EXPERIENCES WITH CROP RESIDUE COVER AND DIRECT SEEDING IN THE BOLIVIAN HIGHLANDS

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ABSTRACT Surveys of small farmers in the Bolivian highlands have shown that moisture stress and soil erosion are the two major factors limiting wheat crop productivity. This paper discusses results of the research conducted to increase system water-use efficiency and so help increase productivity. Research began in two highland departments in 1994 to assess the effects of crop residue retention on increasing water infiltration and crop yields. In the Cochabamba high valley, yields consistently have been increased significantly by residue retention, and initial water infiltration rates are considerably higher in plots with ground cover. In contrast, at two sites in Chuquisaca the effects of ground cover have been small or occasionally negative. Direct seeding of wheat into the crop residues was originally undertaken with small single-row ox-drawn no-till seeders brought from Brazil. Although these seed the crop adequately, operator control is difficult. A prototype three-row animal-drawn small grain no-till seeder, therefore, was developed in cooperation with the DFID-funded PROMETA project and the Bolivian research institution, IBTA. Initial results of seeding efficiency and farmer acceptance are positive.

INTRODUCTION

The wheat farmers of the highland areas of Bolivia are characterized by their small farms (1-5 ha), low input use on the wheat crop, hand sowing, harvesting, and winnowing, and land preparation either by animal-drawn wooden plow or tractor-drawn disc harrow. The crop is grown in rotation with potatoes, maize, barley, peas, and faba beans in areas with average annual (summer) rainfall greater than 500 mm (Table 1). In areas receiving less than 500 mm, or with degraded soils (i.e., with low rainfall-use efficiency), wheat and barley are the two major crops, often in monoculture broken only by occasional weedy fallow periods. Wheat is seldom grown under irrigation as water is used for crops that have higher profit margins and can be cultivated more intensively. Average yields are approximately 700 kg/ha, although yields in excess of 5 t/ha are readily achievable in non-degraded areas.

A survey of wheat farmers in the department of Cochabamba in the late 1970s identified crop nutrition, landrace varieties, and weeds as the major limitations to wheat productivity. This survey shaped the wheat research program of the National Institute for Agricultural Technology (IBTA) for more than a decade. The technological recommendations—a package including fertilizer applications, semi-dwarf varieties, and chemical weed control—resulting from this research have not been widely adopted. Nevertheless, they have been the basis of the technological package used by various NGOs involved in promoting wheat crop productivity. The recommendations have generally functioned well as long as they have been accompanied by other services provided by these NGOs: credit and assistance with marketing.

More recent surveys of wheat farmers in the departments of Cochabamba and Chuquisaca, conducted in 1994 by IBTA and the recently established bilateral CIMMYT Wheat Agronomy project, showed that the major limitations to wheat productivity in both departments are two interrelated factors not identified in the previous survey: moisture stress and soil erosion. These two factors were probably the major limitations to productivity at the time of the previous survey, but were overlooked as it was assumed that they were unchangeable characteristics of the environment, or simply that they did not offer opportunities for research. This, together with the fact that IBTA did not have a working program on soil management and conservation, has resulted in an almost complete lack of research on these important factors in the past.

An analysis of the causes of moisture stress suggests that, apart from the limitations in rainfall amount, the major factors are runoff of water due to reduced infiltration rates, usually caused by surface sealing, reduced soil moisture retention as a result of important decreases in soil organic matter content (often below 1%), and evaporation from bare soils. At the same time, soil erosion is caused by runoff due to low infiltration rates and soil

| Principal crops in the intermountain valleys of the Bolivian highlands |
|---------------------------|---------------------------|
| 1,500-3,000 m asl         | 3,000-3,700 m asl         |
| < 500 mm rainfall/yr and/or degraded soils | wheat barley |
| > 500 mm rainfall/year and more fertile soils | potatoes, maize, wheat, faba beans, peas potatoes, wheat, peas, faba beans |

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surface sealing, crop production on slopes without adequate structures to control the runoff, and the use of cultural practices that increase the velocity of runoff, such as tillage and crop rows down the slope, rather than across it.

Over recent years there have been spectacular increases in the area seeded without tillage in the Southern Cone of South America. There are many benefits of direct seeding into crop residues. They include increased water infiltration and rainfall-use efficiency, increased soil organic matter, better soil structure, increased availability of nutrients, increased biological activity in the soil, increased seedling opportunity, reduced surface sealing, reduced soil erosion, and a reduction in the proportion of the crop that has to be re-seeded. When the compounded effects of these benefits accrue over several years there is also an increase in crop yields and a reduction in production costs. The difficulties associated with the system are weed control, the efficiency and cost of seeding equipment, crop diseases when an adequate crop rotation is not employed, and the need for increased farmer managerial capability.

Given the likely benefits of direct seeding and residue retention in the small farmer systems of the Bolivian highlands, the CIMMYT project decided to focus its effort on testing and promoting this system. From the beginning it was understood that there would be difficulties and that important changes in the farmers’ current production system would be required. At the same time it was apparent that the magnitude of the problem warranted a thorough evaluation. The major system limitations are the removal of the straw from the field for threshing, the use of straw as animal feed, and the grazing of the stubble. The project, therefore, also investigated alternative forage sources and harvest methods.

Although the research was not extended to consideration of structures to reduce water runoff and soil erosion, there was collaboration with other projects involved in these activities. Emphasis is on trying to maximize water infiltration and so to reduce runoff and erosion. The work focused on the “relatively flat land”—land with slopes of up to 20%—which represents approximately 70% of the area seeded to small grain cereals (wheat and barley).

RESEARCH SUMMARY

Work was started in the 1994/95 summer season to evaluate the effects of crop residue ground cover on yield and water infiltration, and to convince researchers and research directors that rainfall-use efficiency can be improved. These trials have been continued for four seasons in two departments, Chuquisaca and Cochabamba. Rainfall in the 1994/95 and 1995/96 seasons was relatively close to the long-term averages, while the 1996/97 season was extremely wet and the 1997/98 season extremely dry.

In Chuquisaca the trials were conducted at two sites with sandy loam soils and gentle slopes. However, there is a fragipan between 10 and 40 cm below the surface which restricts water infiltration and root growth. At these two sites, yield increases with ground cover were small or non-existent in the first two seasons (Figure 1) despite markedly better vegetative growth and higher spike numbers in the plots with ground cover. In the very wet season of 1996/97, barley was seeded in the plots to reduce the effect of diseases, but this proved very susceptible to excess moisture which accumulated above the fragipan, exacerbated by the increased infiltration with surface residue cover, and yield was markedly reduced by ground cover (Figure 1). In the very dry season of 1997/98 (240.7 mm of rain during the growing season) yields were very low (max. 240 kg/ha) but directly related to the amount of ground cover.

In the 1995/96 season, soil moisture at seeding was appreciably higher in the surface 60 cm in plots with ground cover (Figure 2). This resulted in the better initial growth on the plots and a 12-day delay in flowering. However, there was an increase in moisture stress during grain filling in the drier part of the season. This was especially so in 1995/96 when rainfall was lower than normal during February, March, and April (Figure 3). The crop was seeded in late December and the check plots flowered in the second week of March. It was decided that in future the trials should be seeded as early as possible (late November or early December) to allow adequate expression of the potential developed with the better initial growth with direct seeding. Nevertheless, the following two seasons have been so atypical that this hypothesis could not be properly tested.

![Figure 1. Grain yield of wheat (barley in 1996/97) in four seasons and three levels of residue retention at two sites, Tarabuco (T) and Yampara (Y), in Chuquisaca. Bars within the same cluster (site x season) that do not share the same letter are significantly different (LSD at 95% probability).](image-url)
In Cochabamba most of the results to date have been obtained on the Tarata Experiment Station, on gentle slopes with silty-loam soils and no natural impediment to drainage. However, these soils are very degraded and have soil organic levels below 1%. The soil surface seals easily when exposed to rainfall. Grain yields at all sites and in all years have been directly related to the amount of ground cover applied after the previous harvest (Figure 4). Even in the very wet 1996/97 season, there was a positive economic effect of ground cover on yield. In the very dry 1997/98 season, no yield was obtained from plots without ground cover and, on average, 220 kg/ha with 4 t/ha of straw residue. Over all sites and seasons yield has been increased economically with ground cover: 980 kg/ha without cover, and 1,450 kg/ha and 1,860 kg/ha with 2 t/ha and 4 t/ha of ground cover respectively. In general, these results have been corroborated by trials in farmers’ fields in other areas of Cochabamba, although here also there were problems with the delay in flowering associated with the better initial growth. This has resulted in an increase in frost damage at higher sites in Cochabamba.

Soil moisture at seeding in the 1995/96 season is shown in Figure 5. There were appreciable increases in soil moisture in the top 30 cm, especially with 4 t/ha of residue cover. As the Permanent Wilting Percentage of the surface horizons is between 9 and 7%, there was little available moisture in the plots without ground cover.

Soil water infiltration rates were measured at the end of the 1995/96 season (Figure 6). Initial infiltration rates, determined largely by soil surface structure, were greater with straw cover: 2 t/ha gave an 80% increase in initial infiltration rate compared to the check plots without ground cover, and 4 t/ha of residues gave an in-
crease of 280%. Equilibrium infiltration rates, determined more by conditions below the surface, were similar (ranging from 18 mm/h in the check treatment to 23 mm/h in the treatment with 4 t/ha of residue cover). However, the difference in initial infiltration rates was sufficient to ensure increases of 7 and 20 mm in total infiltration in the first hour with 2 and 4 t/ha of surface residues respectively. These differences could be observed also in the depth of penetration of rainfall. With light rains (less than 5 mm) there was little difference in depth of penetration, but with heavier rainfalls (>30 mm) moisture penetrated to twice the depth in the 4 t/ha residue plots than it did in the plots without residues.

To date the direct seeding of the trials has been done with single-row direct seeders designed for animal traction and brought from Brazil. Two models have been used, the Buffalo from Fundisul in Santa Catarina, and the Gralha Azul, designed by IAPAR, from Paraná. These seeders, although designed for seeding maize and beans, have given satisfactory results with wheat and barley. The results from trials in Tarabuco, Chuquisaca, in 1995/96 (Figure 7) are representative of results obtained from other sites and seasons. The increase in yield with direct seeding into residues, compared to the conventional farmers’ seeding method involving tillage with a wooden plow, broadcast seeding and seed incorporation with another pass of the plow, has been consistent in contrast to the effects of ground cover alone shown earlier. This is due to the effects of both the crop residue cover and the improved stand obtained with the row seeder. However, the importance of the crop residue cover can be seen in the results of a trial at the Tarata Station in Cochabamba, comparing the yield of wheat under different tillage methods (Figure 8). In all seasons the highest yields were obtained from the plots with zero tillage and crop residue retention, and the lowest yields from the plots with zero tillage and no residues.

Although results with the Brazilian single-row direct seeders have been positive, and the draft required to
pull them is only about one third of that required for the wooden plow, operator control of the implements is difficult, especially when turning at the end of the field. The machines are heavy, approximately 80 kg, and require considerable effort to turn. Both machines use cutting discs at the front to cut through the crop residues, followed by double-disc openers in the case of the Gralha Azul and a chisel opener in the case of the Buffalo. The force necessary for the penetration of the cutting disc is applied by the operator. The point of draft is high and in front of the cutting disc, and so tends to lift the back of the seeder out of the soil. This forces the operator to apply downward pressure to maintain the seeding unit in the soil.

Given the difficulties in operating the Brazilian seeders, a joint project was initiated with the Center for Research, Training and Extension in Agricultural Mechanization (CIFEMA) of the University of San Simón (UMSS), under their DFID-funded PROMETA project. IBTA also collaborated in the development and testing of an animal-drawn direct seeder for small grains, adapted to the conditions of highland Bolivia. The principal characteristics of the three-row prototype that has been developed are chisel openers and spiked wheels alongside each chisel to remove accumulating straw. The prototype has been completed recently and field tests were initiated in December 1998. At first the farmers were skeptical that their animals could pull a three-row machine, and it took considerable discussion to get them to try. The oxen appeared frightened at first by the metallic noises coming from the machine (these can be reduced once a production design is agreed upon), but soon settled down. Seed distribution and depth appeared adequate. After the trial, the farmers were skeptical not of the machine, but of the concept of direct seeding. Nevertheless, they agreed that if the crop emerged well they would definitely consider using the seeder in the future. Given the earlier results it seems certain that emergence will be successful provided sufficient straw cover can be maintained.

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