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The effect of fertilizer use on rain-fed barley: A case study from Syria

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ICARDA Social Science Papers

This is the eighth of the *ICARDA Social Science Papers*, a series which is intended to contribute to sustainable agriculture in the West Asia and North Africa (WANA) region.

ICARDA Social Science Papers present the results of on-going research both within the Center and in collaboration with national program partners in the region. The series is designed to disseminate findings widely to encourage discussion and comment on improved agricultural technologies, their use and benefits—including the sustainability of small-scale food-production systems. So this can be done as quickly as possible, the papers are not subject to the rigorous approval procedures of more formal publications. But each one is subject to peer review by a panel of ICARDA senior social scientists before publication.

The papers are intended to be more substantial in content than journal articles, and to present technical material so it is accessible to colleagues in all disciplines, including interested readers with general backgrounds in agriculture and economic development.

The papers are particularly aimed at scientists and researchers within the national agricultural research systems of WANA, the international research community, policy-makers, donors and international development agencies.

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Part of the work summarized here comprises the PhD study of one of the authors (A. Mazid), who is most grateful to Dr M. Seabrook of the University of Nottingham for his wise guidance; and to many other ICARDA colleagues for their advice and constructive comments over the years. Not least, the authors would like to acknowledge the invaluable contribution of a large number of Syrian farmers, without whose interest and generous cooperation this study would not have been possible.

1. Introduction

Chemical fertilizers were introduced to Syria during the 1950s. These fertilizers were used primarily on high-value irrigated crops such as cotton and vegetables. In the dry areas of Syria, barley and wheat cover the largest cultivated area. Barley is the most common crop and occupies the largest cropping area, while wheat is more important in higher-rainfall areas or where irrigation is available. Barley is grown using traditional practices and materials. Production and yields of barley show wide fluctuation due to the variability of rainfall within and between seasons.

In areas that receive 200–350 mm annual rainfall, the agricultural policy has encouraged farmers to shift from wheat to barley, which is better adapted to dry areas (Somel 1987). The shift of wheat production to wetter areas and the promotion of the use of improved technologies, including fertilizer application, has maintained the long-term yield growth of wheat, and, consequently, Syria became self-sufficient in wheat in 1991. Barley is currently the principal crop in the dry areas of Syria; it is grown primarily for livestock feed.

One of the tasks of the International Center for Agricultural Research in the Dry Areas (ICARDA) is to improve the productivity of basic food and feed commodities in the West Asia and North Africa (WANA) region. ICARDA holds the world mandate from the Consultative Group on International Agricultural Research (CGIAR) for barley improvement. There are many research dimensions to this. One dimension has been the breeding of improved varieties suitable for dry areas. Collaborative work with national programs has resulted in the release of some new barley cultivars, but their adoption and spread need to be monitored. Another dimension has been to improve the efficiency of crop water use. Research conducted by the Farm Resource Management Program (FRMP)[1] in ICARDA found that barley yields are low, not simply because of the low rainfall, but also because the poor soils in these areas prevent the efficient use of the rain that does fall. On many farmers' fields, only 15% of the rain received is used by the crop, the remainder being lost to evaporation from the soil surface (ICARDA 1983).

Diagnostic farm surveys on barley production (Somel et al. 1984) found that average barley yields were less than 1 t/ha, available phosphorus (Olsen-P) in the topsoil (0–20 cm) averaged 5.8 parts per million (ppm), 71% of the sampled barley fields had less than 6 ppm of Olsen-P, organic matter averaged less than 1% in the topsoil, and only about 10% of farmers used fertilizer on barley. Due to the low and variable rainfall, fertilizer use in these areas was perceived as risky, and supply and credit policies did not encourage its use (Mazid and Bailey 1992; Somel et al. 1992).

1 FRMP has now been incorporated into ICARDA's Natural Resource Management Program (NRMP).

Earlier studies (Mazid and Somel 1987) indicated that using fertilizer on rain-fed barley is profitable at the farm level and has potential for a positive impact at the national level in terms of grain and straw production and net revenue. Predictions of increases in these parameters due to fertilizer use in Zones 2 and 3[2] were estimated according to potential adoption rates, as in Table 1.

Table 1. Potential increase in national grain and straw production and net revenue due to fertilizer use on barley in the 1987 season.

Indicator	Adoption rate		
	50%	70%	90%
Grain (1000 t)	140.7	196.0	253.3
Straw (1000 t)	280.4	392.6	504.7
Net revenue (million SYP)	221.8	310.5	399.2

Source: Mazid and Somel (1987)

Farmers in Syria perceive using fertilizer on rain-fed barley as a new idea, because it was introduced to the dry areas only a few years ago. "Newness" of a technology need not only refer to new knowledge, or new persuasion; the innovation or new technology may not be new to people in general but, if has not yet been accepted by an individual, for that person it is a new technology (Mazid 1994).

The objectives of this paper are to document the effect of fertilizer use on rain-fed barley, appraise its impact and appropriateness, and estimate a diffusion model for that technology.

2. Generation of recommendations for fertilizer use on rain-fed barley

FRMP started by investigating the possibility of increasing the efficiency of crop water use through the application of fertilizer. Research-station trials showed that barley responds significantly to fertilizer, especially phosphate, even under low-rainfall conditions. Results from research-station trials over a range of years and sites showed that fertilizers increased water-use efficiency (defined as output per unit of water) by around 75% (Cooper et al. 1987; Shepherd et al. 1987). Two mechanisms are involved in this yield increase (Jones and Mazid 1988):

2 Syria has been divided into five agricultural stability zones according to average annual rainfall. The zones are defined in terms of suitability for rain-fed crop production, and to some degree the probability of rainfall. Zone 2: annual rainfall of 250–350 mm with not less than 250 mm during two-thirds of the monitored years; it is possible to get two barley crops in three years. Zone 3: annual rainfall of 250–350 mm with not less than 250 mm during half of the monitored years; it is possible to get one or two barley crops in three years.

1. A more rapid development of crop cover, so less water is lost by evaporation from the soil surface and, therefore, more is used by the crop, giving more dry-matter production;
2. A more rapid completion of the growth cycle, so that a greater proportion of that growth is achieved under the moderate temperatures and higher humidity of early spring; and the higher temperatures and higher evaporative demand in late spring are at least partly avoided.

In 1984, FRMP and the Soils Directorate (SD) of the Syrian Ministry of Agriculture and Agrarian Reform (SMAAR) initiated a collaborative project through multiple seasons, multiple location trials using a farming systems-research approach. The objective was to assess the biological responses and economic viability of fertilizer use on barley in dry areas. The history and details of the project have been described elsewhere (SD/FRMP 1985; 1990).

Trials on farmers' fields were conducted over a period of four years, to investigate whether the large yield response to fertilizer obtained on research stations could be reproduced under the highly variable soil and rainfall conditions that farmers face. The results obtained from this project were positive, and confirmed the results from research stations.

3. Impact of fertilizer use on rain-fed barley yields

The assessment of the impact of fertilizer use on rain-fed barley yields is reviewed under the following subjects: yield response, economic returns, yield gaps, fertilizer-response function, and risk involved in fertilizer application under a range of variable rainfall and economic environments.

3.1 Yield response

Seventy-five researcher-managed trials were conducted between 1984/85 and 1987/88 in northern Syria to assess the response of barley to nitrogen (N) and phosphate (P) fertilizers in farmers' fields. The trial sites represented a range of rainfall conditions, soil types, soil fertility, and cropping sequences (barley–barley and fallow–barley). Each site was characterized by environmental variables that could affect fertilizer response. Each trial comprised two replicates of the 16 factorial combinations of four rates each of N (0, 20, 40, and 60 kg N/ha) and P (0, 30, 60 and 90 kg P_2O_5/ha) fertilizers. For each trial, initial cultivation was done by the farmer, but the final seedbed was prepared by the research team immediately prior to sowing, and barley seed—local variety Arabi Aswad, treated with Vitavax (carboxin)—was sown at the rate of 100 kg/ha using an Oyjord plot planter. The P fertilizer and half of the N were drilled with the seeds. The remaining N was top-dressed at tillering stage. Weeds were controlled by a single application of bromoxynil at the time of top-dressing (Mazid and Somel 1987).

The trials were confined to agricultural stability Zones 2 and 3 and covered the Aleppo, Hama, Idleb, Raqqa, and Hassakeh provinces, which account for about 85% of the barley area in Syria, of which 60% is in Zones 2 and 3. At each site, soil analyses were conducted and weekly rainfall monitored. These experiments were supplemented by surveys of the cooperating farmers and nearby villages.

Agronomic analysis of the mean yields of grain and straw across the 75 researcher-managed trials showed highly significant responses to both nitrogen and phosphate fertilizers (Table 2). Seasonal rainfall, soil type, natural soil fertility, and crop sequence all had important effects on crop growth (Table 3). Of the 75 trials, 74 produced a significant grain or straw yield response to fertilizer, either to N or P or both (ICARDA 1989).

Table 2. Mean effect of fertilizer treatment over 75 sites on barley grain and straw yields (t/ha) and 1000-grain weight (g).

	N-fertilizer	P-fertilizer (kg P_2O_5/ha)				
	(kg N/ha)	0	30	60	90	Mean
						***
Grain	0	1.48	1.56	1.68	1.71	1.61
	20	1.57	1.82	1.93	1.93	1.81
	40	1.63	1.88	2.02	2.09	1.91
	60	1.64	1.98	2.08	2.19	1.97
				***		
	Mean	1.58	1.81	1.93	1.98	1.82
						***
Straw	0	1.83	1.99	2.15	2.24	2.05
	20	2.02	2.47	2.66	2.71	2.47
	40	2.22	2.67	2.93	3.14	2.74
	60	2.33	2.86	3.22	3.44	2.96
				***		
	Mean	2.10	2.50	2.74	2.88	2.56
						***
1000-grain weight	0	33.5	33.3	33.2	33.2	33.3
	20	32.7	32.4	32.3	32.2	32.4
	40	32.0	31.6	31.6	31.7	31.7
	60	31.6	31.1	30.9	31.0	31.2
				***		
	Mean	32.5	32.1	31.0	32.0	32.1

Standard error (±) of main treatment means: grain, 0.015; straw, 0.042; 1000-grain weight, 0.083. Analyses did not test for significance of N × P interactions.

*** Means are significant at $P < 0.001$.

Table 3. Summary of the percentage distributions of significant responses to N and P fertilizer as affected by main site factors.

Factor		No. sites	Grain		Straw	
			N	P	N	P
Rainfall (mm)†	<225	24	21	88	50	96
	225–300	29	52	52	76	79
	> 300	22	73	41	86	59
Zone	2	31	61	45	74	74
	3	44	39	70	68	82
Rotation	barley–fallow	54	44	65	65	81
	Continuous barley	21	57	48	86	71
Soil group	Gypsiorthid	14	21	86	36	100
	Xerochrept	36	64	53	89	72
	Calciorthid	18	39	61	72	89
Available P (ppm)	< 5.0	50	46	68	64	88
	5.1–8.0	19	37	53	79	68
	>8.0	6	100	17	100	33
Mineral N (ppm)	<8.0	22	68	55	91	68
	8.1–16.0	36	50	64	72	86
	>16.0	17	18	59	41	76

† Rainfall values are totals from mid-October to end of April.

In general:

1. The importance of N increased and that of P decreased with increasing rainfall, but response to N and P applied together increased with rainfall;
2. Nitrogen was more important under continuous barley cropping than in the fallow-barley rotation;
3. Phosphorus was most important, and N least important, in gypsiorthid soils as compared with calciorthid and xerochrept soils;
4. Initial soil status of available P (Olsen) and mineral-N influenced barley response to fertilizer.

Detailed agronomic analyses of the results from these trials are presented elsewhere (Jones, 1989; SD/FRMP 1990; Jones and Wahbi 1991).

3.2 Economic returns[3]

The researcher-managed trials were analyzed using a partial budget analysis of the four-year data set (Mazid 1989). Values of net revenue and marginal net benefit/cost

3 The analyses in this research took into account only the short-term financial returns on the investment in fertilizer and not the long-term costs and benefits to the natural-resource base.

ratios were compared for each fertilizer treatment among three groups of trials, using 1989 prices of grain, straw, and fertilizers (Table 4). Net revenue values indicate that fertilizer use on rain-fed barley is profitable in all treatments except (a) the low P rate without N ($P_{30}N_0$) in barley–fallow rotation in Zone 2; and (b) all N rates without P, except P_0N_{20}, in barley–fallow rotation in Zone 3.

Table 4. Calculated mean values of net revenue and marginal net benefit:cost ratio of Barley–Fallow (B–F) rotation, Zones 2 and 3 separately, and continuous barley (B–B).

Crop sequence/ Zone	N (kg/ha)	Net revenue (SYP/ha)				Net benefit:cost (ratio)			
		0†	30†	60†	90†	0†	30†	60†	90†
F–B Zone 2 (25 sites)	0	0	-66	545	71	0	<0	1.04	0.10
	20	-123	1076	1418	1168	<0	1.91	1.75	1.71
	40	455	1468	1992	2138	1.11	1.92	1.93	1.69
	60	653	1537	2180	2547	1.10	1.64	1.79	1.74
F–B Zone 3 (29 sites)	0	0	335	609	893	nd	1.17	1.15	1.16
	20	69	1269	1363	1448	0.33	2.18	1.69	1.41
	40	-54	897	1542	1898	<0	1.33	1.51	1.60
	60	-532	1205	1767	2315	<0	1.33	1.51	1.60
B–B all (12 sites)	0	0	216	133	214	nd	0.78	0.28	0.30
	20	977	1171	1648	1335	3.27	1.05	1.98	1.31
	40	1278	1913	2046	2091	2.59	2.36	1.97	1.66
	60	1562	2575	2597	2576	2.28	2.48	2.07	1.75

†Applied P_2O_5 (kg/ha).

3.3 Yield gaps

There were yield gaps between potential and actual farm yields, arising from biological and/or socioeconomic constraints (De Datta et al. 1978). In both Zones 2 and 3 there were substantial yield gaps between actual farm and researcher-managed trial yields during the 1984/85 to 1987/88 seasons (Figure 1). It appears that farm yield can be increased by around 114–168% in Zone 2 and 136–211% in Zone 3. Of this potential increase, 630–952 kg/ha in Zone 2 and 250–1017 kg/ha in Zone 3 are directly attributable to fertilizer use. The remainder of the potential increase is due to other management factors, such as land preparation, seed rate, rotation and use of a seed drill (Mazid and Somel 1987).

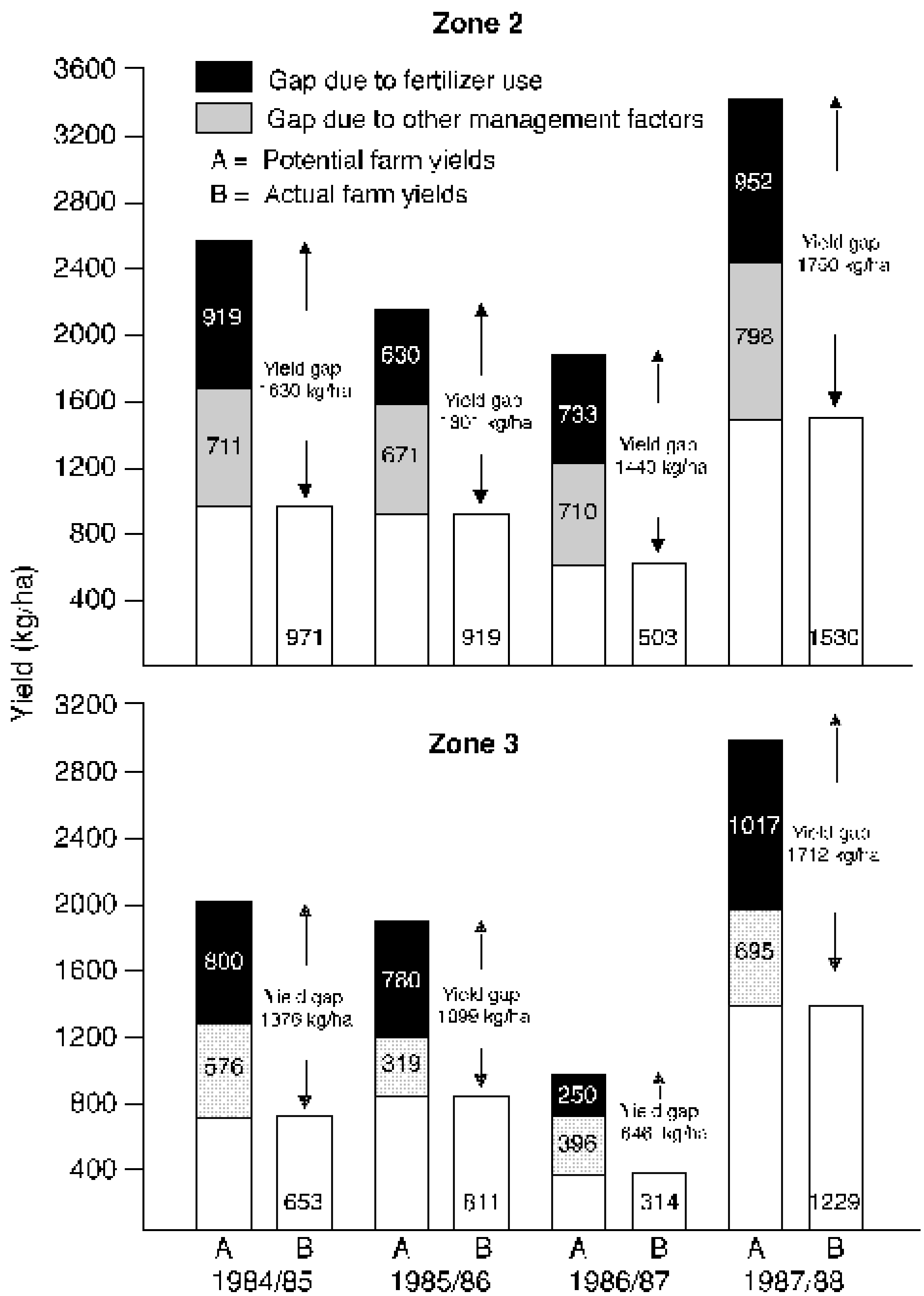

Figure 1. Yield gaps in barley grain yields, SD/FRMP trials.

3.4 Fertilizer-response function

Agronomic data were pooled across years and sites and the following response function was specified (Jones and Wahbi 1991):

$$Y = b_0 + b_1N + b_2P + b_3R + b_4N^2 + b_5P^2 + b_6R^2 + b_7NP + b_8NR + b_9PR \quad \textbf{(1)}$$

where Y = grain yield (kg/ha);
N = nitrogen applied (kg N/ha);
P = phosphate applied (kg P_2O_5/ha);
R = total seasonal (Oct–Apr) rainfall (mm).

Since there were significant rotation effects on response of barley to fertilizer, the response functions were estimated separately for barley–fallow rotation and continuous barley cropping (Table 5).

Table 5. Estimated response functions of barley to fertilizer.

Independent variables	Barley–Fallow		Continuous barley	
	Coefficient	SE	Coefficient	SE
N	–2.037	2.9888	0.289	3.755
P	7.556**	1.992	6.047*	2.503
R	22.459	0.860	24.945**	1.091
N^2	–0.0752*	0.035	–0.1117*	0.046
P^2	–0.0532**	0.016	–0.0408*	0.020
R^2	–0.0263**	0.001	–0.0310**	–0.001
NP	0.0632**	0.019	0.0263	0.024
NR	0.0299**	0.006	0.0506**	0.008
PR	0.0013	0.004	–0.00013	0.005
Constant	–2394.17**	152.66	–3238.14**	197.32
Adj. R^2	0.605		0.656	
F	294.0**		143.0**	

*, ** Significant at $P = 0.05$ and 0.01, respectively.

Economic optimal rates of N and P are found by maximizing the net gain to fertilizer use. Net gain is the difference between the value of output and the variable costs associated with fertilizer use. In this research, the prevailing price of barley grain was used to obtain the value of grain output. Variable costs associated with fertilizer use include the cost of the fertilizer, transportation and application. The cost of harvesting is also included because yields vary with fertilizer rate and, in Syria, most harvesting is done by combine harvesters at a cost in kind of 10% of the yield. Thus, net returns to fertilizer can be expressed as (Mazid and Bailey 1992):

Net Return, $Z = Q_y (Y - 0.1Y) - Q_nN - Q_pP$

$$= 0.9\, Q_yY - Q_nN - Q_pP \qquad \textbf{(2)}$$

where Q_y = price of barley grain,

Q_n, Q_p = cost/kg of nutrients N and P_2O_5, respectively, where costs include those of transport and application.

Economic optimum rates of N and P are those that maximize net return such that

$$0.9\partial F(N, P, R)/\partial N = Q_n/Q_y \text{ and } 0.9\partial F(N, P, R)/\partial P = Q_p/Q_y \qquad \textbf{(3)}$$

where F(N, P, R) expresses yield as a function of N, P, and rainfall R, as in Equation **(1)**, and Q_n/Q_y and Q_p/Q_y are the relative costs of N and P_2O_5, respectively. Thus, economic optimum rates of fertilizer are a function of relative costs and rainfall. Economic optima have been estimated for a range of relative costs and rainfall and are presented in Table 6 for the two rotations. The net benefit and benefit:cost ratios associated with the estimated optima are also given in Table 6.

Net benefit (BEN) is the change in net return from applying fertilizer compared with no fertilizer:

$$BEN = 0.9Q_y (Y_{np} - Y_{00}) - (Q_nN + Q_pP) \qquad \textbf{(4)}$$

where Y_{np} = yield (kg/ha) with fertilizer rates of N and P,

Y_{00} = yield without fertilizer.

Dividing by Q_y, one can express net benefit in kg/ha grain equivalents i.e., in terms of physical output:

$$BEN\ (kg/ha) = 0.9(Y_{np} - Y_{00}) - (\frac{Q_n}{Q_y} \times N + \frac{Q_p}{Q_y} \times P) \qquad \textbf{(5)}$$

The benefit:cost ratio (BCR) is the ratio of the change in net returns to the change in costs associated with applying fertilizer:

$$BCR\ (\%) = \frac{BEN}{(Q_nN + Q_pP)} \times 100 \qquad \textbf{(6)}$$

Optimal rates of N and P increase with rainfall and decline with relative costs (Table 6). Net benefit, for any given rainfall and relative cost, is higher under continuous barley cropping, except at the lowest rainfall (150 mm). This is because the optimal rates of N and P, and thus costs, are lower under continuous barley cropping, but the yield increase—the difference between fertilized and unfertilized yield—is higher.

Consequently, benefit:cost ratios also tend to be higher under continuous barley cropping.

Table 6. Estimated economic optima by rainfall and relative price.

Barley–Fallow

Relative price of N & P_2O_5	150	200	250	300	350	400	450
5	0 1. 16 29	0 20 22 22	11 29 39 15	25 37 55 18	38 46 100 24	52 55 64 31	66 65 247 39
4	0 31 46 37	13 40 57 27	27 48 87 29	40 57 135 35	54 66 202 42	68 74 283 31	81 83 393 69
3	5 51 95 48	29 59 128 43	43 68 180 54	56 77 250 63	70 85 340 73	83 94 443 84	97 103 575 95
2	31 70 178 88	45 79 254 94	58 88 308 105	72 96 401 119	85 105 513 134	99 114 643 51	113 123 792 68
1	47 90 298 217	60 99 375 236	74 108 472 260	88 116 587 288	101 125 72 319	115 134 874 352	128 142 1045 386

Rainfall (mm)

Continuous barley

Relative price of N & P_2O_5	150	200	250	300	350	400	450
5	12 10 14 13	23 13 54 29	35 17 120 46	47 21 213 63	59 24 333 80	70 28 479 97	82 32 653 115
4	18 25 46 27	30 29 101 43	42 33 183 61	54 36 292 81	65 40 427 101	77 44 589 122	89 48 778 142
3	25 41 101 51	37 45 172 70	49 49 269 92	60 52 393 116	72 56 544 141	84 60 722 167	96 63 926 194
2	32 57 179 101	44 61 265 127	56 64 378 157	67 68 517 191	79 72 684 227	91 76 877 263	103 79 1096 301
1	39 73 279 250	51 76 381 300	62 80 509 357	74 84 664 420	86 88 846 487	98 91 1054 558	109 95 1290 631

Rainfall (mm)

N P BEN BCR			
	N, P	=	economic optima for given rainfall and relative costs ;
	BEN	=	net benefit (kg/ha grain equivalents) from applying N and P;
	BCR	=	net benefit:cost ratio (%).

From the estimated response functions it was possible to determine optimal fertilizer rates. This analysis shows that using fertilizer on barley is profitable if the rate is appropriate. However, this analysis is essentially static and deterministic. Because the optimal rates vary considerably, depending on rainfall and relative prices, it is useful for making recommendations only when prices and rainfall can be specified.

3.5 Risk analysis

It is assumed that in the barley/livestock system in Syria, where barley is primarily an input into the livestock production system, farmers aim to maximize their output of barley, while at the same time minimizing the risk of loss of return on their investment in inputs (Mazid and Bailey 1992). In maximizing output, a farmer is minimizing the amount of supplemental feed otherwise needed. In modelling the response of barley to fertilizer use, barley grain was used as the measure of output. This does not mean that farmers are not interested in their straw yields; straw is an important additional source of feed in these areas and, especially in dry years, can have considerable market value. However, including straw would involve the estimation of joint production functions and greatly complicate the analysis. So, for the purposes of this study, attention is limited to barley grain.

Under the low and variable rainfall conditions prevailing in the area, farmers tend to minimize risk of financial loss by producing barley with the minimum of inputs. The adoption of fertilizer would therefore involve the investment of a farmer's limited capital resources in what is perceived as a risky and expensive input. A farmer is unlikely to accept a new technology unless he is assured of some minimum average return on his investment (Perrin et al. 1974). However, the minimum rate of return acceptable to a farmer is itself a function of his attitude toward risk.

According to Dillon and Hardaker (1984), it "is generally accepted that the rate of return to farmers on their working capital over the cropping season should be at least 40%, of which half is an allowance for risk." Perrin et al. (1974) acknowledge that the figure of 40% is a 'rule of thumb,' but it is consistent with behavior observed among farmers in less-developed agricultural areas with high yield variability. The minimum acceptable rate of return is likely to be higher. Thus, in subsequent analysis in this research, a minimum acceptable rate of return is taken to be 50% as a 'rule of thumb.'

The risk associated with applying fertilizer on barley in dry areas can be attributed to two sources: yield variability and price variability. Yield variability is a function of both environmental variability, primarily rainfall, and variability in agronomic conditions, including the rate of fertilizer applied. In Syria, prices of both fertilizer and barley grain are controlled by the state and, for the purpose of simplifying the model, are regarded as fixed; therefore, variability in rainfall is taken to be the main source of risk facing farmers.

Seasonal rainfall data for the years 1959/60 to 1985/86 from 25 meteorological stations in the barley-growing areas of Syria were used to estimate an expected rainfall for each of the 27 years. Substituting the estimated expected rainfall into the response function in Equation (1), yields were predicted for each of the 16 treatments in the trial for each of the 27 years. Then, based on these predicted yields, and using relative prices for 1989 for N and P_2O_5 of $\frac{Q_n}{Q_y} = 2.351$ and $\frac{Q_p}{Q_y} = 2.484$, net benefits and benefit:cost ratios were estimated according to Equations (5) and (6). The resulting cumulative distributions of net benefits for each treatment are shown in Figures 2 and 3 for barley–fallow and continuous barley. Means and standard deviations are given in Table 7.

In the barley–fallow rotation, net benefits from using P alone are low but highly stable as indicated by the near vertical distributions for N_0P_{60}, and N_0P_{90}. In contrast, use of N without P results in highly variable net benefits as shown by the slopes of the distributions for $N_{20}P_0$, $N_{40}P_0$, and $N_{60}P_0$ (Figure 2). Moreover, the higher the rate of N when P = 0, the higher the probability that net benefits will be negative. These three treatments also give the lowest mean returns. Similarly, under the highest rate of N and lowest rate of P ($N_{60}P_0$), there is about 18% probability that net benefits will be negative. These four treatments can therefore be eliminated from further consideration under the barley–fallow rotation.

Of the remaining treatments, net benefits increase with the various combinations of N and P, especially in response to increases in N (compare the distributions within each level of P in Figure 2). However, variability in net benefits, as measured by the standard deviation, also increases more or less linearly with increases in N and P (Table 7).

In continuous barley, the response function predicted negative yields at the lowest levels of rainfall, which lie outside the experimental range. When calculating net benefits, these negative yields were set to zero. In these cases, net benefits represent a 100% loss of investment in fertilizer, i.e., the benefit:cost ratio = –100%. As a result, all treatments display some probability (9–10%) of loss in net benefits (Figure 3). Otherwise, results are similar to those for fallow–barley but with some important qualifications.

The upper tails of the distributions, and the mean net benefits (Table 7) are much higher than under barley–fallow, particularly for the higher combinations of N and P. Again, net benefits from applying P alone are highly stable, but are lower than in barley–fallow and at the highest level of P (N_0P_{90}) they are negative over the full range of average annual rainfall. Applying N alone, on the other hand, is not as 'risky' as in barley–fallow (see $N_{20}P_0$, $N_{40}P_0$, and $N_{60}P_0$ in Figure 3 compared with Figure 2).

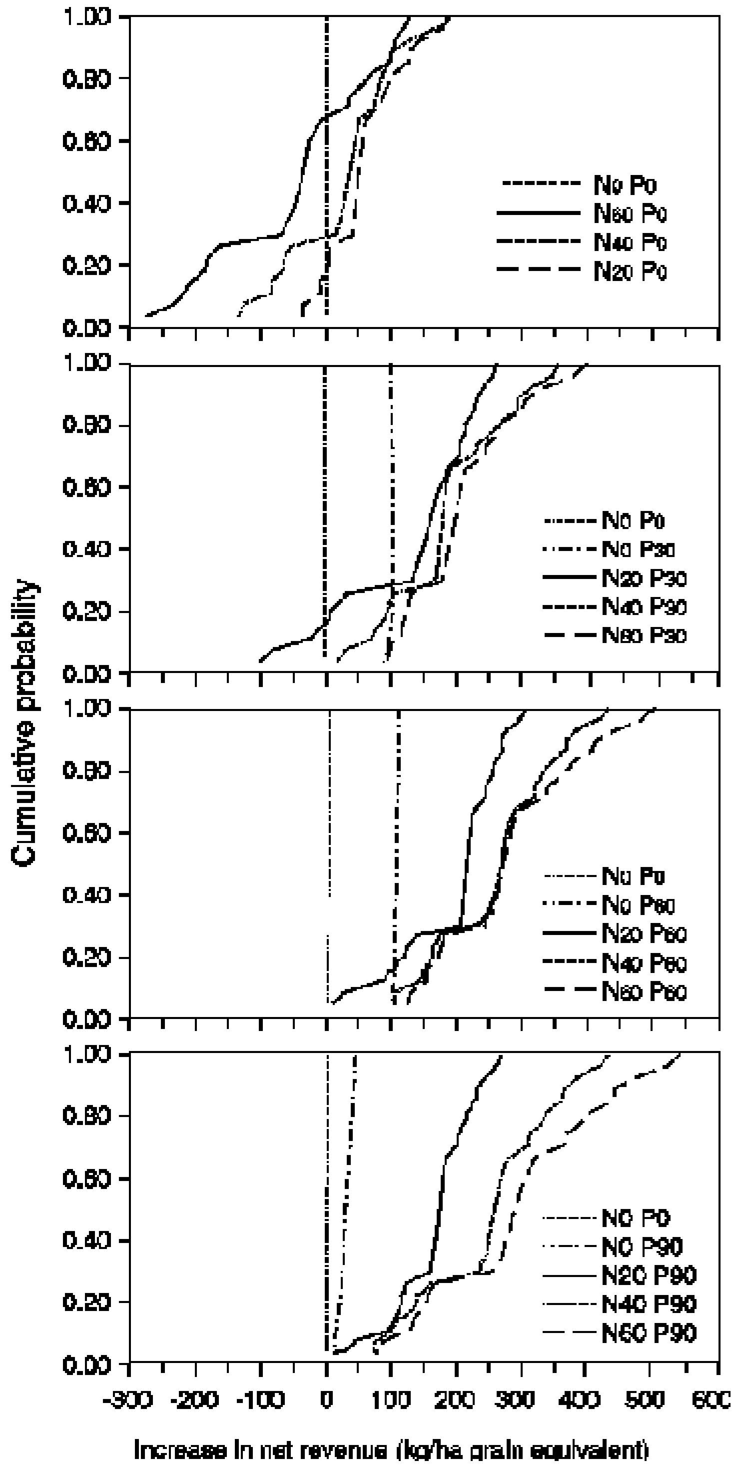

Figure 2. Cumulative distributions of net benefits, barley–fallow.

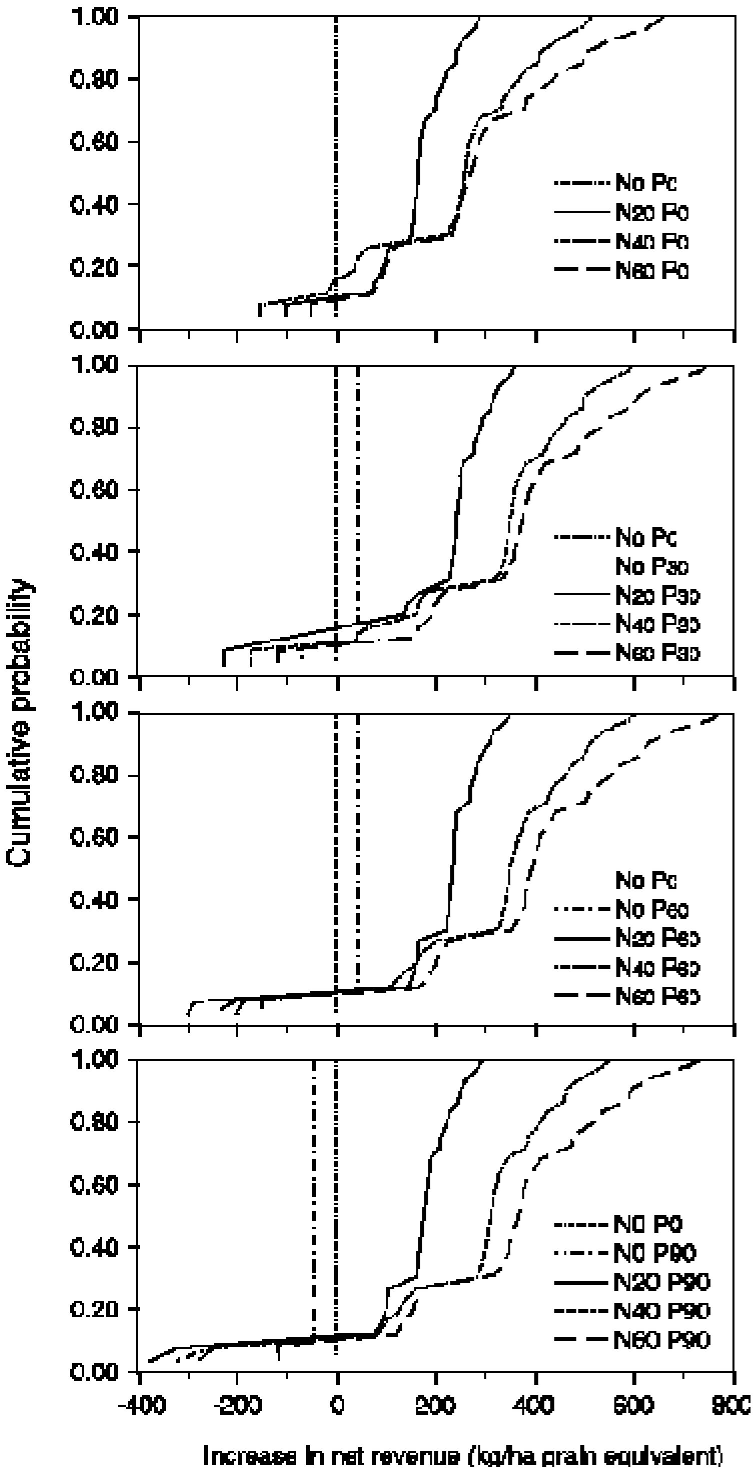

Figure 3. Cumulative distributions of net benefits, continuous barley.

Table 7. Means and standard deviations for predicted distributions.

Treatment	Barley–Fallow				Barley–Barley			
	Net benefit		Benefit:cost ratio		Net benefit		Benefit:cost ratio	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
$N_0 P_{30}$	96.3	2.7	103.0	2.6	45.1	33.8	49.6	42.3
$N_0 P_{60}$	106.5	5.4	60.0	2.8	29.0	50.4	16.1	32.8
$N_0 P_{90}$	30.5	8.1	12.1	3.2	–48.2	49.6	–20.4	22.5
$N_{20} P_0$	38.1	42.5	58.0	65.9	165.7	85.1	209.0	104.9
$N_{20} P_{30}$	168.5	44.2	106.1	24.9	224.0	115.0	131.1	71.7
$N_{20} P_{60}$	212.8	46.9	86.3	17.4	221.5	131.3	86.6	55.9
$N_{20} P_{90}$	170.9	49.6	52.6	14.5	157.8	132.5	47.0	43.6
$N_{40} P_0$	22.0	83.0	13.3	73.2	257.0	155.6	170.1	100.7
$N_{40} P_{30}$	186.6	85.7	84.8	36.4	328.4	185.0	134.8	78.4
$N_{40} P_{60}$	265.0	88.4	85.3	26.2	340.6	198.4	103.4	63.1
$N_{40} P_{90}$	257.2	91.1	65.5	21.8	290.6	20.1	71.0	52.2
$N_{60} P_0$	–46.2	120.8	–34.6	78.2	273.8	214.2	125.9	98.4
$N_{60} P_{30}$	150.5	127.2	53.7	45.3	358.4	242.2	115.7	79.7
$N_{60} P_{60}$	263.1	129.9	71.0	33.3	382.3	260.4	96.3	68.2
$N_{60} P_{90}$	289.4	132.6	63.5	27.7	346.0	264.1	72.2	58.1

The question remains as to how to select among the distributions. It is often posited that farmers prefer stability of yields to more variable yields. However, as can be seen from Figures 2 and 3, there are occasions when more variable returns may be preferred to more stable but lower yields, e.g., at P = 90 the distributions of net benefits from high rates of N would be preferred to N_0P_{90} by anyone who prefers more to less.

Selecting between treatments involves a trade-off between lower but more stable distributions and more variable distributions that give some probability of considerably higher returns. The best combination of N and P depends on where these cross-overs occur and what criteria are used to evaluate the trade-offs. However, this analysis provides evidence that there are options among the fertilizer treatments that exhibit lower, or no-higher, risk, while having higher yields as compared with using no fertilizer (Mazid and Bailey 1992).

4. The appropriateness of fertilizer use on rain-fed barley in Syria

It is important that any study of adoption and/or impact should include an assessment of the appropriateness of the technology for the farmers who are viewed as potential adopters. The appropriateness of fertilizer for dry areas is discussed by focusing on the characteristics of fertilizer, especially the following points: it is simple to incorporate into the current farming system, and to experiment with on a limited basis; its impact is observable, compatible with farmers' beliefs, and environmentally sustainable.

4.1 The relative advantage of fertilizer use on rain-fed barley

Fertilizer use on rain-fed barley has a relative advantage in aspects of biological yields, profitability and risk (see above).

4.2 Suitability of fertilizer use on rain-fed barley for experimental trials

Any innovation that can be tested through experimental trials is less uncertain for adopters and will generally be adopted more rapidly than an innovation that is difficult to experiment with. Fertilizer has characteristics that facilitate experimental trials.

When the SD/FRMP collaborative project was running, farmers were asked in 1987/88 and 1988/89 to plant their own trials next to the researcher-managed trials (RMT). These farmer-managed trials (FMT) were very simple. Each comprised a single replicate of four or five large plots. In the 1987/88 season, 10 sites were chosen to include both barley–fallow and barley–barley. Each FMT comprised four large plots (75 × 6.25 m) planted by farmers. Treatments were the four factorial combinations of two rates of nitrogen, 0 and 40 kg/ha, and two rates of phosphate (P_2O_5), 0 and 90 kg/ha. Farmers were provided with the recommended quantities of fertilizer for each plot, but were otherwise allowed to plant the trial with their own seed and manage the crop in their own way.

Twenty sites were used in 1988/89. RMT and FMT each comprised five plots, although plot size differed (RMT, 2.1 × 67.5 m; FMT, 6.25 × 67.5 m). Fertilizer rates were the same as in 1987/88 with an additional treatment of $N_{20}P_{45}$ (half of the full rates of N and P_2O_5).

The 1987/88 and 1988/89 seasons experienced different rainfall conditions; 1987/88 was very wet (10-site mean, 422 mm), and 1988/89 was very dry (20-site mean, 174 mm). However, yield trends in each of FMT and RMT were similar in both seasons: RMT outyielded the FMT significantly in the dry year (1988/89), non-significantly in the wet year (1987/88). Crop sequence had no effect on this pattern, but barley yields following fallow were higher than those following barley, and this was consistent in both seasons in FMT and RMT (Table 8) (Wahbi et al. 1994; Jones and Mazid 1988).

Table 8. Average total dry matter production (t/ha) for the 1987/88 and 1988/89 seasons from different treatments on farmers' fields.

Season	Treatment	Overall			F–B			Continuous barley		
		RMT	FMT	Mean	RMT	FMT	Mean	RMT	FMT	Mean
1987/88						(8 sites)			(2 sites)	
			***			***				*
	N_0P_0	4.57	4.44	4.51	4.86	4.50	4.68	3.41	4.19	3.80
	$N_{40}P_0$	5.92	5.77	5.84	5.74	6.04	5.89	6.66	4.68	5.67
	N_0P_{90}	5.24	4.88	5.06	5.39	5.00	5.19	4.64	4.40	4.52
	$N_{40}P_{90}$	7.93	6.66	7.29	8.04	6.58	7.31	7.50	6.95	7.23
		ns			ns			ns		
	Mean	5.92	5.43	5.68	6.01	5.53	5.77	5.55	5.05	5.30
SE ±										
Management means				0.249			0.228			1.159
Treatment means				0.243			0.228			0.459
Management × treatment means				0.263			0.263			0.446
1988/89						(7 sites)			(13 sites)	
			***		ns				***	
	N_0P_0	1.42	1.32	1.37	1.92	1.78	1.85	1.15	1.08	1.11
	$N_{40}P_0$	1.75	1.49	1.62	1.95	1.73	1.84	1.65	1.36	1.50
	N_0P_{90}	4.63	1.45	1.45	2.15	1.91	2.03	1.34	1.20	1.27
	$N_{40}P_{90}$	2.06	1.85	1.96	2.28	2.19	2.23	1.95	1.67	1.81
	$N_{20}P_{45}$	1.88	1.61	1.75	2.27	1.85	2.06	1.68	1.47	1.56
		***			ns			**		
	Mean									
SE ±										
Management means				0.035			0.073			0.040
Treatment means				0.054			0.118			0.048
Management × treatment means				0.054			0.102			0.063

ns, not significant.
*, **, *** Significant at P < 0.05, 0.01 and 0.001, respectively.
RMT: researcher-managed trial; FMT: farmer-managed trial.

4.3 Observability of fertilizer use on rain-fed barley

Some results of new technology are easily observed, while some others are not so recognizable. Fortunately, the results of fertilizer use on rain-fed barley were visible to farmers. During the SD/FRMP collaborative project, the experiments were complemented by a survey: 129 farmers were monitored with two visits during the seasons. These visits were directed to three groups of farmers: the farmers collaborating with the project, others from the same village, and others from neighboring villages.

The farmers' main reaction to the trials was manifested in changes in fertilizer use. Although these trials were not demonstrations nor part of an extension effort, but were conducted as an integral part of research with a farming systems perspective, the farmers reported that the trials were beneficial, successful, and interesting. Among the monitored farmers, fertilizer use on rain-fed barley in the following season increased. The actual use of, or interest in, fertilizer was higher among those who were able to observe the trials (Mazid and Somel 1987).

4.4 Compatibility of fertilizer use on rain-fed barley

According to Rogers (1983), compatibility of an innovation can be associated with (1) socio-cultural values and beliefs, (2) previously-introduced ideas, or (3) client needs for innovations.

Fertilizer use on rain-fed barley was not expected to be affected by socio-cultural values and beliefs in Syria because most farmers in the irrigated and wet area were already using fertilizers. Fertilizer use on barley is compatible with the current barley/livestock farming system, since barley is the dominant crop in that system, it does not involve any changes to the system, and is compatible with farmers' need to increase their farm barley production, since many farmers in that system are purchasing barley and other feedstuff to meet their livestock feed requirements.

4.5 Simplicity of fertilizer use on rain-fed barley

Any new agricultural technology may be classified as complex or simple according to how farmers perceive it. Fertilizer use on rain-fed barley is perceived as a simple technology by farmers in Syria. During the survey on adoption of fertilizer use carried out in 1993, none of the farmers mentioned or reported that fertilizers were difficult to use or understand.

4.6 Environmental effects of fertilizer use on rain-fed barley

There is a growing awareness of, concern about, and increasing attention to the interface between agriculture and the environment (Young 1991). Chemical fertilizer usually increases agricultural production and this in itself represents an influence on the environment.

According to Finck (1982), the effects of chemical fertilizer on the environment can be categorized under:

1. Soil: Effects on soil reaction, soil structure, and soil life, and possible accumulation of toxic substances.
2. Water: Eutrophication of surface water, and accumulation of fertilizers in groundwater.
3. Air: Effects on air quality, possible accumulation of noxious substances, and possible destruction of the Earth's ozone shield.

These effects are in varying degrees, positively or negatively, affected by fertilizer application in agriculture. However, the negative effects of chemical fertilizer may appear with intensive application of fertilizer. In the case of fertilizer use on rain-fed barley, the recommended rates of fertilizer are low and appear to be environmentally sustainable, both in the short and long term (Pala and Mazid 1992). The application of a low rate of phosphate is considered safe by most studies on phosphate-deficient soil in the Near East (Matar et al. 1987). Improved root growth as a result of the application of fertilizers has been shown to be highly effective in reducing soil erosion (Cooper et al. 1987; Osman et al. 1991). Furthermore, the introduction of soil-protecting crops leads to improved agricultural production (Tregubov 1981).

4.7 Farmers' perceptions of fertilizer use on rain-fed barley

Farmers usually know why they do or do not adopt a new technology, and are able to explain their reasoning, which usually reflects their own experiences. According to a 1993 survey on adopting fertilizer use on rain-fed barley, the majority of barley farmers perceived fertilizer as profitable, advantageous, and not risky. The farmers were asked for their reasons for using chemical fertilizer on rain-fed barley and the degree to which these reasons influenced their decision. About 97% of the farmers who had adopted fertilizer said that they wanted to increase barley yield, 85% reported that fertilizers reduced the possibility of crop failure, and 65% reported that fertilizers were not risky to use on rain-fed barley. Of the non-adopters, 50% regarded fertilizer as risky on rain-fed barley, and 20% reported that there was no real benefit from the use of fertilizer.

5. Diffusion of fertilizer use on rain-fed barley

Fertilizer use on rain-fed barley in Syria is a new technology for barley producers. The adoption rate is the most important factor influencing potential impact in terms of increasing barley production at the national level. Some rain-fed barley producers have adopted fertilizer, but others, especially those in the drier areas, have not. It is understandable that not everyone adopts a new agricultural technology at the same time. The main underlying hypothesis of this paper is that the time dimension is essential in understanding the adoption and diffusion process. Therefore, this factor was investigated by studying the adoption rate and the diffusion pattern.

According to most theories on the adoption and diffusion of new agricultural technologies, adoption is not a sudden event, rather, it is a process. It is also distinguishable from the diffusion process: diffusion occurs among a population while adoption occurs for individuals (Rogers 1962; Thirtle and Ruttan 1987). The diffusion of an innovation has frequently been defined as a process by which the innovation is communicated through certain channels over *time* among the members of a social system (Rogers 1983). A social system is defined by Rogers (1962) as "a population of individuals who are functionally differentiated and engaged in collective problem-solving behavior." In the context of this study the social systems consist of the potential adopters, or the farming communities, in barley-producing areas.

The time dimension is essential in the diffusion process; it is an important aspect of any communication process. Researchers (Rogers 1983; Mahajan and Peterson 1985; CIMMYT 1993) have shown that adoption of an innovation when plotted against time often follows a normal distribution curve. If the cumulative number of adopters is plotted over time, the resulting distribution is an S-shaped curve in which there is slow initial growth in the use of the new technology, followed by a more rapid increase, and then a slowing down as the cumulative percentage of adoption approaches its maximum.

Early research on the diffusion process focused on describing the observed diffusion patterns in terms of pre-specified distributions (Mahajan and Peterson 1985). Subsequent research has attempted to develop more theory-based models. Diffusion models have been developed to represent the spread of an innovation through a given population of prospective adopters in terms of a simple mathematical function of the time that has elapsed from the introduction of the innovation. The objective of such a diffusion model is to show the successive increase in the number of adopters over time. This provides valuable information about trends and prospects for a new technology. It enables researchers to estimate the rate of adoption and to make predictions about future progress and demand for inputs. It also determines whether there is a need to quantify the change in the number of users of agricultural technology over time in order to evaluate its impact (CIMMYT 1993).

5.1 Diffusion model

The logistic function is the most common form used to represent the diffusion model with an S-shaped curve (CIMMYT 1993). The logistic S-shaped curve is represented mathematically as:

$$Y_t = K \div (1 + e^{-z-xt}) \qquad \textbf{(7)}$$

where

Y_t = the cumulative proportion of adopters at a time t,
K = the upper bound of adoption,
x = a constant, related to the rate of adoption,
z = a constant, related to the time when adoption begins.

It is possible to rewrite Equation (7) as

$$K \div Y_t = 1 + e^{-z-xt}$$
$$(K - Y_t) \div Y_t = e^{-z-xt}$$
$$Y_t \div (K - Y_t) = e^{z+xt}$$
$$\text{Ln} \frac{Y_t}{K - Y_t} = z + xt \qquad \textbf{(8)}$$

Least squares regression of Equation (8) will produce estimates of **z** and **x**. To calculate **K**, CIMMYT (1993) proposes two approaches. The first is to plot the data and to choose the level that appears to be the upper bound or ceiling of adoption. The second method is to run the regression using different values of **K** and select the one that maximizes R^2. T-tests and the R^2 coefficients from these regressions, in general, provide no statistical indication. This technique only helps in selecting the **K** that gives the best fit to the data.

Although the logistic curve is the most common way of representing technology diffusion, it must be recognized that this model is static, and does not take into account the stage of the adoption process. It is assumed that there is complete, pair-wise interaction between previous adopters of an innovation and potential adopters, and the innovation itself does not change over the diffusion process.

5.2 Data collection and estimation of logistic function for the diffusion of fertilizer

Data were gathered from 105 rain-fed barley producers chosen randomly, and interviewed in Aleppo, Idleb, Hama, Hassakeh and Raqqa provinces, during March and April 1993, using a two-stage sampling procedure. Sixty farmers were located in Zone 2 and 45 farmers in Zone 3 (Mazid 1994).
Annual time-series data of the number of adopters of fertilizer use on rain-fed bar-

ley in Syria obtained from the survey are used. The surveyed farmers were asked questions about when they started using nitrogen and/or phosphate fertilizers on their rain-fed barley. Their answers were plotted as cumulative percentages (Figure 4); the adoption of any type of fertilizer has been higher in Zone 2 than in Zone 3 with greater total adoption of phosphate than of planting-time nitrogen or top-dressed nitrogen (Mazid 1994).

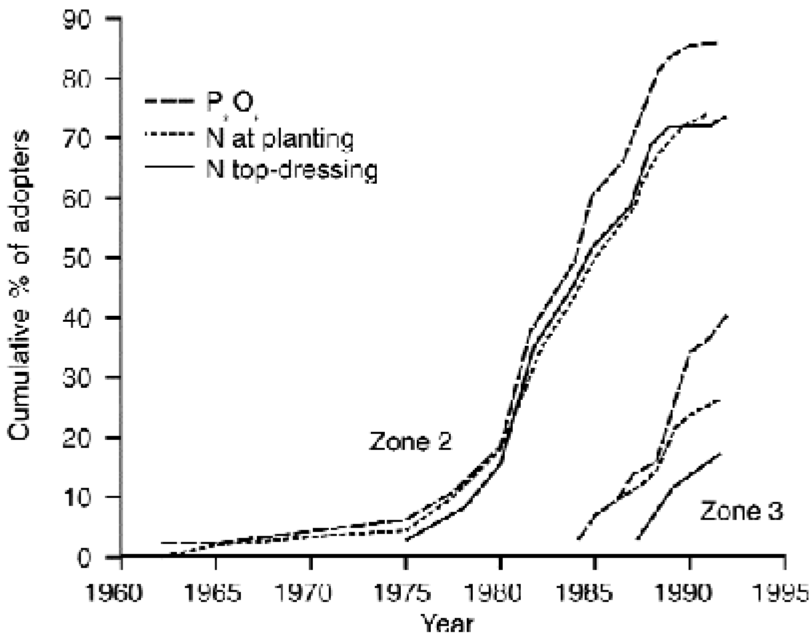

Figure 4. Actual diffusion curves of fertilizer use on rain-fed barley in Syria.

The definition of an adopter, in this research, was a farmer who adopted at least one component of the fertilizer package: nitrogen, phosphate, or both. As stated above, due to agricultural policy, fertilizer was available earlier in Zone 2 and therefore adoption started earlier there than in Zone 3. Farmers did not have access to fertilizer in Zone 3 until the 1980s and so the diffusion and adoption process lags behind that of Zone 2. For this reason, the cumulative percentage of adopters has been higher in Zone 2 than in Zone 3 (87.7% versus 46.7%).

It was decided, in the light of the different starting times for the adoption and diffusion process in Zones 2 and 3, that the analysis would be carried out for each zone separately. Therefore, linear regression analysis was applied to estimate the coefficient values of the logistic function based on Equation (8), assuming several upper bounds of adoption **K** for each zone. The coefficient values of the logistic functions which gave the best fit of the time-series data in both zones is summarized in Table 9, and the actual and predicted cumulative percentages of adopters is shown in Figure 5.

Table 9. Estimated coefficient values that gave the best fit of logistic functions based on Equation (8).

	z	x	K	Adj. R^2
Zone 2 (1975–92)	–28.57	0.342	94	0.985
Zone 3 (1984–92)	–52.03	0.585	54	0.983

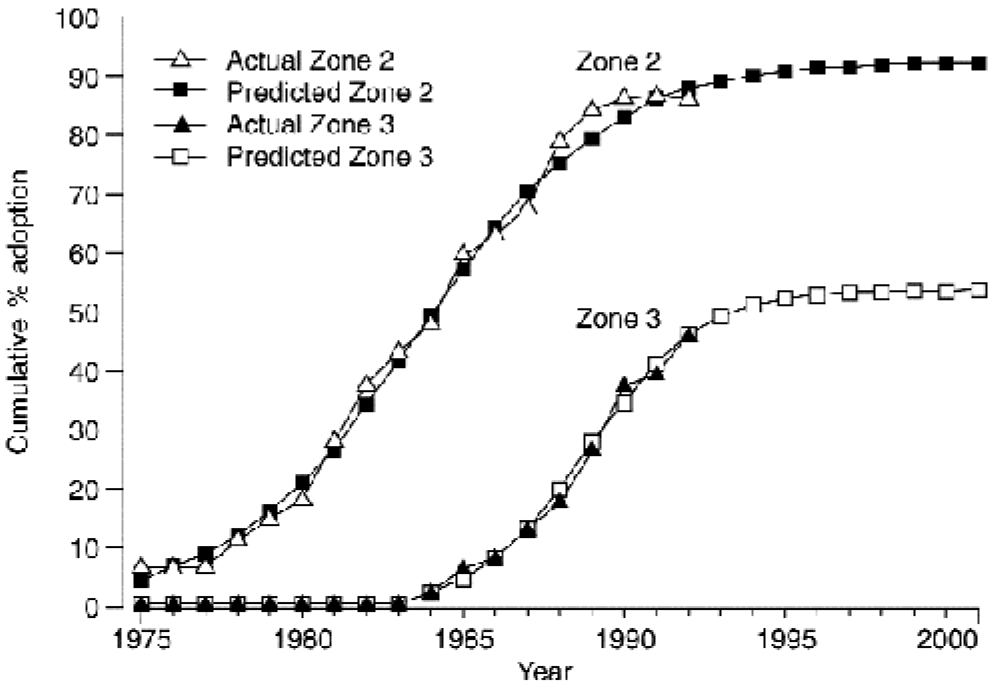

Figure 5. Actual (1975–92) and predicted (1975–2001) cumulative adoption from the estimated logistic model.

Based on the above analysis, it is possible to conclude the following:

1. The logistic function provides a good representation of the actual adoption time-series data related to fertilizer use on rain-fed barley in Syria. The analysis shows that the majority of farmers in Zone 2 adopted fertilizer technology, while more than half of the farmers in Zone 3 had not yet adopted it.

2. Adoption started earlier in Zone 2, but the rate of adoption (represented by the coefficient **x**) was higher in Zone 3 i.e., once fertilizer became available in Zone

3 farmers adopted more rapidly than in Zone 2. This could be due to some diffusion of experience from Zone 2 to Zone 3.

3. There is a lack of adoption of fertilizer technology especially in the drier areas. It is predicted that the ceiling or upper bound of adoption in Zone 2 is much greater than that in Zone 3.

6. Impact assessment of fertilizer diffusion on barley production in Syria

As addressed in the previous section, adoption and diffusion of a new technology is essential to achieve impact on barley production at the national level. In this study, it was found that fertilizer use has been diffused among barley producers in Syria, especially in Zone 2, but two questions remain unanswered. What is the current situation of barley production in Syria? How much of the increase in barley production at the national level is due to fertilizer use?

Official statistics on national trends indicate that between 1981 and 1995 there was a clear increase in both barley area and barley production in Syria. The total area under barley increased by 46%, from 1,346,000 ha in 1981 to 1,963,000 ha in 1995, and total barley production increased during this period to reach 1,722,000 tonnes in 1995. A major issue is the large year-to-year fluctuation in total barley production, the consequence of more than 95% of the barley area being under rain-fed conditions. Despite this fluctuation, growth in production and yield has been observable since 1990, with total barley production increasing from 846,000 tonnes in 1990 to 1,722,000 tonnes in 1995, and barley yield rising from 448 kg/ha in 1990 to 877 kg/ha in 1995.

However, for a better understanding of barley-production trends at the national level, and to avoid the influence of year-to-year fluctuation, the average annual area, production and yield of barley were calculated for five-year periods (Table 10). Between 1981–85 and 1991–95 the average annual area of barley increased by 48% and total production by 67%. Yield per unit area increased by 11%. The difference between the zones is instructive. Over this period, the proportion of total Syrian national barley production from Zone 2 increased from 34 to 54%, and area productivity from 750 to 1064 kg/ha (38%). In contrast, there was no yield increase in Zone 3. This is because the majority of Zone 3 barley farmers have practiced continuous barley cropping over the last 10 years (Mazid 1994). Fertilizer use was diffused in this zone and some farmers adopted it, but its effectiveness was limited to stopping the decline in barley yield due to cultivating the land every year.

Table 10. Annual average of area, production and yield of barley in Syria, 1981–1995.

Years	Area (000 ha)	Production (000 t)	Yield (kg/ha)
Syria total			
1981–85	1425	831	583
1985–90	2116	1129	534
1991–95	2108	1371	650
Zone 2			
1981–85	374	286	765
1985–90	620	480	774
1991–95	702	747	1064
Zone 3			
1981–85	304	153	503
1985–90	451	211	468
1991–95	502	235	468

Based on the data collected from the survey on adoption of fertilizer, the fertilizer-response functions and yield-gap analysis, and the official statistics for barley, a preliminary estimate of the average annual impact of fertilizer use on rain-fed barley in Zones 2 and 3 was calculated. The following formula was applied (Mazid and Somel 1987):

$$\text{Total increase} = \Sigma Y_{ij} S_{ij} M_i A_i$$

where
- Y = estimated yield increase due to fertilizer application in Zone i under rotation j,
- S = size of barley area planted in Zone i under rotation j,
- M = factor reflecting management in Zone i (range 0–1),
- A = rate of adoption (range 0–1).

The estimated impact of fertilizer use on rain-fed barley, in terms of the annual increase in grain barley production and net revenue at the national level is summarized in Table 11. The estimated increased yield of 261,000 tonnes increased the national income by about 873 million Syrian Pounds (SYP) annually (equivalent to US$ 20.8 million at 42 SYP/US$ exchange rate). About 81% of this increase came from Zone 2 and the remainder from Zone 3.

Table 11. Estimated increases in grain and net revenue from barley production from fertilizer use in Zones 2 and 3 in Syria.

Area	Grain yield increase (tonnes)	Fertilizer applied		Fertilizer costs (000 SYP)	Net revenue (000 SYP)
		P_2O_5 (t)	N (t)		
Zone 2	212,474	26,286	24,713	672,987	708,095
Zone 3	48,221	4,900	6,155	148,581	164,859
Total	260,695	31,186	30,868	821,568	872,952

7. Conclusions and policy implications

Fertilizer use on rain-fed barley was a new technology for barley producers in Syria. Barley yields of grain and straw showed highly significant responses to nitrogen and phosphate fertilizers. Economic analysis indicated that fertilizer use on rain-fed barley is profitable at the farm level, with a positive impact at the national level in terms of production and net revenue; is not risky under a range of rainfall and relative prices, in terms of net benefits and benefit-cost ratios; and there are certain fertilizer options that carry no risk. Fertilizer is also simple to incorporate into the current barley/livestock farming system, easy to experiment with on a limited basis, observable, compatible with farmers' beliefs, and environmentally sustainable. It is thus an appropriate technology for farmers of rain-fed barley.

The agricultural policy implications would be to reconsider any policies restricting the allocation of fertilizer to rain-fed areas; conduct focused on-farm research to evaluate responses to fertilizer; and execute a cooperative extension effort for fertilizer use if results of research are promising. It is gratifying that, as a result of the SD/FRMP project, the Syrian agricultural policy-makers have changed their policy of not allocating fertilizer to part of the barley producing areas and are complementing the research effort with an extension project. Furthermore, since the diffusion model can be used to predict the percentage of fertilizer adopters, the effects of policy changes on fertilizer-supply requirements can be estimated. Any changes in the fertilizer-adoption rate will provide the basis for estimating changes in planned fertilizer requirements.

References

CIMMYT Economic Program. 1993. The adoption of agricultural technology: A guide for survey design. CIMMYT, Mexico, D.F., Mexico.

Cooper, P.J., P.J. Gregory, D. Tully and H.C. Harris. 1987. Improving water-use efficiency of annual crops in the rain-fed farming systems of West Asia and North Africa. *Experimental Agriculture* 23: 113–158.

De Datta, S.K., K.A. Gómez, R.W. Herdt and R. Barker. 1978. Methodology for an integrated experiment survey on rice yield constraints. International Rice Research Institute (IRRI), Philippines.

Dillon, J.L. and J.B. Hardaker. 1984. Farm management research for small farmer development. FAO Agricultural Service. Bulletin 41.

Finck, A. 1982. Fertilizer and Fertilization. Verlag Chemie Press, Germany.

ICARDA. 1983. Annual Report 1983. Aleppo, Syria.

ICARDA. 1989. Annual Report 1989. Aleppo, Syria.

Jones, M. 1989. Researcher-managed trials: an agronomic summary, 1984–1988. Pages 31–62 *in* Farm Research Management Program Annual Report for 1989. ICARDA, Aleppo, Syria.

Jones, M. and A. Mazid. 1988. Case study: fertilizer use on barley in the dry areas of Syria. Paper presented at the International Seminar on Farming Systems Research, Çukurova University, Adana, Turkey.

Jones, M.J. and A. Wahbi. 1991. Site-factor influence on barley response to fertilizer in on-farm trials in Northern Syria: descriptive and predictive models. *Experimental Agriculture* 28: 63–87.

Mahajan, V. and R.A. Peterson. 1985. Models for innovation diffusion. Sage University Paper Series, Quantitative Applications on the Social Sciences, no. 7–48. Sage Publications: Beverly Hills, California, USA, and London, UK.

Matar, A.E., MC. Saxena and S. Silim. 1987. Soil test calibration for phosphorus with five food and forage legumes in Syria. Pages 92–104 *in* Proceedings of the Second Regional Workshop on Soil Test Calibration, ICARDA, 1– 6 September 1987, Ankara, Turkey, and ICARDA, Aleppo, Syria.

Mazid, A. 1989. Economic analysis of researcher-managed trials. Pages 62–67 *in* Farm Research Management Program Annual Report for 1989. ICARDA, Aleppo, Syria.

Mazid, A.M. 1994. Factors influencing adoption of new agricultural technology in dry areas of Syria. PhD Thesis, University of Nottingham, UK.

Mazid, A. and E. Bailey. 1992. Incorporating risk in the economic analysis of agronomic trials: Fertilizer use on barley in Syria. *Agricultural Economics* 7: 167–184.

Mazid, A. and M. Hallajian. 1983. Crop-livestock interaction: Information from barley survey in Syria. ICARDA research report no. 10. Aleppo, Syria.

Mazid, A. and K. Somel. 1987. Fertilizer use on barley in North Syria: Yield-gap analysis and potential impact. Pages 143–150 *in* Farm Research Management Program Annual Report for 1987. ICARDA, Aleppo, Syria.

Osman, A.E., P.S. Cocks, L. Russi and M.A. Pagnotti. 1991. Response of Mediterranean grassland to phosphate and stocking rates, biomass production and botanical composition. *Journal of Agricultural Science* 116: 37–46.

Pala, M. and A. Mazid. 1992. On-farm assessment of improved crop production practices in northwest Syria. *Experimental Agriculture* 28: 175–193.

Perrin, R.K., D.L. Winkelmann, E.R. Moscardi and J.R. Anderson. 1974. From agronomic data to farmer recommendation: an economics training manual. CIMMYT, Mexico D.F., Mexico.

Rogers, E.M. 1962. Diffusion of Innovations. Free Press, New York, USA.

Rogers, E.M. 1983. Diffusion of Innovations. Third Edition. Free Press, New York, USA.

SD/FRMP. 1985. Annual report on cooperative research on fertilizer use on barley in north Syria. ICARDA, Aleppo, Syria.

SD/FRMP. 1990. Collaborative research project on fertilizer use on barley in northern Syria, Part 1, 1984–1989. ICARDA, Aleppo, Syria.

Shepherd, K.D., P.J.M. Cooper, A.Y. Allan, D.S.H. Drennan and J.D.H. Keatinge. 1987. Growth, water use and yield of barley in Mediterranean-type environments. *Journal of Agricultural Science* 108: 365–378.

Somel, K. 1987. Food and Agriculture in West Asia and North Africa: Projections to 2000. Pages 122–143 *in* Farm Research Management Program Annual Report for 1987. ICARDA, Aleppo, Syria.

Somel, K, A. Mazid and M. Hallajian. 1984. Survey of barley producers in Northern Syria, 1981–82. Vol. 3: Descriptive statistics. ICARDA research report no. 12–III. Aleppo, Syria.
Somel, K., A. Mazid and K. El-Hajj. 1992. Risk implications of fertilizer use on rainfed barley. Middle East Technical University (METU) Studies in Development 19(3): 413–447. METU, Ankara, Turkey.
Thirtle, C.G. and V. Ruttan. 1987. The Role of Demand and Supply in the Generation and Diffusion of Technical Change. Harwood Academic Publisher, New York, USA.
Tregubov, P.S. 1981. Effective erosion control in the USSR. Pages 451–459 *in* Soil Conservation Problems and Prospects (R.P.C. Morgan, ed.). John Wiley and Sons, Chichester, UK.
Wahbi, A., A. Mazid and M.J. Jones. 1994. An example of the farming systems approach: the fertilization of barley in farmer and researcher-managed trials in northern Syria. *Experimental Agriculture* 30(2): 171–176.
Young, M.D. 1991. Towards sustainable agricultural development. Belhaven Press, London and New York.

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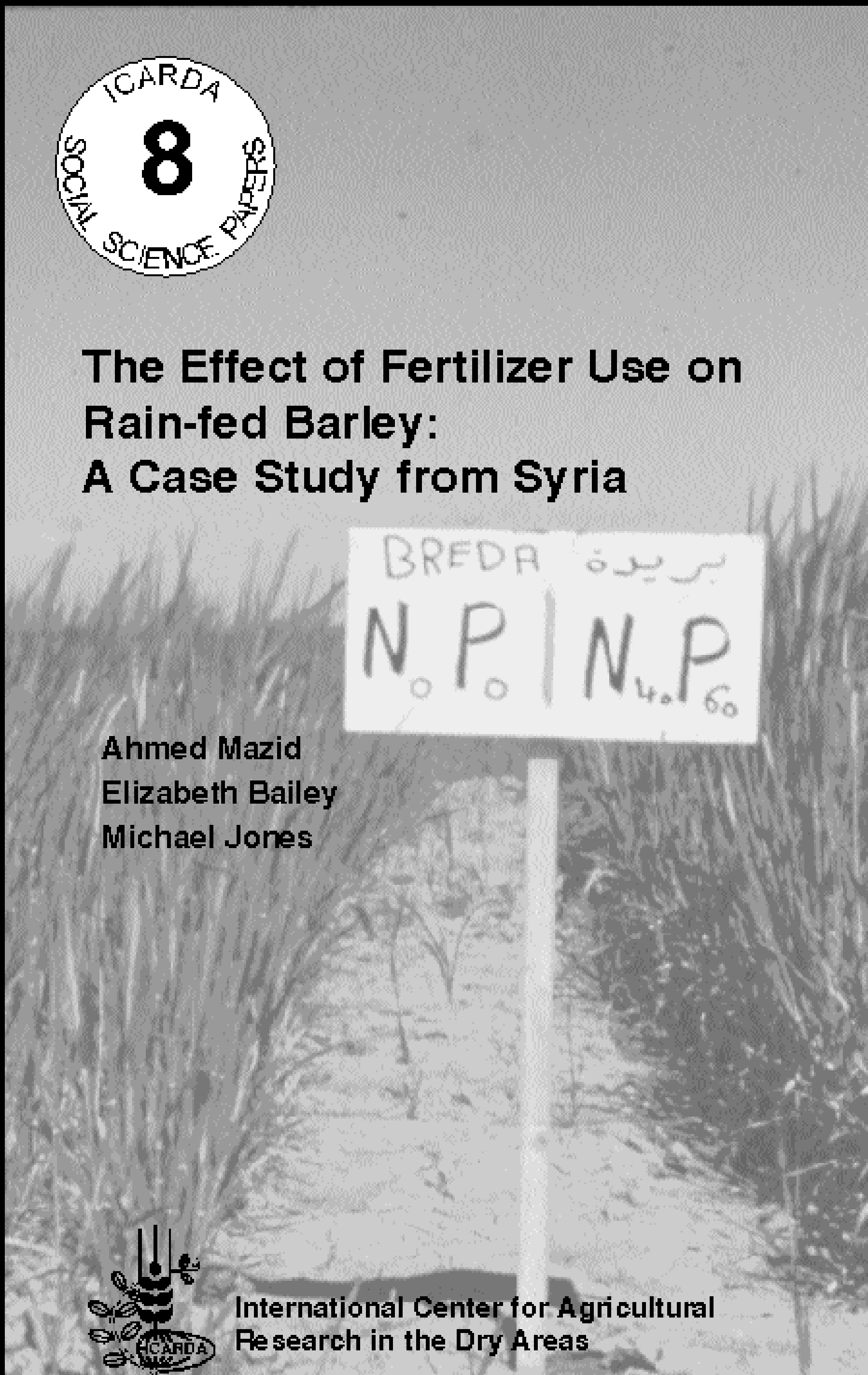

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