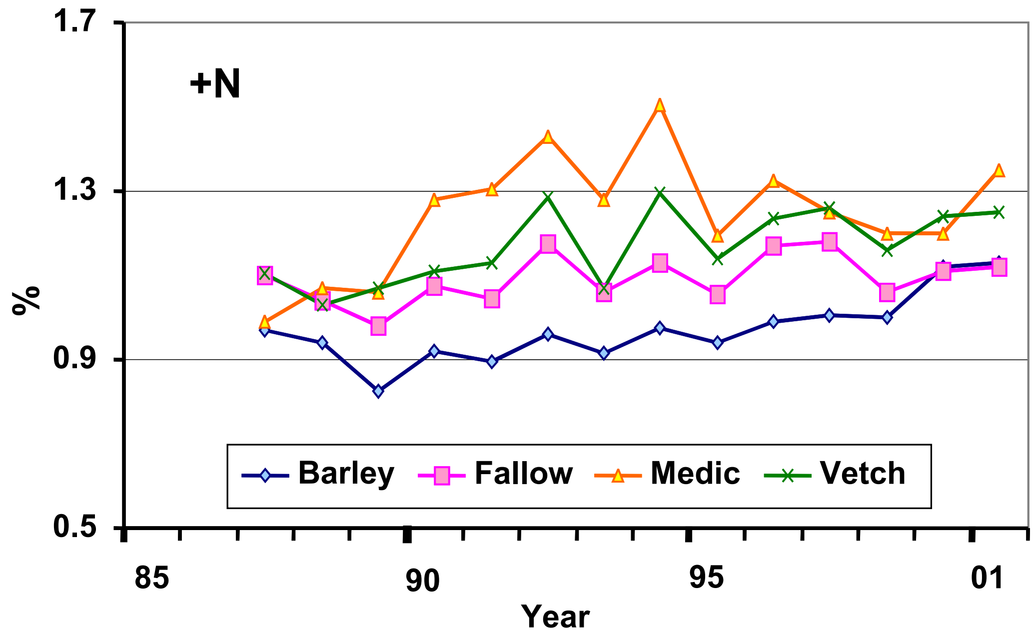

Figure 3. Mean organic matter levels throughout the course of the trial.

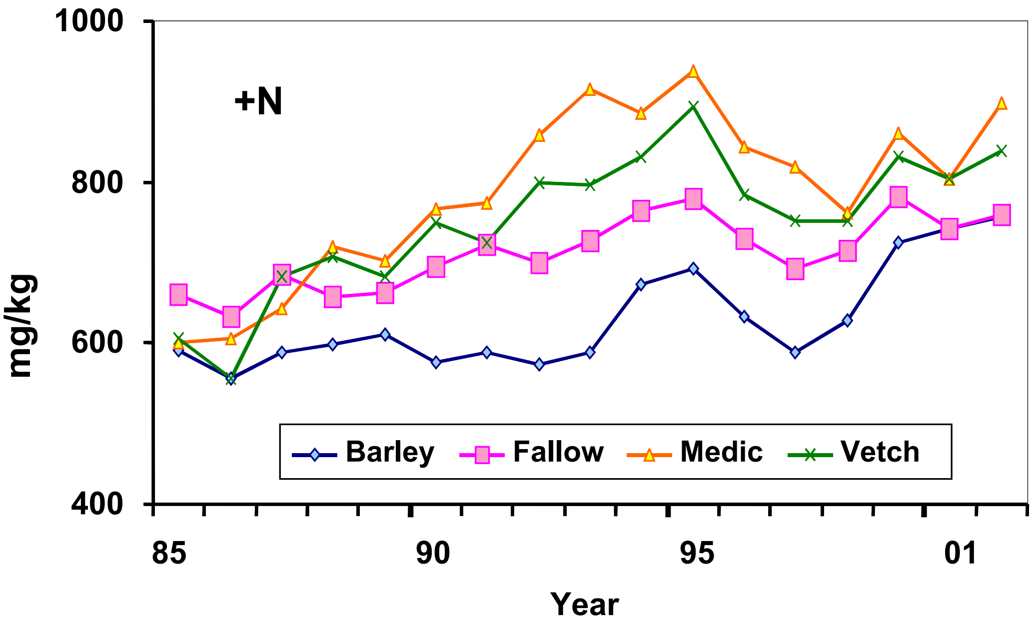

Figure 4. Mean total soil nitrogen values throughout the course of the trial.

Conclusions

Though the trial described is large, complex, and ongoing, a few main conclusions can be made from the data so far.

- Forage legumes in rotation with barley offer a viable alternative to fallow or continuous barley in the Mediterranean environment; such a rotation produces more total biomass and sustains more animal productivity. The use of sheep in the system promotes greater income stability for farmers.
- While medic, as a self-regenerating legume, has advantages in the legume/barley system, it is unlikely such as difficulty in establishment maintenance of the seed bank in the soil and uncertainly of seed supply to be adopted widely by farmers in the Mediterranean region for practical reasons. In addition, it has a negative effect on the succeeding cereal crops due to moisture depletion as compared with vetch.
- Vetch, whether for grazing or cut for hay, is the ideal forage legume in rotation with barley. Vetch is already being adopted by farmers in northern Syria and elsewhere with considerable success.
- Biomass and N values, along with C/N ratios, were too variable to draw any definitive conclusions.
- Forage legumes in rotation with barley also enhance soil quality, resulting in a build-up of soil N, which reduces the need for N application in the cereal phase, and organic matter as reflected by increases in total, labile, and microbial biomass C forms. The increased organic matter is associated with improved soil aggregate stability.
- The legume/cereal system not only enhances and stabilises crop production, but it also increases C sequestration and thus mitigates the adverse effect of global warming from atmospheric carbon dioxide gas.
- Differences between N and C forms following legumes were not as pronounced as from the adjacent wheat-based rotation trial. With time, such differences may be accentuated.
- There was, as yet, no consistent effect of different management of the vetch in relation to cereal yields and soil properties.
- While lentil is profitable in the rotation, its impact on the cereal crop and soil properties is least of the alternatives, being just above continuous barley.
- As with any long-term rotation trial, several years may be necessary before the effect of all cropping management becomes evident; this is especially true in Mediterranean environments where biomass inputs are low and where moisture and temperature dictate the extent of organic matter accumulation.

References

Christiansen, S., M. Bounejmate, F. Bahhady, E. Thomson, B. Mawlawi, and M. Singh. 2000. On-farm trials with forage legumebarley compared with fallowbarley rotations and continuous barley in northwest Syria. Expl. Agric., 36: 195204.

Cocks, P.C., and E.F. Thomson. 1988. increasing feed resources for small ruminants in the Mediterranean Basin. p. 51-66. In E.F. Thomson and F.S. Thomson (Ed.) Increasing Small Ruminant Productivity in Semi-arid Areas Kluwer Academic Publ., Dordrecht, The Netherlands.

Cooper, P.J., and P.J. Gregory. 1987. Soil water management in the rain-fed farming systems of the Mediterranean region. Soil Use & Manage., 3(2): 5762.

Cooper, P.J.M., P.J. Gregory, D. Tully, and H.C. Harris. 1987. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Expl. Agric. 23: 113158.

Harris, H. 1994. Water-use efficiency in crop rotations in a Mediterranean environment. Aspects of Applied Biology 38: 165172.

Harris, H.C. 1995. Long-term trials on soil and crop management at ICARDA. Adv. Soil Sci. 19: 447469.

Harris, H.C., J. Ryan, T.T. Treacher, and A. Matar. 1995. Nitrogen in dryland farming systems common in northwestern Syria. p. 323335. In J.M. Powell, S. Fernandez Rivera, T.O. Williams, and C. Renard (Ed.) Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa. Vol. 11. Technical papers. Proceedings of an international conference hold in Addis Ababa, Ethiopia. International Livestock Centre for Africa, Addis Ababa, Ethiopia.

Jones, M.J., and M. Singh. 1995. Yields of crop dry matter and nitrogen in long-term barley rotation trials at two sites in northern Syria. J. Agric. Sci. (Camb.), 124: 389402.

Jones, M.J., and M. Singh. 2000. Long-term yield patterns in barley based cropping systems in northern Syria. I. Comparison of rotations: J. Agric. Sci. (Camb.), 135: 223236.

Kassam, A.H. 1981. Climate, soil, and land resources in the West Asia and North Africa region. Plant & Soil 58: 1028.

Keatinge, J.D.H., N. Chapanian, and M.C. Saxena. 1988. Effect of improved management of legumes in a legume-cereal rotation on field estimates of crop nitrogen uptake and symbiotic nitrogen fixation in northern Syria. J. Agric. Sci. (Camb.) 11: 651-659.

Osman, A.E., M.H. Ibrahim, and M.A. Jones (Ed.). 1990. The Role of Legumes in Farming Systems of the Mediterranean Areas. Kluwer Academic Publ., Dordrecht, The Netherlands.

Papastylianou, I. 1993. Productivity and nitrogen fertilizer requirements of barley in rotation system in rainfed Mediterranean conditions. Eur. J. Agron. 2: 119129.

Ryan, J. 1998. Changes in organic carbon in long-term rotation and tillage trials in northern Syria. p. 285295. In R. Lal, J. Kimble, R. Follett, and B.A. Stewart (Ed.) Management of Carbon Sequestration in Soil. Adv. Soil. Sci. CRC, Boca Raton, Florida.

Ryan, J., and M. Abdel Monem. 1998. Soil fertility management for sustainable production in the West Asia North Africa region: need for long-term research. p. 155174. In R. Lal (Ed.) Soil Quality and Agricultural Sustainablity. Ann Arbor Press, Michigan, USA.

Ryan, J., S. Masri, S. Garabet, J. Diekmann, and H. Habib. 1997. Soils of ICARDA's Agricultural Experiment Stations and Sites: Climate, Classification, Physical and Chemical Properties, and Land Use. ICARDA Tech. Bull., ICARDA, Aleppo, Syria.

Wahbi, A., A.E. Matar, and M.J. Jones. 1993. Responses of a forage hay crop to the residual effects of nitrogen and phosphorus fertilizers in on-farm trials in northern Syria. Expl. Agric., 29: 429435.

White, P.F., N.K. Nersoyan, and S. Christiansen. 1994. Nitrogen cycling in a semi-arid Mediterranean region: Changes in soil N and organic matter under several crop/livestock production systems. Aus. J. Agric. Res. 45: 12931307.