Conservation Agriculture Increased Wheat Yields and Water Efficiency in the Hexi Corridor, Gansu, China

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I. INTRODUCTION

Conservation tillage (CT) has been proven to combat drought and improve soil physical conditions in China. Increased water infiltration and reduction in water and wind erosion are achieved through zero tillage and stubble cover. CT research started with the support from the Ministry of Agriculture (MOA) and an Australian Centre for International Agricultural Research (ACIAR) project in 1992.

By the end of the 1990s, successful CT research influenced MOA to establish the Conservation Tillage Research Centre (CTRC). Following continued success, MOA established an ongoing demonstration project in northern China and by 2004 there were more than 4,000,000 ha covering 100 counties from 14 provinces under CT. The MOA initiative has spurred Northern provinces to increase the area under this advanced farming system.

After three years of field demonstrations, CT adoption has been proven to increase farmers' net income by increasing yield and reducing inputs. CT also protects the environment by reducing water and wind erosion, and improving soil condition, through zero tillage and stubble retention. CT is viewed as a new agricultural revolution by many agencies in China. The challenge now is for Chinese agricultural to embrace the next step in the revolution called conservation agriculture (CA).

In the north western Chinese province of Gansu lies the Heihe river basin, situated between Qilian mountains and neighbouring Inner Mongolia more commonly known as the Hexi Corridor. The middle section of the Hexi Corridor Region, located between the Qilian and Beishan Mountains, has an elevation from >1000 m to 2000 m, with the mean annual precipitation ranging from 250 mm in the south of the Heihe River Basin to less than 100 mm in the north.

In the past hundreds of years, reliable snowmelt water has sustained the irrigated agricultural areas along the length of the corridor. In the last 30 years, reduced snowmelt water has led to significant reductions in available surface water, while over extraction and decreased recharge has lowered water tables in groundwater systems. As a consequence,

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there is increasing desertification in the region and severe water restrictions are placed on farmers which experience up to 50 per cent reduction in allocations.

Therefore the aim of this project was to introduce and extend CA employing practices such as zero tillage, permanent raised beds (PRB) and crop residue retention, to reduce irrigation water use, wind erosion, maintain farm yields and improve farmer incomes. As demonstrated in many parts of the world, changes in soil management practices from intensive tillage farming to CA, alters the partitioning of the water balance, decreasing soil evaporation and increasing transpiration, infiltration and deep percolation, leading to increased wheat yields and water use efficiency (WEU) (Zhang, 2006).

CA holds tremendous potential for all sizes of farms and agro-ecological systems, but its adoption is perhaps most urgently required by smallholder farmers, especially those facing acute labour shortages. It is a way to combine profitable agricultural production with environmental concerns and sustainability and has been proven to work in a variety of agroecological zones and farming systems. It has been perceived by practitioners as a valid tool for sustainable land management (Anon, 2007).

However key constraints to the practical implementation of CA in Hexi are: lack of appropriate machinery; farmers are steeped in conventional tillage and basin flood irrigation methods; competition for crop residues; and whether or not an economic benefit exists from implementation of PRB in this region.

2. METHODOLOGY

Experiments were conducted at the Zhangye Water Saving Research Station near Zhangye City and at two demonstration sites located at Qingquan Town, Shandan County, 60km southwest of Zhangye City and Suzhou borough of Jiuquan City in the west of Hexi Corridor, Gansu Province. Rainfall in the region is less than 200mm/year and the soil is described as cinnamon Loess soil, low in organic matter (<1 per cent) and slightly alkaline (pH 7.7). According to the FAO-UNESCO soil map (1974), the soil in the area is Chromic Cambisol. The soils of the Heihe River Basin are generally described as porous and homogenous medium to fine sand and silt to some depth, turning gradually to large-pore gravel deposits, with limited variance across fields.

The experimental site consisted of 400m2 plots, prepared to measure soil moisture, and water application in two replicates of four treatments; PRB fresh raised bed (FRB), zero till-control traffic (ZT) and conventional tillage (CT). Bed and furrow width of the PRB sites were 65cm and 35cm respectively and bed height was 20cm. FRB has the same specifications as PRB; however the FRBs are pulled down and reformed each season. The 30cm wheel tracks in ZT were 100cm apart centre to centre. PRB and ZT retained 20cm of standing stubble after harvest, whereas FRB and CT had the majority of stubble removed during harvest and any remaining crop residue incorporated into the soil during the intensive tillage processes prior to planting.

All planting was conducted using a mechanical planter in five rows on PRB, FRB and ZT. CT sites were solidly planted following normal procedure for the region. All the fertilizers were applied at planting at an average rate of 217kg/ha for N and 205kg/ha for P. ZT and CT treatments were flood irrigated, whereas PRB and FRB were furrow irrigated without flooding the top of the beds. Irrigation volume was based on replacement of the soil moisture deficit for PRB, FRB and ZT, while CT received $100m^3$ per mu ($667m^2$) per irrigation event as is the normal farmer practice. Daily crop water use was estimated by the FAO56 ET0 model and volumetric soil moisture was continuously monitored by soil moisture probes. Soil moisture deficit was determined by point measurement using a theta probe immediately prior to irrigation and confirmed gravimetrically at various times of the year.

The demonstration sites consisted of three treatments PRB, ZT and CT in fields of approximately $3000m^2$ each. The fields were treated the same as those at the research station, except for soil moisture deficits, which were not measured. Irrigation scheduling was estimated by the local farmers' methods. Irrigation water was applied to fill the furrows, but not to "over-top" the beds of PRB. ZT and CT fields were flood irrigated according to the normal farming practices. All irrigation volumes were measured using a 1200 V notch weir at the field inlet.

3. RESULTS

The different treatments had an important effect on yield, the results are shown in Table 1, and indicate that there was no significant difference between the conventional farming practice (CT) and PRB in 2006, whereas yield in PRB during 2007, was significantly different from all other treatments and 7 per cent better than CT.

Plant population had an important deciding effect in wheat yield in the initial establishment season of 2006 and season two. CT emergence rate was 85 per cent in both seasons, whereas emergence of PRB and FRB were extremely low in 2006 at ~65 per cent. ZT performed slightly better at ~75 per cent emergence (Figure 1). In 2007 emergence for the new farming methods were similar at ~75 per cent but still considerably inferior to CT, by about 10 per cent as shown in Figure 1.

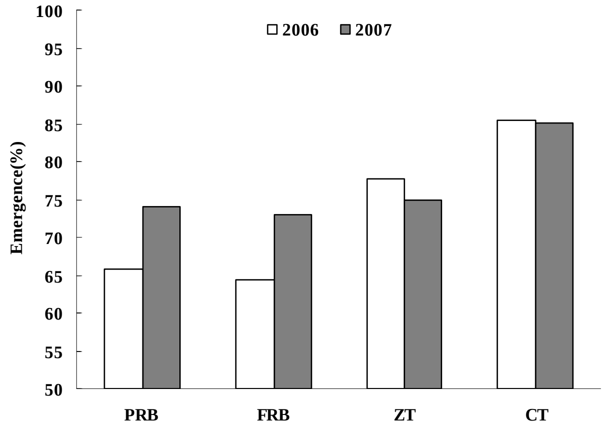

Figure 1. Wheat emergence (%) for the first two seasons at the Zhangye Research Station for the four treatments PRB, FRB, ZT and CT.

Weight per thousand grains and grains per spike was a very important factor in determining final wheat yield of the various treatments. The data in Figures 2a and b indicate that the new farming techniques outperformed CT by considerable margins in both seasons. Most significantly, PRB at 43g/1000 grains in comparison to CT at 39g/1000grains in 2007 (Figure 2a). The number of grains per spike in PRB were 3-4 more than CT in both years (Figure 2b). Although ZT improved in 2007 to be higher in grains per spike, it was considerably less than CT in 2006. FRB performed poorly in 2007 compared with 2006, which was reflected in poor emergence and reduced yield compared to the other treatments (Table 1).

Table 1. Crop yield (kg/ha) for the First Two Seasons at the Zhangye Research Station for the Four Treatments PRB, FRB, ZT and CT.

Treatment	Yield(kg/ha) 2006	2007
PRB	5575^{ab}	7132^{a}
FRB	5306^{b}	6651^{b}
ZT	5420^{b}	6356^{b}
CT	6088^{a}	6458^{b}

Note: Yields followed by the same letter are not significantly different within years at P<0.05

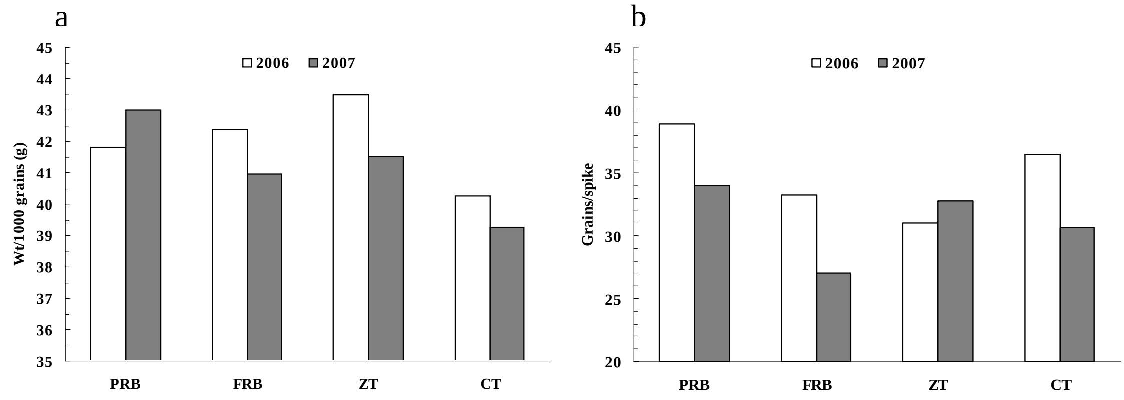

Figure 2. 1000 grain weight (a) and the numbers of grains per spike (b) for wheat in each treatment PRB, FRB, ZT and CT at the Zhangye Research Station for 2006 and 2007.

Among four different farming techniques, PRB demonstrated effective water-saving in comparison to the other treatments as shown in Table 2a and b. The number of irrigations were reduced by 1 and the volume of those irrigations applied to the PRB sites were considerably less, around 20mm in 2006 (Table 2a) and up to 50mm less in 2007 (Table2b). In general terms, PRB irrigations were often done two weeks after CT irrigations, demonstrating the extra water available to the plants under CA farming conditions. The “tillage” and “winter” irrigations are invariably large irrigations and all treatments received considerable volumes in both years in comparison to the smaller in-crop irrigations. Although these volumes were quite variable and large, there was a 21 per cent saving in irrigation water in 2006 by converting from conventional farming to PRB CA farming. The savings were more pronounced in 2007 with 43 per cent less irrigation required for PRB compared with that of CT.

Table 2. Applied irrigation volumes (mm) by date and total seasonal application during 2006 (a) and 2007 (b) for the four treatments at the Zhangye Research Station.

a

Irrigation Date	21/11/05	22/04/06	1/05/06	16/05/06	23/05/06	6/06/06	22/06/06	2/07/06	Total
PRB	174*	79		53		78	113		496
FRB	131*	73	88		78	105	132		606
ZT	153*	96		77		95	144	69	634
CT	145*	89		94		107	140	53	629

b

Irrigation Date	18/10/06	9/11/06	4/05/07	16/05/07	30/05/07	2/06/07	5/06/07	23/06/07	Total
PRB		180*		55		73		95	403
FRB	110**	131*	36		111			117	505
ZT		185*		106			81	85	457
CT	95**	177*	150		143			137	701

Note: Irrigation values followed by ** indicate tillage irrigations and values followed by * indicate winter irrigations. Both irrigations are post-harvest irrigations in preparation for winter and the following season.

Water productivity of PRB treatments in both years was considerably improved on CT. As indicated in Figure 3, the 2006 differences were marginal, but in 2007, the superior yield of PRB and 43 per cent improvement in water savings, produced WUE values >17kg/ha/mm. The WUE values included all in-crop irrigations and pre-season irrigations, but did not include rainfall, which in itself was minimal and for the most part fell in the latter stages of crop maturation.

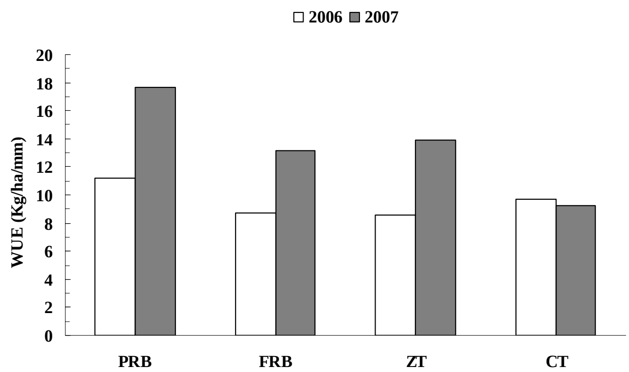

Figure 3. Water Use Efficiency (kg/ha/mm) for wheat in each treatment PRB, FRB, ZT and CT at the Zhangye Research Station for 2006 and 2007.

Crop emergence, yield and applied irrigation water at the Shandan County demonstration site followed similar patterns to those found at the Zhangye Research Station in the first year. In that, PRB emergence was poor at 76 per cent yields were similar to but less than CT, and in-crop water use was marginally reduced by 11 per cent under PRB (Table 3). However, the data presented in Table 3 did not include pre-season irrigations and therefore does not provide total crop water use for the season. Improved plant emergence in 2007 at Shandan resulted in higher yields in PRB and ZT compared with CT and a 46 per cent saving of in-crop irrigation water for PRB (Table 3).

The first season at the Jiuquan demonstration site had poor emergence issues, but not as contrasting between treatments as that experienced in other sites. PRB and ZT experienced lower yields, 5 per cent and 9 per cent respectively in comparison to CT. However, the emergence in 2007 does not appear to be the cause of less than expected optimal performance of PRB yield. Water savings under PRB were in the order of 23 per cent by comparison with CT and 9 per cent saving for ZT.

Table 3. Emergence (percentage), yield (kg/ha) and applied irrigation (mm) in 2006 and 2007 for the two demonstration sites, Shandan and Juiquan Counties, Gansu.

Treatment	Shandan 2006	Shandan 2007	Juiquan 2007
		Emergence (percentage)	
PRB	76	90	82
ZT	83	81	76
CT	86	91	85
	Yield (kg/ha)		
PRB	5033	7314	6644
ZT	5223	7624	6408
CT	5161	7104	6980
	Irrigation (mm)		
PRB	439	214	681
ZT	456	321	804
CT	489	333	877

4. DISCUSSION

During the establishment phase of the research and demonstration sites, crop emergence was poor, generally a result of inexperience in conservation agricultural techniques and the poor performance of prototype machinery, which were operating in high residue, high soil moisture, and frozen soil conditions. Even though the season commenced under adverse conditions, with poor emergence and 30 per cent loss of cropping area to wheel tracks in PRB and ZT, final yield was equivalent to CT in 2006 and considerably improved on CT in 2007.

The plants in PRB and ZT adjacent to the wheel tracks tended to compensate for the loss of area, by utilizing extra sunlight, nutrients and water available adjacent to tracks/furrows. Growing conditions in the root zone are also improved under zero traffic and tillage conditions, hence plant performance improved, which was evidenced by the increase in the number of grains per spike and the weight per 1000 grains in the PRB treatments compared with that of CT. However, other varieties such as Lumai 22 have >50 grains per spike under good light conditions (Wang, et al. 2003).

Longfu 2 used in this study did show moderate improvement achieving 39 grains per spike, but another variety may respond more favourably under CA conditions. The 1000 grain weight for PRB (43g) was comparable with other varieties also grown on zero tillage conditions in Mediterranean climates and in western China, so further gains could be limited to ~45-49g/1000grains (Pisante et al., 2001; Mazzoncini et al., 2001; Hejin, et al., 2006).

The significant limitation to yield performance under PRB and ZT was related to poor emergence. As emergence percentage under PRB and ZT approached that of CT, yield dramatically increased and in the case of the research station in 2007, the 22 per cent improvement in yield was directly attributable to a 10 per cent improvement in emergence. In any event, the yields achieved in the trial so far, exceed the national average (5.58t/ha) by a good margin, but are still short of the “super wheats” (>7.5t/ha) developed in Beijing some years ago (Anon. 2005).

However, PRB yield of 7.1t/ha is clearly approaching that mark and shows great promise for the future. Similarly in the demonstration sites, once the crop establishment issues related to poor machinery performance are resolved, the yield and other tangible benefits of the conservation agricultural methods (PRB and ZT) will be vastly superior to conventional farming methods. Much of these can be attributed to improvement in soil quality under conservation agricultural, including higher transmitting macropores, higher labile carbon, and water-stable aggregation (Chan and Heenan, 2006). French and Schultz (1984) showed that WUE for wheat was often below the potential of 20 kg/ha/mm due the presence of pests, diseases and nutritional disorders. The values achieved under PRB would suggest that the growing conditions were very conducive to wheat production in 2007 and not a great deal of improvement could be expected. Cornish and Murray (1989) noted that shire yields in southern New South Wales were usually much less than the water-limited potential.

Some factors, such as leaf diseases or insufficient nitrogen supply, may reduce the leafiness of the crop and reduce water use, which may be affecting performance in the CT treatments at all sites and those at the demonstration sites (Robinson and Freebairn 1999). However, the style of irrigation in the region leads to inefficient water use and therefore increased performance is possibly unattainable due to leaching of saturated light soils under the current basin flood irrigation methods. To some extent, this is mitigated in ZT by irrigating to the deficit, applying the water as fast as possible to improve water distribution across the field and operating in very small fields. The water savings or increased efficiencies in ZT at the demonstration sites was not as apparent, possibly due to poor deficit estimation, uneven fields and considerably longer fields, which when combined limited the efficient application of irrigation water and lowered the distribution uniformity. Under PRB conditions, filling the furrows as quickly as practicable, to just below the bed surface, has a significant effect on reducing total crop water use by 100 and 200mm as indicated in Shandan and Juiquan. The difference in crop yield and water saving performance between the demonstration and research sites is largely attributed to the availability of a range of monitoring devices and expertise to accurately irrigate to the soil requirement.

5. CONCLUSIONS

The conversion from conventional (intensive tillage, basin-flood irrigation) farming to conservation (permanent raised bed, zero till) farming is justified, in that yield was increased by more than 20 per cent and water savings of >40 per cent were realized.

The results from the intensive research site are transferable to the farming community as indicated by the modest water savings and increased crop performance at the demonstration sites.

Although the exceptional results were achieved through intensive monitoring and measurement of agronomic inputs at a research site, the level of instrumentation is not required to obtain an agronomic benefit on farm.

CA can be implemented into the Chinese rural community without loss of yield and with considerable gains in natural resource conservation, provided that the operational capabilities of the prototype machinery continue to improve.

6. REFERENCES

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