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COMPARISON OF CONSERVATION TILLAGE SYSTEMS IN BARLEY-BASED CROPPING SYSTEMS IN NORTHERN SYRIA

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SUMMARY

Yields of rainfed barley (*Hordeum vulgare*) for feed and forage in small-ruminant production systems in low-rainfall areas of North Africa and West Asia are limited by low and erratic water availability. Therefore, the testing of conservation farming techniques, effective in dryland systems elsewhere, is often suggested. Seven-year results from a typical site in northern Syria showed that zero-till (direct-drill) systems with cereal residue retention may marginally enhance soil moisture status, but the yield effect on barley, either monocropped or rotated with vetch (*Vicia sativa*), was small and non-significant. In the vetch–barley rotation, a small and fairly consistent benefit to vetch was observed, amounting to a 20% yield increase in vetch hay. Given smallholders' strong preference for barley and reluctance to grow vetch as an alternate crop, there is little in this result to encourage the promotion of zero-till conservation techniques in these farming systems.

INTRODUCTION

In the drier rainfed areas of northern Syria between the 200- and 300-mm annual isohytes the main crop is barley (*Hordeum vulgare*) grown to feed sheep whose milk and meat provide the main source of agricultural income. This system is broadly typical of those found in similar winter-rainfall zones across much of the West Asia and North Africa (WANA) region (Jones *et al.*, 1993). Nearly everywhere, economic and demographic pressures are driving such systems in two ways—to be more intensive and to expand into more marginal lands, either with lower rainfall or with steeper slopes and shallower soils.

In Syria, intensification has meant the replacement of fallow–barley sequences with continuous barley, and attempts to promote annual forage legumes (mainly *Vicia* species) as alternate crops have so far met with only limited success (Jones, 1990; Thomson *et al.*, 1992). In such dry areas, water-use efficiency is a major concern. Judicious use of nitrogen (N) and phosphorus (P) fertilizer, to enhance the rapid establishment of ground cover and hasten maturity, can contribute considerably to this (Cooper *et al.*, 1987; Jones and Wahbi, 1992), and research and extension efforts have greatly increased barley growers' use of fertilizer in

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recent years (Mazid and Jones, 1998). However, there may yet remain management techniques, forms of 'conservation farming', that could reduce soil evaporative losses and increase the proportion of available water transpired productively by the crop. At the same time, as cropping encroaches into drier 'steppe' landscapes vulnerability to wind erosion increases. In many cases after harvest the straw is removed and the stubble grazed by small ruminants, leaving the soil exposed to the strong summer winds. The retention even of just the stubble would reduce the erosion risk considerably. It might also improve soil moisture conditions by increasing infiltration and reducing evaporation before and after the next crop is sown.

The world literature on tillage and residue management systems to conserve soil and water in dry areas is large. Much of it derives from North America, where systems utilizing zero-tillage, reduced-tillage, crop residue retention, or a combination of these have been credited variously with reducing soil erosion by wind or water, improving infiltration of rainwater, and reducing soil evaporation (Blevins and Fry, 1993). Applying this considerable body of experience successfully to smallholder systems in the often harsher conditions of WANA is problematic. Even in North America results vary greatly according to local conditions. A comparison of four stubble-management treatments over six years of continuous barley cropping in Cyprus showed directly contrasting results from two different sites (Papastylianou, 1990).

As an initial exploration of the applicability of 'conservation farming' techniques to the physical conditions of barley-based farming systems of northern Syria, a 'tillage and barley residue management' trial was established in 1989–90 on a 2.5-ha field at Breda, an ICARDA experiment station in northern Syria. It tested the hypothesis that conservation tillage benefits water conservation and enhances crop yields in dryland farming systems (Papendick *et al.*, 1991). The present paper reports results from the seven years (1990–1997) subsequent to the 1989–90 establishment season.

MATERIALS AND METHODS

Site

Breda (lat 35°56′N, long 37°10′E), about 30 km due south of Aleppo city, lies within an area cropped intensively by smallholders to rainfed barley and representative of a zone of barley-based farming systems lying across northern Syria. Mean annual rainfall is around 270 mm, falling largely in the period from late October to early April. The experimental field was flat and level. The soil, described as a Typic Calciorthid (Harmsen, 1984) or Calcixerollic Xerochrept (Ryan *et al.*, 1997) has a clay loam topsoil (pH 8.3, 26% $CaCO_3$ and about 1% organic matter) overlying a considerable depth of heavier clay soil. The clay is predominantly montmorillonitic, and the soil cracks extensively to a depth of 40–50 cm during the long, dry summer. The natural availability of phosphate is low (about 3 ppm Olsen-P) and, depending on the rates used, the availability of added fertilizer-P has a half-life rather less than one year (Cooper *et al.*, 1987; Afif *et al.*, 1993).

Trial treatments and design

The experiment comprised the following treatments:

(a) Two rotations of annually planted crops: barley–vetch (*Vicia sativa*) (B–V) and barley–barley (B–B).

(b) Five management treatments involving combinations of tillage (ducksfoot sweep) versus no tillage; time of tillage; straw retention or removal; and stubble retention or grazing by sheep soon after harvest in May–June.

The treatments were as follows:

Treatment	Tillage	Tillage time	Straw	Stubble
1	Yes	October	Remove	Graze
2	Yes	October	Remove	Leave
3	Yes	June	Remove	Graze
4	No	—	Remove	Leave
5	No	—	Leave	Leave

The 'ducksfoot' sweep is the implement most widely used by local farmers. It disturbs the soil to a depth of about 10 cm without inversion. Total mass of straw and stubble in Treatment 5 varied, according to preceding seasonal effects, between 1 and 2 t ha^{-1} in the B–B rotation and about 20–25% greater in the B–V rotation.

(c) Three rates of N fertilizer were topdressed on barley at 0, 20 or 40 kg N ha^{-1}. These rates were applied in both phases of the B–B rotation but not to the vetch.

Both phases of each rotation were represented each year, and the barley crop in the first phase received phosphate fertilizer (60 kg P_2O_5 ha^{-1}) in the seedbed. The direct-drill (zero-till) planter required in Treatments 4 and 5 was used to plant the whole trial and to ensure uniform row spacing (30 cm) and seed rates (90 kg barley seed and 120 kg vetch seed ha^{-1}) across all treatments. Planting dates ranged, according to season, from 6 to 23 November. In the B–V rotation, following the vetch harvest, vetch residues were removed, but tillage treatments were conducted in the same manner as after barley. In this very dry environment, and in contrast to the Cyprus situation (Papastylianou, 1990), weeds were not a serious problem but one herbicide application of brominal was made routinely each year after crop establishment to control broad-leaved weeds in all barley plots.

The trial had a split-split plot design. There were two replicates each of four main plots, which carried the two annual phases of each of the two rotations. Each main plot (62.5 × 45 m) was divided into five subplots for the five management treatments and each subplot was divided further into three sub-subplots for the three N rates applied to barley.

Measurements

Barley grain yields were estimated by harvesting each plot in two ways: by hand cutting (at ground level) five 1-m row samples, and by reaping a swathe from one end of the plot to the other with a Hege plot-harvester. Both methods gave a value for grain yield (but hand-sampled values were usually around 10% greater than those from the machine). Straw (and harvest index and, hence, total biomass) estimates were made from the hand-cut material. For vetch, biomass samples (five 1-m row lengths) were taken at the hay stage (early flowering) and then the whole plots were harvested by hand at maturity (and the residues removed).

Soil water content was monitored by neutron probe to a depth of 150 cm in both phases of both rotations (B–B and B–V) in Treatments 1, 2 and 5 (20N sub-subplots only, but with two replicate access tubes in each). Measurements were made at the beginning of the season (late September or early October) prior to rainfall; at approximately monthly intervals through the growing season; and in mid to late May, after harvest.

This trial ran for eight years. Discounting the start-up year, there were thus seven years of data to evaluate. Results are reported here for barley grain and total biomass (in B–B and B–V rotations, separately); vetch hay biomass and grain and total biomass from the B–V rotation; and soil-water balance (in tillage–residue management Treatments 1, 2 and 5).

Over the eight years of the trial, seasonal rainfall (October–May) ranged between 183 and 360 mm (Table 1). Three seasons were rated average (1991–92, 1992–93, 1993–94), three moderately dry (1990–91, 1994–95, 1996–97), one wet (1995–96), while the start-up season, 1989–90, was very dry. Within-season

Table 1. Weather conditions at Breda station: monthly rainfall totals (mm) and long-term temperature means (°C).

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
				Rainfall					
1989–90	24.6	27.8	34.2	37.0	42.6	8.4	3.0	5.6	183.2
1990–91	4.4	26.2	12.4	50.9	20.6	60.0	35.2	31.6	241.3
1991–92	18.8	28.6	36.4	51.4	75.8	20.4	0.0	28.8	260.2
1992–93	1.0	69.4	32.6	42.7	50.0	36.9	8.0	30.0	270.6
1993–94	3.2	27.8	14.6	88.0	126.2	9.8	15.2	6.4	291.2
1994–95	2.2	59.8	48.0	35.2	18.2	14.8	31.8	15.2	225.2
1995–96	9.8	50.4	35.6	71.6	48.4	95.6	23.4	25.0	359.8
1996–97	29.8	8.8	57.8	25.6	11.2	35.6	53.4	2.2	224.4
				Temperature					
Maximum	26.7	18.0	12.1	10.2	12.4	17.1	23.9	29.2	
Minimum	10.8	5.4	2.0	1.1	1.5	4.2	7.8	12.0	
Frost events	—	2	9	13	10	5	1	—	

rainfall distribution also varied widely. At this site, the main winter months (December–February) are cool and night frosts are quite common. Mean evaporative demand at this time may be as low as 1 mm d^{-1}.

RESULTS

Yields of barley in B–B rotation

There was a fairly consistent response to fertilizer: yields were generally slightly greater in the phase receiving P fertilizer in the current year but, in both phases, were increased by N fertilizer, at least up to the 20 kg N ha^{-1} level. To indicate the general pattern, seven-year means are summarized in Table 2. However, the main focus of the trial was on the effects of the five tillage–residue management treatments. In fact, yield differences due to these treatments proved to be consistently small and never reached statistical significance in any of the seven years (Table 3). For grain, zero-till treatments were among the best in most years, but in the seven-year means the advantage of the best treatment (Treatment 5) over the worst (Treatment 2) was only 9%; the differences between biomass means were smaller, at 5% or less.

Yields of barley in B–V rotation

Grain yields showed an appreciable 'rotation' effect. In all years (except 1990–91) yields were at least 30% higher than those from the corresponding treatment (P-fertilized phase) of the B–B rotation (Table 4), but response to N-fertilizer was small and statistically non-significant, apparently reflecting greater N availability in the soil after the legume. Since barley followed vetch, preceding management treatments differed only in the tillage component; no vetch residues were retained on the soil surface. Nevertheless, there was still some evidence of treatment effects. Highest grain yields tended to be from zero tillage (Treatments 4 and 5) with differences statistically significant in one year, 1993–94. Over the seven years, the two zero-till treatments outyielded the mean of the three tilled treatments by about 6%, but this pattern was absent from straw and total biomass values.

Table 2. Main treatment effects of biennial phosphorus (P) fertilization and annual nitrogen (N) fertilization on barley yields (t ha^{-1}) in the barley–barley (B–B) rotation: seven-year means at Breda.

	Current season's P fertilizer (kg P_2O_5 ha^{-1})		Annual N fertilizer (kg N ha^{-1})		
Yield	0	60	0	20	40
Grain (Hege plot-harvester)†	0.90	0.96	0.69	1.00	1.12
Grain (hand)	0.97	1.08	0.80	1.08	1.20
Total biomass	2.41	2.65	1.92	2.64	3.04

†Data from six years only.

Table 3. Effect of tillage–residue management treatments on annual barley yields (t ha^{-1})† in the barley–barley (B–B) rotation at Breda.

Treatment‡	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	Mean
				Grain (hand harvest)				
1	0.75	0.96	1.05	0.73	0.94	1.72	0.91	1.01
2	0.78	0.91	0.97	0.71	0.91	1.79	1.05	1.02
3	0.83	0.96	0.85	0.74	0.94	1.77	1.05	1.00
4	0.82	0.81	0.88	0.83	0.94	1.87	1.00	1.02
5	0.99	0.90	1.04	0.82	1.09	1.81	0.95	1.09
s.e.	0.066	0.048	0.051	0.066	0.059	0.062	0.045	
Mean	0.83	0.91	0.96	0.77	0.96	1.79	0.97	1.03
				Total biomass				
1	2.34	2.55	2.88	1.63	2.36	3.60	2.50	2.55
2	2.49	2.47	2.64	1.55	2.15	3.60	2.85	2.54
3	2.71	2.61	2.36	1.67	2.41	3.49	2.42	2.52
4	2.04	2.25	2.37	1.89	2.33	3.75	2.61	2.46
5	2.15	2.50	2.67	1.83	2.62	3.64	2.67	2.58
s.e.	0.144	0.081	0.144	0.096	0.150	0.139	0.190	
Mean	2.35	2.48	2.58	1.72	2.37	3.62	2.61	2.53

†All yield values are means over two phases and three N-fertilizer rates; ‡for individual tillage–residue management treatment details, see Materials and Methods section; analysis of variance across 7-year data sets was omitted because, for any given treatment, yield values were drawn from different plots in alternate years.

Table 4. Effect of nitrogen (N) fertilizer and tillage–residue management treatments on annual barley grain yields (t ha^{-1})† in the barley–vetch (B–V) rotation at Breda.

Treatment	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	Mean
N rate (kg ha^{-1})								
0	0.92	1.14	1.79	1.04	1.18	2.28	1.60	1.42
20	0.77	1.28	1.86	1.14	1.32	2.46	1.55	1.48
40	0.88	1.29	1.87	1.09	1.27	3.03	1.80	1.60
s.e.	0.041	0.054	0.071	0.063	0.086	0.101	0.080	
Tillage–residue treatment‡								
1	0.81	1.10	1.65	0.76	1.20	2.50	1.71	1.39
2	0.82	1.33	1.93	1.08	1.16	2.77	1.59	1.53
3	0.87	1.21	1.81	0.97	1.15	2.82	1.55	1.48
4	0.88	1.25	1.95	1.30	1.34	2.36	1.81	1.56
5	0.91	1.29	1.85	1.33	1.44	2.48	1.58	1.55
s.e.	0.067	0.064	0.170	0.035	0.071	0.131	0.103	
Mean	0.86	1.23	1.84	1.09	1.26	2.59	1.65	1.50
Mean as % of barley–barley value	104	135	192	142	131	145	170	146

†All values from hand-harvested crops; ‡ for individual tillage–residue treatment details, see Materials and Methods section; seven-year means of total biomass for treatments 1–5 were, respectively, 3.36, 3.35, 3.50, 3.39 and 3.33 t ha^{-1}; analysis of variance across 7-year data sets was omitted because, for any given treatment, yield values were drawn from different plots in alternate years.

Table 5. Effect of tillage–residue (barley) management treatments on annual vetch yields (t ha^{-1})† in the barley–vetch (B–V) rotation at Breda.

Treatment‡	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	Mean
				Grain				
1	0.40	0.63	0.79	0.61	0.45	1.09	—	0.66
2	0.41	0.55	0.72	0.50	0.46	1.21	—	0.64
3	0.42	0.60	0.73	0.50	0.37	1.11	—	0.64
4	0.45	0.71	0.82	0.61	0.46	1.10	—	0.69
5	0.45	0.56	0.74	0.63	0.57	1.08	—	0.67
s.e.	0.016	0.036	0.031	0.031	0.023	0.081		
Mean	0.43	0.61	0.76	0.57	0.46	1.12		0.66
				Total biomass				
1	1.33	2.42	2.13	2.30	1.28	3.15	—	2.10
2	1.34	2.21	1.98	1.79	1.42	3.34	—	2.01
3	1.36	2.30	2.00	1.83	1.21	3.07	—	1.96
4	1.52	2.62	2.22	2.16	1.51	3.46	—	2.25
5	1.51	2.32	1.97	2.27	1.96	3.37	—	2.23
s.e.	0.022	0.092	0.050	0.117	0.047	0.106		
Mean	1.41	2.37	2.06	2.07	1.47	3.28		2.11
				Hay dry matter				
1	1.40	1.90	1.92	1.41	1.28	3.58	2.11	1.94
2	1.35	1.70	1.68	1.35	1.82	3.51	2.64	2.01
3	1.53	1.76	1.74	1.37	1.54	3.41	2.18	1.93
4	1.51	2.04	1.78	1.56	2.01	4.58	2.73	2.32
5	1.83	1.70	1.88	1.68	2.00	4.21	3.49	2.40
s.e.	0.080	0.083	0.087	0.055	0.091	0.216	0.254	
Mean	1.52	1.82	1.80	1.47	1.73	3.86	2.63	2.12

†Yield values are from hand-harvested samples; ‡for individual tillage–residue treatment details, see Materials and Methods section; analysis of variance across 7-year data sets was omitted because, for any given treatment, yield values were drawn from different plots in alternate years.

Yields of vetch in B–V rotation

Vetch followed P-fertilized barley, received no direct fertilization, and showed no residual response to the different N-fertilizer rates previously applied to the barley (results not shown). The effects of tillage and barley-residue management treatments on grain, mature total biomass (grain + straw) and hay yields again tended to be small but were larger than those for barley (Table 5). Differences were proportionately greatest among values for hay biomass and least for grain yield, with straw and mature biomass intermediate. Over seven years, the mean of the two no-till treatments outyielded the mean of the other three by about 6% for grain, 11% for total biomass, and 20% for hay dry matter.

Crop water balance

Between the September–October and May soil-water measurements rainfall averaged 264.5 mm, of which a mean of 92.8% (annual range 89.1–96.5%) could be accounted for as seasonal evapotranspiration (ET) (Table 6). The remaining

Table 6. Treatment effects on seasonal evapotranspiration (ET): means across rotations† at Breda.

	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	Mean
Total rainfall (mm)	225.3	260.2	267.8	298.6	214.8	359.8	225.0	264.5
ET (mm)								
Treatment 1‡	209.1	244.5	256.9	271.5	203.2	325.3	219.2	247.1
Treatment 2	208.7	241.3	255.2	269.0	204.5	324.9	214.6	245.5
Treatment 5	209.1	241.0	254.2	257.5	207.5	323.8	217.1	244.3
Mean	209.0	242.3	255.4	266.0	205.0	324.6	217.0	245.6
Mean as % rainfall	92.8	93.1	95.4	89.1	95.4	90.0	96.5	92.8
Unused rainfall (mm)	16.3	17.9	12.4	32.6	9.8	36.0	7.9	19.0

†Based on neutron-probe readings, to a depth of 150 cm, taken each season in late September or early October and in May. Rainfall values are not always identical with those given in Table 1 because periods of measurement differed slightly; ‡for individual tillage–residue treatment details see Materials and Methods section.

7.9–36.0 mm (mean 19.0 mm) remained as post-harvest subsoil storage, much of which was slowly evaporated during the following summer (May–September). Measured mean losses from the profile over this period varied from 12–15 mm after relatively low-rainfall cropping seasons, like 1990–91 and 1994–95, to 27 mm after the high-rainfall season (1995–96). Thus, the soil profile was at its driest at the time of the pre-season measurements and always showed a net gain in moisture content over the period of cropping (mean 17 mm).

Generally, in low-rainfall situations, crops tend to use almost all the available water irrespective of management treatment. Any yield differentials arise from small differences in the timing of water use and its partitioning between evaporation and transpiration. Differences here in seasonal ET between the three tillage–residue management treatments were very small, around 1–3 mm a^{-1}. The effect of rotation was also small (Table 7). In the B–B rotation, water use was not appreciably affected by the P-fertilizer regime. In the B–V rotation, on average,

Table 7. Crop rotational effects on seasonal evapotranspiration (ET): means over seven years at Breda.

	Rotation				
	Barley – Barley		Barley – Vetch		
	60 kg P ha^{-1}	0 kg P ha^{-1}	60 kg P ha^{-1}	0 kg P ha^{-1}	Mean
ET (mm)					
Treatment 1†	250.3	250.4	250.6	237.1	247.1
Treatment 2	248.3	246.1	251.0	236.4	245.5
Treatment 5	245.5	244.8	251.8	235.0	244.3
Mean	248.0	247.1	251.1	236.2	245.6

Seven-year means of two replicates each with two access tubes in 20 kg N ha^{-1} subplots; †for individual tillage–residue treatment details see Materials and Methods section.

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Table 8. Treatment effects on cumulative values of evapotranspiration (ET) during the 1990–91 season at Breda†.

	3 Oct.	12 Nov.	28 Jan.	21 Feb.	14 Mar.	3 Apr.	5 May	21 May
Elapsed rainfall (mm)	0.0	30.6	82.3	110.3	118.1	174.5	222.9	225.3
Cumulative ET (mm)								
Treatment 1‡	0.0	13.2	52.3	80.2	96.6	137.6	195.6	209.1
Treatment 2	0.0	13.7	51.6	79.7	95.9	137.2	195.5	208.7
Treatment 5	0.0	13.4	48.4	76.0	93.7	134.1	195.0	209.1
Difference§	0.0	−0.1	−3.6	−4.0	−2.5	−3.3	−0.5	+0.2

†All values are means of values derived from neutron-probe readings to a depth of 150 cm in replicate plots under each of the four rotational crops under each management treatment; ‡for individual tillage–residue treatment details see Materials and Methods section; §difference between Treatment 5 and the mean of Treatments 1 and 2.

vetch used approximately 15 mm less water than barley, but barley used only about 3 mm more than the corresponding (P-fertilized) barley in the B–B rotation. Most of the extra water left unused in the soil profile by the vetch (about 12 of the 15 mm) was lost during the subsequent summer period.

Although management treatments had very little effect on total water use, there is some evidence of differences in the pattern of water use within the growing season. Consistently across seven seasons, cumulative ET values for each crop under Treatment 5 (zero tillage, with all barley residues retained) lagged slightly behind those for the corresponding crops under Treatments 1 and 2. That is, soils under Treatment 5 became relatively wetter during November and December and remained wetter until mid-March or later. In the first, rather dry, season (1990–91), the maximum difference in total profile moisture content was only 4 mm (Table 8). In the six subsequent seasons (1991–97) higher maxima were recorded (6, 11, 22, 8, 13 and 8 mm, respectively). Convergence between treatments towards very similar total seasonal ET values occurred only during April and early May. This implies that, in Treatment 5, less water was used (mainly through soil evaporative loss) during the early stages of the season, so that slightly more was available at the stages of rapid growth and grain-filling.

In all the soil water data, differences between Treatments 1 and 2 were very small and inconsistent. The presence or absence of barley stubble on the soil surface from May until October when the soils were tilled made no appreciable difference to the soil water budget. Any different result was unlikely, given the dryness of the soil surface layers and the generally low level of evaporative loss recorded across all treatments at this time.

DISCUSSION

Although annual yield differences failed to show much statistical significance, a very small but fairly consistent trend was evident over the seven years of the trial. Particularly in the B–V rotation, zero-till systems (Treatments 4 and 5) were somewhat more productive than the other three treatments. In terms of vetch hay yields, this difference reached 20%, but for barley, especially barley in B–B rotation, treatment differences were much smaller and less consistent.

Simple analysis of seasonal ET values showed that the water budgets of individual cropping seasons were essentially independent of those that preceded and followed them and, irrespective of tillage and residue management system, each crop depended solely on the current season's rainfall. However, the within-season soil moisture data indicated that the management system may have affected the timing of the use of that rainwater. The early-season increase in profile moisture content, relative to its October pre-rainfall status, was consistently greater in no-till plots. It seems unlikely that this difference arose from moisture losses during the tillage operation since sweep tillage disturbs only the top 10 cm of soil, which is usually very dry at that time. It is more likely a result of what happened to subsequent incoming rainwater.

The initial hypothesis for this trial was that the retention of residues with zero tillage would improve the soil moisture regime by increasing infiltration and reducing evaporation. In fact, infiltration is not a serious problem at this site, particularly early in the season when the soil is still extensively cracked, and runoff from this flat field has not been observed. However, the ability of barley residues, stubble or lying straw to reduce evaporation by shading and reducing wind speed may be significant, mainly before planting and early in the growth period. The persistence of the soil moisture difference as late as March is a little surprising, for by this time cover provided by the live crop greatly exceeded that contributed by previous crop residues, but a small mulching effect may have remained. Alternatively, the persistent difference may reflect a temperature rather than a water limitation effect on crop growth during much of the winter period. The extra water was not needed until ambient temperatures and evaporative demand began to increase during March.

It is clear that the slightly greater water storage achieved during the early winter allows for slightly greater ET during late growth. Insofar as this extra water contributes to transpiration, the crops in no-till plots have a small advantage. While this may account for the small observed differences in yield, it also raises the question as to why these differences were appreciable only in the vetch crop. The small enhancement in water availability was similar for both crops. No definitive explanation for this can be offered from the present results. It may be noted only that vetch accumulates biomass much more slowly than barley during the coldest winter period, yet it matures earlier. It grows and develops very rapidly during March and April and may therefore respond more than barley to extra moisture at that time.

CONCLUSIONS

To a degree, the results from this trial are consistent with many findings elsewhere and it can be concluded provisionally that the use of zero-till technology, with crop residue retention, can confer a small advantage vis-à-vis sweep tillage under northern Syrian conditions, as exemplified by the Breda station. This advantage appears to comprise the retention in the soil of a slightly greater proportion of the early winter rainfall for use by the crop in the spring. The effect of this on barley yields is almost negligible. On yields of vetch in rotation with barley the effect is greater particularly on biomass production but it is still only small. In sweep tillage systems timing of tillage and stubble retention prior to tillage had no consistent effect on crop yields or (with respect to residue retention) on soil moisture status.

There is little in these findings of immediate value to farmers. In this environment any advantage to be gained from the conservation farming techniques tried here is appreciable only for vetch in the vetch–barley rotation. Although benefits from the adoption of such a rotation can be demonstrated (Jones and Singh, 1995; 1999), most farmers still prefer to grow barley after barley, and to carry off or graze off most of the residues. This situation seems likely to prevail until a more attractive forage legume is developed or pest build-up under monocropped cereal drives farmers to consider alternatives. Even then, the considerable capital outlay needed to introduce zero-till (direct-drill) equipment, even on a commercial hire basis, would be difficult to justify. Where wind erosion is a hazard, the solution probably lies in early post-harvest tillage (after stubble grazing) to roughen the soil surface or, in sandy soils, the planting of economic windbreaks. Farmers would preserve stubble against wind erosion only if it also markedly increased subsequent crop yields. On present evidence this appears unlikely.

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