Comparison of no-tillage and conventional tillage in the development of sustainable farming systems in the semi-arid tropics

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Summary. The results of 5 short-term (4–8 years) experiments and farm demonstrations in which no-tillage technology was compared with conventional or reduced tillage in the semi-arid tropics of the Northern Territory and Far North Queensland, during the mid 1980s to mid 1990s, are reviewed.

In the Douglas–Daly and Katherine districts of the Northern Territory, dryland crops of maize, sorghum, soybean and mungbean sown using no-tillage with adequate vegetative mulch on the soil surface have produced yields comparable with, or higher than (especially in drier years), those obtained under conventional tillage. The importance of a surface mulch in ameliorating soil temperature, moisture and fertility, and in reducing soil movement and loss in crop production in the semi-arid tropics was confirmed.

Management of mulch (pasture, crop residues and weeds) will be crucial in the application of no-tillage technology to the development of mixed dryland crop and livestock enterprises in the semi-arid tropics.

Introduction

In the tropics, the introduction of no-tillage farming systems that include stubble or mulch retention and the use of knockdown herbicides has been shown to improve crop establishment and growth through the amelioration of the adverse effects of high soil temperature, high rainfall intensity (causing soil dispersion, erosion and crusting), and water deficits (Lal 1975; McCown *et al.* 1980, 1981; Thomas *et al.* 1990; Gibson *et al.* 1992; Radford *et al.* 1992; Abrecht *et al.* 1996). If soil drying can be delayed for few days as a result of surface mulch, both temperature and soil strength will be lower during the emergence of crop seedlings (Bristow 1988). McCown *et al.* (1980) reported that temperatures exceeding 42°C for up to 4 h/day are common at Katherine in the Northern Territory, and high enough to cause severe reduction in seedling emergence under conventional tillage. Abrecht and Bristow (1990) found that mulching increased the length of the first internode positioning of the apical meristem and increased shoot growth rate before and after emergence.

Research on no-tillage cropping was begun in the semi-arid tropics of north-west Australia by the Animal Industry and Agriculture Branch of the Northern Territory Administration in the early 1970s but, because of lack of suitable planting machinery, little was achieved. However, no-tillage establishment of improved pastures was practised extensively from mid 1960 to the mid 1970s using fire or grazing to create a seedbed and reduce competition by native species (Sturtz *et al.* 1975).

In the late 1970s, a research program on conservation tillage and mulch farming was initiated by CSIRO at Katherine Research Station (14°28'S, 132°18'E) with the aim of ameliorating soil crusting, improving crop establishment and reducing soil erosion problems associated with conventional tillage (McCown *et al.* 1985). Subsequently, CSIRO, Northern Territory Department of Primary Industry and Fisheries (DPIF), machinery–chemical companies and private farmers developed and tested farm machinery for conservation tillage in the Katherine and Douglas–Daly (13°51'S, 131°12'E) districts (Gould *et al.* 1996*a*). Research and demonstration trials were conducted on both research stations and commercial properties using a farming systems approach, integrating conservation tillage, legume leys, crops and livestock (McCown *et al.* 1985). The need for these studies was accentuated by the difficulties encountered by project farmers growing crops in the Douglas–Daly district during the 1980s under the former Agricultural Development and

Marketing Authority (ADMA) (Chapman *et al.* 1996; Price *et al.* 1996).

In the mid 1980s, the Cropland Erosion Research Project (CERP) was established in the Douglas–Daly district under the National Soil Conservation Program (van-Cuylenburg 1986–87). Large-scale plots were set up to show farmers how no-tillage or reduced tillage practices could improve machinery trafficability, create a more favourable seedbed environment for crop establishment and reduce soil erosion, compared with conventional tillage. During the same period, crop rotation x tillage studies were begun to determine the effects of tillage practice on crop yield and nutrient requirements, and on long-term soil fertility.

This paper draws together data from several tillage experiments conducted in the Katherine and Douglas–Daly districts of the Northern Territory during the past 10 years and reviews similar work at Pinnarendi, south-west of the Atherton Tableland in Far North Queensland, in an effort to compare no-tillage with conventional tillage for crop production in the semi-arid tropics.

Materials and methods

Sites and experiments

Five tillage experiments, conducted on both research stations and commercial farms during the mid 1980s–mid 1990s, form the basis of the comparisons in this paper. Three experiments were conducted in the Douglas–Daly district, one at Katherine and one (a semi-commercial trial) at Pinnarendi in Far North Queensland. Crops grown were sorghum, maize, soybean, mungbean and peanut. Legume leys, where used, were *Stylosanthes hamata* cv. Verano, *Centrosema pascuorum* cv. Cavalcade and *Macroptilium atropurpureum.* Sites, tillage treatments, attributes measured and other details are summarised in Table 1.

Soils

The soils at all experimental sites are loamy and sandy textured red earths of low fertility and low water holding capacity. They are easily erodible and prone to crusting after dispersion by rain. Clay content may reach 30% in the surface soil and 50–70% in the subsoil (Lucas *et al.* 1985; Williams *et al.* 1985; Grundy and Bryde 1989). Formerly described as massive sesquioxidic soils, these soils have been reclassified recently as Kandosols (Isbell 1996).

Rainfall

Annual rainfall in the Douglas–Daly district during the 1980s was generally below that of the 1970s which showed a peak in the long-term trend line (G. Kirby pers. comm.). In addition, rainfall distribution during the main growing season was much less favourable during the 1980s than during the previous decade. According to local sources, there were 6 poor cropping seasons, 3 fair seasons and 1 very good season during 1981–82 to 1989–90, compared with 1 poor season, 3 fair seasons, 1 good season and 4 very good seasons during the 1970s (T. Price pers. comm.).

Tillage treatments

Most farmers in the semi-arid tropics of northern Australia use intensive, conventional tillage practices to

Table 1. Summary of experiments

NT, no-tillage; CT, conventional tillage; RT, reduced tillage; MT, minimum tillage

Seasons	Crops	Plot size (ha)	Treatments	Reps	Data collected	Reference
			Experiment 1, Katherine Research Station			
1984–86	Sorghum	0.12	NT, CT with and without mulch	2	Yield, soil N, infiltration	Dalgliesh and McCown (1996)
			Experiment 2, Douglas–Daly Research Farm			
1984–88	Maize, soybean	0.33	NT, CT, rotations	3	Yield; soil moisture and nutrients	Thiagalingam *et al.* (1991)
1989–95	Maize, soybean, sorghum, mungbean	0.33	NT, CT	3	Yield, soil nutrients	Thiagalingam *et al.* (1994); Thiagalingam, Gould and Shottan unpublished data
			Experiment 3, Douglas–Daly Research Farm			
1985–89	Maize, soybean	4	NT, MT, CT	0	Yield, soil runoff	Dilshad and Bateman unpublished data
			Experiment 4, Douglas–Daly Commercial Farm			
1985–87	Sorghum	10	NT, CT	3	Yield; soil moisture, temperature, strength, and loss	van-Cuylenburg (1986–87)
			Experiment 5, Pinnarendi			
1985–89	Sorghum, peanut, Verano	1.4	NT, CT, RT	0	Yield, soil organic C, soil N	Cogle *et al.* (1995)

control weeds and prepare seedbeds for their crops. Such practices typically include a primary cultivation with an offset disc plough (a single furrow, 1-way disc plough may be used on new land), followed by 1 or 2 passes with a chisel plough or other tined implement, depending on soil condition and amount of weed growth. This land preparation is often followed by 1 pass with tined harrows. The crop is then sown with a conventional tined combine drill to which a light trailing cover harrow is usually attached. Alternatively, a conventional row crop planter of some kind may be used, generally with tines removed, if the machine was not designed to be trash clearing.

Conventional tillage. After rain in November–early December, plots were cultivated with offset discs followed by a chisel plough fitted with finger harrows.

No-tillage with mulch. Regenerating vegetation (pasture–weeds) was allowed to grow following the onset of the wet season until 1 week before the anticipated sowing date. At this stage, the vegetation was sprayed with a knockdown herbicide. The resulting mulch varied from predominantly legume material (Table 1, experiment 1) to mainly weed grasses and broadleaf plants in the experiments at Douglas–Daly. Mulch quantity ranged from about 2–4 t/ha. The only soil disturbance was that caused by the Buffalo planter.

No-tillage without mulch. Before the wet season commenced, surface residue was removed leaving a bare soil surface. This treatment simulated the situation where heavy grazing left the soil surface bare by the end of the dry season. Otherwise, the treatment was identical to the no-tillage with mulch treatment.

Minimum tillage (Table 1, experiment 5). Primary and secondary cultivations were undertaken with tined implements (chisel plough with sweeps and rod weeder) leaving most of the plant residues on the soil surface. The planter used was a Mason SR Integral fitted with tines.

Herbicides

Glyphosate (at recommended rates) was the knockdown herbicide. Atrazine was used for weed control in maize and sorghum crops, and metolachlor in peanut and soybean crops.

Results and discussion

Effect of tillage treatments on crop and soil attributes

Crop establishment. Under experimental conditions over 4 years at the Douglas–Daly Research Farm, the emerged populations of soybean sown using no-tillage were significantly higher than those sown using conventional tillage, with differences within individual years varying from 132 (1985–86) to 44% (1986–87) (Gould *et al.* 1996*b*) (Table 1, experiment 2). During the same period, soybean and other crops grown on commercial farms in the same district using conventional tillage failed to establish successfully. This was largely the result of high soil temperature due to lack of surface mulch resulting from over-intensive grazing of stubble before the land was prepared for sowing (Price *et al.* 1996).

At Katherine Research Station, sorghum sown using no-tillage established better, showed better rooting ability and water utilisation, developed more rapidly and produced a higher grain yield compared with sorghum grown under conventional tillage (Dalgliesh and McCown 1996) (Table 1, experiment 1). In contrast, at Pinnarendi in a similar environment under semi-commercial conditions, but where surface mulch was apparently not sufficient to reduce soil temperature and weeds were poorly controlled, yields of peanut, maize and sorghum were lower under no-tillage than under reduced tillage [Cogle *et al.* (1995) Table 1, experiment 5)].

From these results, it is clear that the presence of an adequate cover of mulch on the soil surface at planting had a beneficial effect on crop establishment, growth and development. Since no-tillage or reduced tillage systems provide the best means of creating these favourable conditions, their adoption in crop production should be an essential part of any strategy to develop sustainable farming systems in the semi-arid tropics. It is also evident that if livestock are to be integrated in ley farming enterprises, stocking rates on pastures and/or crop residues during the dry season must be managed to ensure there is adequate mulch cover for successful establishment of the following crop.

Table 2. Effect of no-tillage (NT) and conventional tillage (CT) on maize, soybean, sorghum and mungbean yields at Douglas–Daly Research Farm (Table 1, experiment 2)

Year	Yield (t/ha) NT	Yield (t/ha) CT	l.s.d. ($P = 0.05$)	NT yield increase over CT (%)
		Maize		
1985	3.99	3.61	n.s.	11
1986	3.69	1.60	0.85	131
1987	4.06	3.74	n.s.	9
1988	2.83	1.35	0.41	110
1992	3.74	3.43	n.s.	9
Mean	3.66	2.75		33
		Soybean		
1985	2.74	2.59	0.118	6
1986	2.18	1.48	n.s.	46
1987	2.20	2.00	n.s.	9
1988	2.29	1.77	n.s.	29
1993	1.76	0.68	0.199	159
Mean	2.24	1.71		31
		Sorghum		
1989	3.25	2.90	n.s.	12
		Mungbean		
1995	1.79	1.53	n.s.	17

Table 3. Effect of no-tillage (NT), minimum tillage (MT) and conventional tillage (CT) on rainfall runoff and yield of maize and soybean at Douglas–Daly Research Farm (Table 1, experiment 3)

Year	Yield (t/ha)			Runoff (mm)	
	NT	CT	MT	NT	CT
		Maize			
1985	3.76	3.60	3.72		
1987	4.10	4.08	3.68		
1989	5.90	5.52	5.04		
Mean	4.59	4.40	4.15	526	824
		Soybean			
1986	1.38	1.23	—		
1988	1.46	1.30	1.02		
Mean	1.42	1.27	1.02	103	208

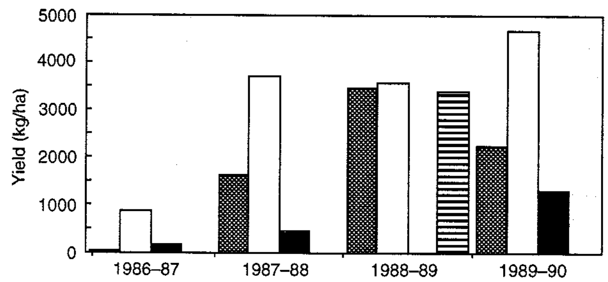

Figure 1. Effect of tillage treatments on sorghum grain yield grown at Katherine in four seasons. Stippled bars, conventional tillage; open bars, no-tillage with mulch; solid bars, no-tillage—bare; striped bar, minimum tillage.

Crop yield. Average maize and soybean yields (5 crops each) over 11 years (1985–95) at Douglas–Daly (Table 1, experiment 2) were 33 and 31% higher, respectively, under no-tillage than under conventional tillage. Sorghum and mungbean yields (1 crop each) showed a similar trend (Table 2).

In seasons with prolonged dry spells or with low rainfall (1986 and 1988), overall maize yields under no-tillage exceeded those under conventional tillage by 131 and 110%, respectively. Also, in one season, soybean yield was 159% higher under no-tillage compared with conventional tillage; the difference was attributed primarily to higher established plant populations under no-tillage (Thiagalingam *et al.* 1994). Similarly, in another soybean–maize rotation experiment on Tippera clay loam (Rhodic Paleustalf) at Douglas–Daly (Table 1, experiment 3), maize and soybean yields were generally higher under no-tillage compared with conventional and minimum tillage (Table 3). The differences were attributed to less runoff under no-tillage compared with conventional tillage. Also, runoff was found to be lowest under no-tillage soybeans and higher under maize, compared with soybeans, irrespective of tillage (Table 3).

In an experiment conducted at Katherine Research Station (Table 1, experiment 1) in which the effects of 4 tillage treatments on sorghum yield were compared over 4 years, the no-tillage with surface mulch treatment outyielded conventional tillage by an average 79% (Fig. 1). Sorghum grown under no-tillage with mulch increased 4-fold compared with the no-tillage without mulch treatment, indicating the importance of mulch in a no-tillage system, especially during dry years. These large yield increases were attributed to a more favourable seedbed environment and better rainfall

Table 4. Effect of tillage on nutrient content in soybean (S) and maize (M) grain at Douglas–Daly Research Farm (Table 1, experiment 2)

NT, no-tillage; CT, conventional tillage

Tillage	Nitrogen (kg/ha)		Phosphorus (kg/ha)		Potassium (kg/ha)		Sulfur (kg/ha)		Zinc (g/ha)	
	M	S	M	S	M	S	M	S	M	S
					1984–85					
NT	60	178	14	16	19	53	4	7	99	103
CT	59	164	12	14	17	48	4	7	87	93
l.s.d. (P = 0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
					1985–86					
NT	60	120	20	12	25	45	4	6	135	98
CT	27	72	9	8	11	29	2	4	67	72
l.s.d. (P = 0.05)	14.6	n.s.	6.5	n.s.	8	n.s.	1.2	n.s.	52	n.s.
					1986–87					
NT	64	128	14	14	17	41	4	5	—	—
CT	65	116	13	13	16	36	4	5	—	—
l.s.d. (P = 0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	—	—
					1987–88					
NT	48	135	8	12	11	49	3	5	62	88
CT	24	114	4	11	6	42	1.5	5	35	82
l.s.d. (P = 0.05)	6.0	n.s.	1.3	n.s.	2.6	n.s.	0.41	n.s.	13	n.s.

infiltration due to the presence of mulch (Maurya and Lal 1981; Unger *et al.* 1986; Dalgliesh and McCown 1996). Furthermore, yields were higher when the cover crop was killed 3 weeks before sowing, instead of at sowing, indicating that early killing resulted in higher conservation of soil moisture, especially during dry years. Farm demonstrations by the DPIF at Katherine (O'Gara 1996) have also shown that sorghum yield can be higher under no-tillage compared with conventional tillage, especially during dry years when yield under no-tillage exceeded the district average.

In a 4-year trial under semi-commercial conditions at Pinnarendi (Table 1, experiment 5), reduced tillage (2 passes of a chisel plough with sweeps and rod weeder before planting with a tined planter) gave higher yields of sorghum and peanut, compared with no-tillage, in dry years. In wet years, there was no difference in yield between no-tillage and reduced tillage. Conventional tillage was not included as a treatment in this study. Crop yields were, however, low in both tillage treatments because of poor weed control and unfavourable seasons (Cogle *et al.* 1995).

The positive response to no-tillage, compared with conventional tillage, under experimental conditions at Douglas–Daly and Katherine contrasts with that obtained at Pinnarendi. This emphasises not only the importance of season and site in determining the response to no-tillage but also of management, i.e. getting the technology right under commercial conditions, especially in dry years when the yield benefit is expected to be greatest.

Nutrient uptake by crops. Little information is available on the nutrient uptake and utilisation of nutrients by crop plants under no-tillage and conventional tillage in north-western Australia. However, in 1 trial with maize and soybean at Douglas–Daly Research Farm (Table 1, experiment 2),

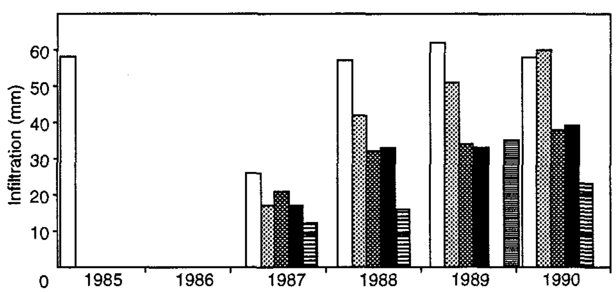

Figure 2. Effect of tillage system on water infiltration in the first minute (measurements taken 5–6 months after the last tillage event). Heavily stippled bars, conventional tillage; solid bars, no-tillage with mulch; heavily striped bars, no-tillage—bare; finely striped bars, minimum tillage; open bars, pasture; lightly stippled bars, woodland.

Table 5. Effects of tillage on soil organic carbon and nitrogen after 8 years at Douglas–Daly Research Farm (Table 1, experiment 2) and 4 years at Pinnarendi (Table 1, experiment 5)

NT, no-tillage; CT, conventional tillage; RT, reduced tillage

Depth (cm)	Carbon (%) NT	CT	RT	Nitrogen (%) NT	CT	RT
			Douglas–Daly			
0–5	1.05	0.63	—	0.12	0.08	—
5–15	0.69	0.61	—	0.08	0.07	—
15–30	0.36	0.35	—	0.05	0.05	—
			Pinnarendi			
0–5	1.35	—	0.89	0.06	—	0.04
5–10	1.15	—	0.77	0.06	—	0.05
10–20	0.88	—	0.61	0.05	—	0.05

nitrogen uptake in maize grain was significantly (P<0.05) higher under no-tillage than under conventional tillage in the drier years of 1985–86 and 1987–88 (Table 4). The trend in nitrogen uptake by soybean was similar but differences were not significant. Total phosphorus, potassium, sulfur and zinc uptake in maize and soybean grain were also generally higher under no-tillage compared with conventional tillage, and the differences were significant (P<0.05) in maize during the 2 drier years.

Water infiltration. At Katherine (Table 1, experiment 1), Dalgliesh and McCown (1996) reported that ponded infiltration (mm of water in the first 60 s measured at the end of each cropping season) under no-tillage with mulch was similar to that under conventional tillage in all 4 years of an experiment in which grain sorghum was grown following a Verano stylo pasture (Fig. 2). Infiltration was consistently lowest under no-tillage without mulch and, in all tillage treatments, was lower than that in native woodland and a long-established *Urochloa mosambicensis* pasture. While infiltration rates varied between years, the relativities among tillage treatments remained.

In this experiment, water entry during the first 60 s was used as a convenient index of the degree to which the high macroporosity and infiltration capacity of the surface soil in native woodland or long-term pasture was affected by tillage treatment. The fact that ponded infiltration was lowest under no-tillage without mulch illustrates, again, the importance of maintaining adequate surface mulch if no-tillage technology is to be used successfully on easily dispersed soils in the semi-arid tropics. Lal (1976) estimated that 6 t/ha of crop residue mulch gave an annual saving of 32% in rainfall runoff.

Soil carbon and nitrogen status. After 8 years of cropping on land which was previously under a *Macroptilium atropurpureum and Stylosanthes hamata* pasture for 2 years at Douglas–Daly Research Farm (Table 1, experiment 2), the organic carbon content of

Table 6. Effect of tillage on sorghum yield and soil physical properties on commercial farms in the Douglas–Daly district (Table 1, experiment 4)

Measurements of soil moisture (0–20 cm depth), temperature, strength and movement were taken 21 days after sowing (van-Cuylenberg 1986–87)

Soil loss was measured outside the paddock; soil movement was measured inside the paddock

NT, no-tillage; CT, conventional tillage

Tillage	Yield (t/ha)	Gravimetric soil moisture (%)	Soil temp. (°C)	Soil strength (kg/cm)	Soil movement (t/ha)	Soil loss (t/ha)
			Loamy red earth (Tippera)			
NT	1.7	14.92	39.21	3.84	0.53	0.9
CT	2.9	13.35	44.85	2.35	0.67	3.9
			Yellow podzolic (Ejong)			
NT	0.75	6.11	19.83	1.80	0.32	1.8
CT	1.02	5.43	24.47	2.08	0.35	2.7
			Sandy red earth (Blain)			
NT	2.70	10.04	40.01	3.22	0.54	0.8
CT	3.50	8.66	43.99	2.33	0.69	4.8
			Sandy red earth (Oolloo)			
NT	2.50	12.37	42.02	2.86	0.45	—
CT	3.48	11.79	45.45	2.10	0.63	8.1

the 0–5 cm soil layer was 40% higher under no-tillage compared with conventional tillage (Table 5). At Pinnarendi (Table 1, experiment 5), after 4 years, soil organic carbon in the top 5 cm was 34% higher under no-tillage compared with reduced tillage (Table 5). The results are also consistent with the findings of Francis and Knight (1993) that a gradient in soil organic carbon developed under no-tillage. Table 5 shows that under no-tillage, organic carbon was highest in the 0–5 cm layer, decreasing by 34 and 66%, respectively, in the 5–15 and 15–30 cm layers (experiment 2) and by 15 and 35% in the 5–10 and 10–20 cm layers, respectively, in experiment 5, while under conventional tillage organic carbon was distributed evenly in the 0–15 cm layer. In the subtropics, organic carbon loss has been found to increase with increasing number of cultivations (Dalal and Mayer 1986).

Total nitrogen in the surface soil (0–5 cm) in the Douglas–Daly experiment was 33% higher under no-tillage than under conventional tillage, and at Pinnerandi it was 33% higher under no-tillage compared with reduced tillage (Table 5). Other studies have also shown higher levels of organic carbon and nitrogen in soils under no-tillage compared with conventional tillage after 7 years (Packer and Hamilton 1993), as well as surface accumulation of phosphorus, magnesium, zinc and copper and a lower rate of acidification under no-tillage (Lal 1989; Thiagalingam *et al.* 1994).

At both Pinnarendi and Douglas–Daly, the potentially arable red earth soils have physical attributes which, combined with the harsh environment, make them susceptible to hardsetting leading to poor crop establishment and lower yield. Mullins *et al.* (1987) have shown that soil organic carbon levels are inversely proportional to the degree of hardsetting. Therefore, for such soils, it is important to develop farming systems that will conserve soil organic carbon and improve soil structure and fertility.

Rainfall runoff and soil physical properties on commercial farms

A survey of farms in the Douglas–Daly district by the Northern Territory Department of Lands, Planning and Environment found that extensive areas of both sandy and loamy red earths with slopes greater than 1.5% were being cropped using conventional tillage, resulting in excessive soil erosion (van-Cuylenburg 1986–87).

No-tillage and conventional tillage demonstration plots were established on 4 soil types on commercial farms and sorghum grain yield and various soil physical attributes were measured 3 weeks after sowing (Table 1, experiment 4). The results (Table 6) show that soil moisture and soil temperature were more favourable, and soil movement and soil loss were lower under no-tillage than under conventional tillage. However, on the loamy red earth soil, sorghum grain yield was significantly higher under conventional tillage than under no-tillage. This result, which contrasts with the work of Lal (1976, 1985), Freebairn and Boughton (1985), McCown *et al.* (1985) and Thiagalingam *et al.* (1991) was attributed to poorer management and the inadequate experience of local farmers and researchers. As a consequence, the higher weed incidence in the no-tillage plots was considered to have reduced crop yield relative to that of the conventionally sown plots (van-Cuylenburg 1986–87).

No-tillage technology and ley farming

If no-tillage technology is to be used to sustain cropping in ley farming systems in the semi-arid tropics, the provision and management of mulch will be as crucial as any improvement in planting or other machinery. However, balancing mulch requirements of no-tillage cropping with dry season forage needs of more intensive animal production will be a difficult compromise (Jones *et al.* 1991; Winter *et al.* 1996). Trade-offs will have to be made. While pure legume leys enable the nitrogen contribution to the systems to be maximised, their great disadvantage in no-tillage systems is their rapid decomposition when killed to provide mulch for establishment of crops (Jones *et al.* 1991; Dimes *et al.* 1996). Furthermore, legume leys are difficult to manage in pure stands in competition with a highly invasive, yet valuable, pasture grass such as *Urochloa mosambicensis*, and undesirable nitrophilous weeds. Thus, the successful adaptation of no-tillage technology to the commercial production of grain or fodder crops in more intensive mixed farming systems in the semi-arid tropics will hinge on the successful management of pasture and crop residues for mulch, as well as the consistent control of weeds and other pest organisms (Martin 1996; Price *et al.* 1996). To this end, further collaborative work by both researchers and producers is required to devise suitable strategies.

Conclusion

In short-term (4–8 years) experiments on research stations and in farm demonstrations in the Douglas–Daly and Katherine districts, dryland crops (cereals and grain legumes) sown using no-tillage with adequate vegetative mulch on the soil surface have produced yields comparable with or higher than (especially in drier years) those obtained under conventional tillage. The importance of mulch, as an environmental ameliorant, in the application of no-tillage technology to the semi-arid tropics cannot be overstated.

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