Linking Research and Marketing Opportunities for Pulses in the 21st Century

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The Role of Legumes in Sustainable Cereal Production in Rainfed Areas

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Abstract

Cool season food legumes (CSFL) are minor crops compared to cereals, but they are important in farming systems, in human and animal nutrition and as a source of biological N. They protect the soil from erosion, add organic matter, fix nitrogen and spare soil mineral N as well as helping control cereal diseases. They provide more flexible weed control options. Two major factors may lead to the increased use of cool season food legumes in cereal based cropping systems. The first is the demand for grain with a high protein content and other nutritional factors, for human and animal consumption. The second is the realisation of their importance as a "break" crop in continuous non-legume cropping systems.

The contribution of pulses to increased cereal production will come from a better understanding of rotations and production packages, better information on the residual effects of legumes, development of simulation models to predict these effects and the enhancement of biological N_2 fixation. The pulses themselves require continued support to develop better disease resistance, higher yields, better fashioned cultivars for specific cropping environments, technological packages and extension support and ,more sophisticated local and international marketing strategies. Cereal-legume rotations enable the use of different herbicides in the respective crops and reduce the risk of herbicide resistance in weeds.

INTRODUCTION

Sustainable agriculture has become a concern all over the world in the last decade because of the increasing degradation of natural resources, low commodity prices leading to low-input systems and concern about food quality and the welfare of rural life. Sustainable agriculture systems are designed to use existing soil nutrient and water cycles, and naturally occurring energy flows to produce food and feed that is nutritious and harmless to human and animal health. In practice, such systems should rely on crop rotations, crop residues, animal manure, legumes, green manure, off-farm organic wastes, mechanical cultivation, and mineral bearing rocks to maintain soil fertility and productivity, and on natural biological and cultural controls for insects, weeds, and other pests (MacRae et al., 1990).

Cool season food legumes (CSFL) are minor crops, compared with cereals, but are important for human and animal nutrition and as a source of biological N. The ability to fix N_2 enables them to grow on low-N soils and to produce seed high in protein. They provide nutritionally rich crop residues for animal feed; and play a key role in maintaining the productive capacity of soils with their N fixation (Hamblin, 1987; Beck and Materon, 1988; Osman et al. 1990) and by breaking disease and pest cycles (Papendick et al. 1988). Legumes ideally should comprise 30-50% of the cropland (Parr et al., 1983).

RECENT TRENDS IN PULSE PRODUCTION

Although the production of pulses in WANA and South Asia has increased over time (Table 1) supply has fallen short of demand, resulting in high prices and the need to import about 1.3 million MT (FAO, 1994a). As can be seen from Table 1, the area of all pulses in the region of WANA, South Asia, including Pakistan, and Oceania (Australia and New Zealand) covers about 50% of the world area under pulses, and

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40% of world production of pulses. However for CSFLs, this proportion increases significantly to 60% of total world area. The area of pulses and CSFLs worldwide increased by 12% and 10% respectively between 1979-81 and 1989-91, and production by a remarkable 38% and 45% respectively. Since then, there has been little change to CSFLs in the world. Regional increases in area and production of these crops are higher than that of the world figures since 1979-81 (Table 1). However, irrespective of their contribution to the farming systems, all pulses including the CSFLs have not assumed their rightful place. Their area and production has increased very little relative to cereals since 1979-81(Table 2).

Table 1 Regional distribution of area and production of cereals, pulses, CSFLs and wheat with barley

Cereals	(Area, 1000 ha))			(Production, * 1000 MT))		
Region	1979-81	1989-91	1993-95	1979-81	1989-91	1993-95
N. Africa	20640	22971	24712	23812	33641	35370
W.Asia	31029	31127	35667	44688	55125	64327
S.Asia	128981	128978	126508	182135	252603	270053
Oceania	16197	12995	13957	21974	22207	23655
Region total	196847	196071	200844	272609	363576	393404
World	717137	708039	695198	1573337	1901136	1915903
% of world	27.4	27.7	28.9	17.3	19.1	20.5
Wheat +Barley	(Area, * 1000 ha)			(Production, * 1000 MT)		
N. Africa	10803	12383	11293	10216	17574	15599
W.Asia	27246	31251	32556	38133	47468	55339
S.Asia	32077	34153	35451	48753	71059	79571
Oceania	14134	11063	11906	18310	18055	19614
Region total	84260	88850	91206	115412	154156	170123
World	316135	301591	291989	591333	729118	701633
% of world	26.7	29.5	31.2	19.5	21.1	24.2
Pulses	(Area, * 1000 ha)			(Production, * 1000 MT)		
N. Africa	1801	1825	1983	1723	1766	1789
W.Asia	1452	3257	3293	1439	2640	2889
S.Asia	25583	26260	26768	11928	14876	15636
Oceania	235	1522	1975	259	1596	2089
Region total	29071	32864	34020	15349	20878	22403
World	60754	68285	68802	40628	55949	56888
% of world	47.9	48.1	49.4	37.8	37.3	39.4
CSFL	(Area, * 1000 ha)			(Production, * 1000 MT)		
N. Africa	1421	1290	1231	1417	1347	1161
W.Asia	867	2524	2583	838	1974	2199
S.Asia	10487	10315	10338	6067	7123	7177
Oceania	96	615	661	147	698	756
Region total	12871	14744	14813	8469	11142	11293
World	23089	25467	24529	19818	28770	27564
% of world	55.7	57.9	60.4	42.7	38.7	41

Source FAO Production Year Book 1994 1995

There has been a significant increase in the areas under pulses in Australia and Turkey, over the last two decades (FAO, 1994b; FAO, 1995). While the area in Turkey decreased slightly over the last 5 years, in Australia, the area has increased from almost nothing in the mid 1970s to about 2 million hectares now (Siddique and Sykes, 1997)

Table 2. Area and production of pulses and CSFL as percentage of cereals, and CSFL as percentage of pulses and wheat+barley

	Pulses area (% of cereals)			Pulses production (% of cereals)		
Region	1979-81	1989-91	1993-95	1979-81	1989-91	1993-95
N. Africa	8.7	7.9	8.0	7.2	5.2	5.1
W.Asia	4.7	10.5	9.2	3.2	4.8	4.5
S.Asia	19.8	20.4	21.2	6.5	5.9	5.8
Oceania	1.5	11.7	14.2	1.2	7.2	8.8
Region total	14.8	16.8	16.9	5.6	5.7	5.7
World	8.5	9.6	9.9	2.6	2.9	3.0
	CSFL areas (% of cereals)			CSFL production (% of cereals)		
N. Africa	6.9	5.6	5.0	6.0	4.0	3.3
W.Asia	2.8	8.1	7.2	1.9	3.6	3.4
S.Asia	8.1	8.0	8.2	3.3	2.8	2.7
Oceania	0.6	4.7	4.7	0.7	3.1	3.2
Region total	6.5	7.5	7.4	3.1	3.1	2.9
World	3.2	3.6	3.5	1.3	1.5	1.4
	CSFL areas (% of pulses)			CSFL production (% of pulses)		
N. Africa	78.9	70.7	62.1	82.2	76.3	64.9
W.Asia	59.7	77.5	78.4	58.2	74.8	76.1
S.Asia	41	39.3	38.6	50.9	47.9	45.9
Oceania	40.9	40.4	33.5	56.8	43.7	36.2
Region total	44.3	44.9	43.5	55.2	53.4	50.4
World	38	37.3	35.7	48.8	51.4	48.5
	CSFL areas(% of wheat+barley)			CSFL production (% of wheat+barley)		
N. Africa	13.2	10.4	10.9	13.9	7.7	7.4
W.Asia	3.2	8.1	7.9	2.2	4.2	4
S.Asia	32.7	30.2	29.2	12.4	10	9
Oceania	0.7	5.6	5.5	0.8	3.9	3.9
Region total	15.3	16.6	16.2	7.3	7.2	6.6
World	7.3	8.4	8.4	3.4	3.9	3.9

PROBLEMS RESULTING FROM CONTINUOUS CEREAL PRODUCTION

There is increasing concern about the deterioration of crop/livestock systems because of the pressure put on them by the ever-rising demands for food and feed. Continuous cereal systems are increasing in parallel with the increasing demands for food from humans and feed by animals in the regions of WANA and South Asia (Harris et. al., 1991; Jones, 1993; Harris, 1994; Paroda et al., 1994).

Cereal-fallow or continuous cereal cropping are the common rotations in the WANA region, but the inclusion of legumes has been accompanied by many benefits. For example, the organic matter content of the soil has been increased under wheat-legume systems compared to continuous wheat or wheat-fallow systems (FRMP, 1993; Masri, 1996). The inclusion of legumes in the crop rotation in the WANA region has alleviated problems created by replacing a 'fallow-cereal' rotation with a 'continuous cereal', such as the build-up of noxious weeds, pests and pathogens, and an accumulation of allelopathic compounds. For example, continuous cereal production leads to yield decline accompanied by cereal cyst nematode (*Heterodera avena*), soil-inhabiting fungi such as *Cochliobolus sativus* syn. *Helminthosporium sativum,* take-all diseases (*Gaeumannomyces graminis* var. *tritici*) and wheat ground beetle (*Zabrus tenebroides*) (Saxena et al., 1991, Harris, 1994).

The high input rice-wheat cropping systems in the Indo-Gangetic Plain of India are reaching productivity limits, and the edaphic resource base is under threat of degradation (Paroda et al., 1994). Evidence for this includes the plateauing of rice and wheat yields in regions of high productivity, declining organic matter and productivity of soils, increasing salinity, and build-up of pests, diseases and weeds (Hobbs and Morris, 1996). Many of the maladies associated with continuous rice-wheat cropping are yet to be precisely diagnosed (e.g. soil chemical, physical and biological factors).

Similarly in Australia, farming practices prior to the 1970s traditionally centred around wheat/sheep enterprises in which cereals were rotated with legume-based pastures in a ley farming system (Greenland 1971). Typically, 3-5 years of a pasture containing subterranean clover, medic, lucerne and grasses was followed by a crop of oats, then by several years of wheat to conclude with a crop of wheat or barley undersown with pasture. Such a long cereal cropping phase obviously became unsustainable in terms of the supply of nutrients such as N and by the perpetuation of cereal diseases such as take-all (*G. graminis*), yellow leaf spot (*Pyrenophora tritici-repentis*) and crown rot (*Fusarium graminearum*). This dilemma was ultimately bought to a head in 1969 when Australian authorities introduced wheat quotas to prevent a potential overproduction of wheat. Farmers were then quick to look for profitable alternative crops to fill the void. This resulted in a new era of farming in Australia whereby broad-leaf crops became accepted and more widely grown in rotation with cereals in a more sustainable and profitable manner (Farrington, 1974; Gladstones, 1975; Hamblin, 1987; and Robson 1994).

In the wet environmental conditions of the United Kingdom large amounts of take-all (*G.graminis*) in wheat-wheat and wheat-barley rotations have also caused significant yield losses (Prew et al. 1985;McEwen et al. 1989).

Soil erosion and the loss of soil organic matter and essential nutrients are increasing problems in all three regions. Legume cultivation to protect against erosion, add soil organic matter, fix atmospheric nitrogen, to spare soil mineral N, to eliminate cereal diseases, and to provide more flexible weed control options, offers a means of maintaining production and environmental resources in the face of ever-increasing crop intensification in less favourable areas.

ADVANTAGES OF LEGUMES IN CEREAL ROTATIONS

A. Increased Crop Yield

Increased cereal yields may well be one of the most practical justifications for having legumes in crop rotations (Prew et al. 1985; Armstrong, 1986a, 1986b; Saxena, 1988; McEwen et al., 1989; Mason and Rowland, 1990; Silsbury, 1990; Evans *et al.*, 1991; Karaca et al. 1991; Mitchell et al., 1991; Reeves, 1991; Hamblin *et al.*, 1993: Martin and Felton, 1993; Heenan *et al.*, 1994; Rowland *et al.*, 1994; Karlen et al., 1994; Harris, 1995; Saraf et al., 1997; and Yadav et al., 1997). The predominant consensus of all these reports is that crop rotation increases cereal yields and rotational profits, and allows for more sustained system of production. The following case studies highlight many of these points.

Karaca et al (1991) reported that wheat following lentil, chickpea and vetch provided yields that were nearer to those from wheat following fallow, and much better that wheat following sunflower and safflower, in a two-year crop rotation in highland areas of Turkey. Wheat after wheat was the most yield reducing sequence. Wheat yield following chickpea, lentil, vetch and fallow increased 68, 69, 75, and 80% respectively over the yield of wheat after wheat, respectively. Badaruddin and Meyer (1994) indicated that pulses had a positive effect on the subsequent wheat crop suggesting that they should be considered in higher moisture areas of the northern Great Plains to maintain crop productivity.

In an area of Syria with a Mediterranean-type climate, Harris (1995) obtained data over a seven-year period from 1985/86 to 1991/92 for a two-course rotation of wheat following either wheat, medic, chickpea, lentil, vetch, melon or fallow. Relative to the yield of wheat following wheat, the percentage increases in wheat yields followed these other crops were 39, 46, 82, 84, 119 and 126%, respectively. The highest yields (2.26 t/ha) were obtained from a wheat-fallow rotation, however this result must be credited to a two- rather than a one-year period, while the lowest yield (1.00 t/ha) was from wheat after wheat. The experiment is still running and the most recent results show very similar trends (Figure 1). Saxena (1988) reported that the grain yield of wheat following lentil, faba bean and dry pea was significantly higher than that of wheat following wheat under rainfall of about 340 mm in a Mediterranean-type climate. Large yield increases in the yield of barley following medic, vetch, faba bean and chickpea compared to continuous barley, and barley after oat or ryegrass were also reported in Cyprus (Papastylianou, 1988). Barley-vetch rotations are reported to be more productive than continuous barley or fallow-barley systems in northern Syria (Harris et al., 1991) and Cyprus (Papastylianou, 1993).

Results from a series of experiments on the typical Australian wheat rotation system, conducted at five sites, (Armstrong 1986a and 1986b) showed that wheat yields after lupin, pea or faba bean were 50-55% higher than wheat yields after wheat and gross margins were 137-153% higher in situations where no fertiliser was used (Figure 2). In Australia, a farmer's choice of the pulse to grow should be based on issues of local adaptation, farm infrastructure and marketing opportunities as the beneficial effects of the different pulses on the following wheat crop appear to be similar.

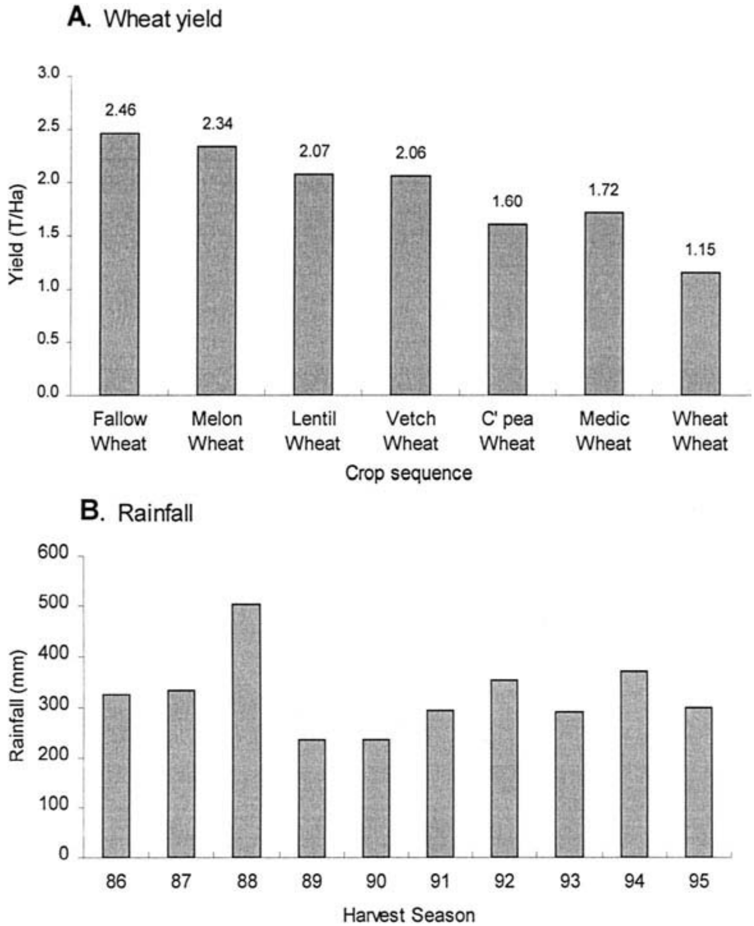

Figure 1. Mean grain yield of a wheat crop following various pulses in a two-course rotation study over a 10 year period (1986-95) at Tel Hadya, ICARDA Syria and (B.) annual rainfall incident over the same period.

B. Additions of Fixed Nitrogen

Nitrogen input is the single most limiting soil fertility factor constraining productivity and water-use efficiency of crops in dry areas. In N-deficient environments, the soil N-budget will be improved or at least the amount of N removed from the soil decreased (soil mineral N sparing) when well-managed nodulated legumes are grown in rotation with cereals. This has been well documented across many regions, including WANA (Beck and Materon, 1988; Saxena, 1988; Keatinge et al., 1988; Beck et al., 1991; Afandi et al., 1995), South Asia (Saraf et al., 1997; Yadav et al., 1997), and Australia (Evans et al., 1989; Armstrong et al., 1994; Herridge et al., 1994; Unkovich et al., 1997).

Build-up of inorganic soil-N following pulses is a direct consequence of both their N-fixation and their ability to spare soil mineral N during growth, and these amounts often equate to or exceed those of wheat-fallow rotations (Papastylianou and Jones 1989; Papastylianou 1993; Badaruddin and Meyer 1994; Rupela et al., 1995). The fertiliser replacement values (ie. the fertiliser N equivalent required by continuous cereal to equal the yield of cereal after legume with zero N) of various pulses have been reported to vary between 30 to 60 kg N/ha (McEwen et al., 1989; Papastylianou 1993; Saraf et al.1997).

However, N-fixation is affected by many factors, including legume biomass, efficiency of N_2 fixation, soil mineral-N, rhizobium strain and inoculation, water regime and soil and crop management. For example, root nodulation and N-fixation substantially decrease as both plant-available soil-N increases (Bergerson et al., 1989; Brockwell et al., 1989; Beck et al., 1991) and as water deficits become more severe (Kirda et al. 1989). N-fixation in legumes is generally proportional to biomass production, and as such, fixation commonly varies between 25-150 kg N/ha depending on environmental conditions and the inherent ability of the species/genotype to produce biomass (Beck and Materon, 1988; Evans et al., 1989; Beck et al., 1991; Saxena et al., 1993; Armstrong et al., 1994; Shwenke et al., 1997; Unkovich et al., 1997). In southern Australia, field pea and lupin crops are likely to fix around 18-20 kg N for each additional tonne of shoot DM produced per hectare (Evans et al., 1989; Armstrong et al., 1994). Therefore, given comparable levels of biomass and N_2 fixation efficiencies, chickpea; lentil, faba bean, pea, grass pea and chickpea should fix similar amounts of N and have comparable effects on subsequent crops (Papendick et al., 1988; Saraf et al., 1997; Yadav et al., 1997). In budgeting for the final residual N benefit of pulse crops, account has to be taken of the N exported from the system as either forage, hay, straw or grain.

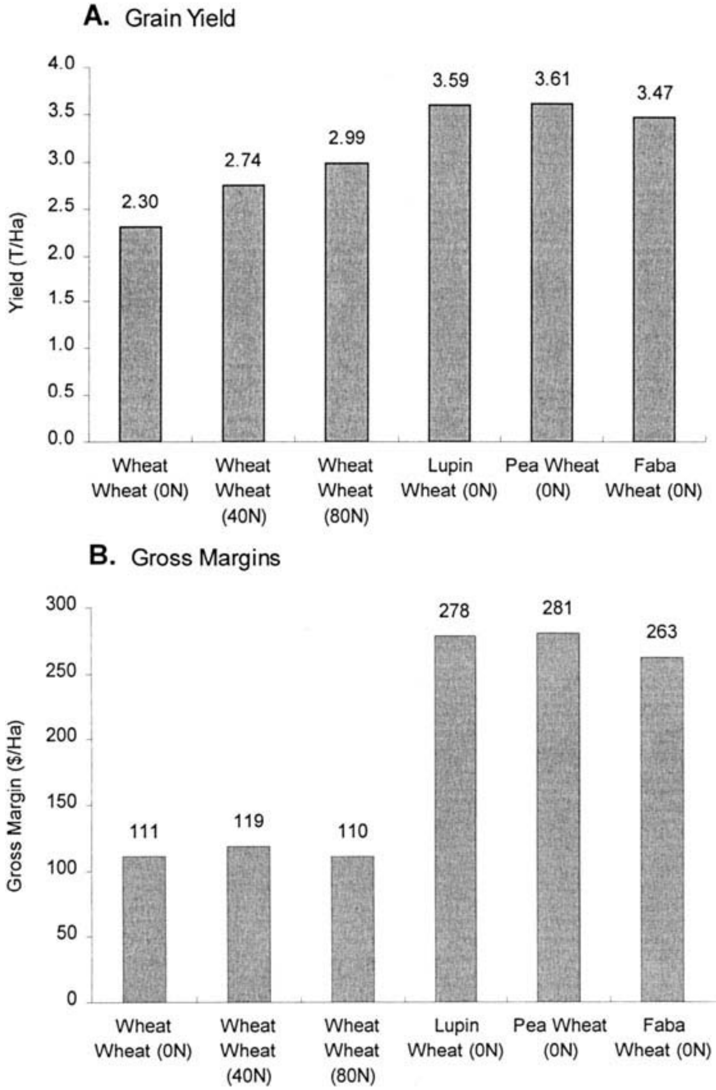

Figure 2 Yields (A.) and gross margins (B.) of wheat following crops of wheat, lupin, pea and faba bean. Trials were located at five sites in the Central West of NSW between 1984-86 and results here are presented as means across the sites. The continuous wheat plots were further divided in year 2 into 3 nitrogen treatments. Wheat on-farm prices per tonne of $130 and production costs per tonne of $188 were used in these calculations. N was costed at $1/kg and its spreading at $10/ha.

N_2 fixation efficiency can increase in cereal/legume intercrops as N_2 fixation of the legume component is stimulated by absorption of free soil mineral N by the cereal (Adu-Gyamfi et al. 1996). However, transfer of fixed N from the legume to the cereal in intercropping systems is more circumspect and undergoing closer scrutiny (Chalk 1996; Chalk and Smith 1997).

C. Reduction in cereal diseases and pests

The vastly superior performance of wheat after pulses compared to N-fertilised wheat after wheat reported by Armstrong (1986a and 1986b) suggests factors other than N nutrition can severely limit wheat productivity. In these case studies, the poor yields suffered in continuous wheat plots were due to the disease take-all (*G. graminis*), resulting in large proportions of unfilled spikelets (white heads). Only one season of a grass-free pulse crop was sufficient to break this disease cycle, allowing maximum expression of yield in the following wheat. This work also showed the use of fertiliser N on wheat may in some instances be unprofitable, particularly when factors such as disease, moisture or weeds are limiting performance. Therefore, despite fertiliser N increasing wheat yields by up to 30% in some instances, gross margins were largely unaffected due to extra costs of the fertiliser (Figure 2). Similar observations have been made at ICARDA Syria (Figure 3), where N applications to continuous cereal was more inefficient than N application to wheat following fallow or pulses. Well maintained bare fallows are as effective as pulses in breaking cereal disease cycles, however the land remains unproductive during this process, soils are more exposed to erosion and extra management and expenses incurred in eliminating weeds (Robson, 1990).

Unpublished work, by the main author, has shown that under conditions favouring severe infestations of wheat ground beetle (*Zabrus tenebroides*), yields of continuous wheat are reduced by up to four-fold compared to wheat after food or forage legumes.

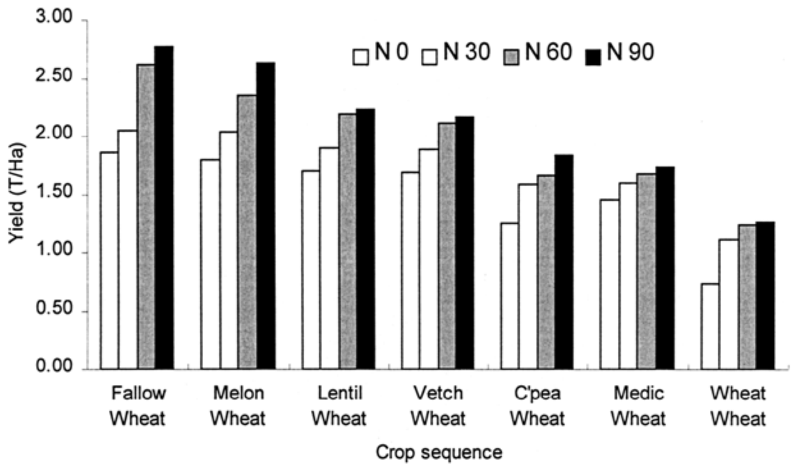

Figure 3 Mean grain yield of a wheat crop, given four rates of N and following various pulses in a two-course rotation study over a 10 year period (1986-95) at Tel Hadya, ICARDA Syria.