Integrating No-Till into Livestock Pastures and Crops Rotation in Uruguay

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ABSTRACT

Uruguay has a temperate sub-humid climate; C3 and C4 grass pastures are its primary vegetation, occupying 80% of the surface area (39.8 million acres). Beef, wool, and dairy are the main products. Crops occupy a portion of the remaining 20%, mainly on Argiudols and Vertisols, rotating with seeded grass and legume pastures. Continuous cropping (CC) with conventional tillage (CT) proved not to be sustainable because of decreasing soil productivity. Productivity recovery during seeded pasture periods made crops-pastures rotation (CPR) the dominant crop production system from the 1960s. The adoption of CPR is explained by better and more stable returns from year to year. But soil degradation remained important during the crops cycle of the crops-pastures rotation with conventional tillage. Farmers' and technicians' interest in no-till (NT) to reduce this problem, lower prices of herbicides, appearance of regionally made no-till planters, and agronomic research solving problems of no-till under Uruguayan conditions, are the explanations for no-till's adoption during the 1990s. in 1999/2000, 52.5% of the crop-producing farms and 25% of the dairy farms used it. This paper presents research results regarding the transition period from conventional tillage to no-tillage, and soil compaction and soil organic carbon (SOC) content in the crops-pastures rotation with no-tillage. It concludes by discussing the relative sustainability of continuous cropping vs. crops-pastures no-till based systems.

KEYWORDS

Soil quality, soil compaction, soil organic carbon, no-till, pasture crop rotation

INTRODUCTION

Uruguay is located in South America, between 30 and 35° latitude. Annual mean rainfall varies between 40 inches in the south to 55 inches in the northeast. Daily mean temperature varies from 55 ˚F in winter to 77 ˚F in summer. Winters are cold, but the soils are not frozen; summers are hot. Monthly average rainfall distribution is fairly uniform, but potential evapotranspiration is driven by solar radiation, thus during fall and winter water is abundant, and during late spring and summer it may be deficient. The country's total surface area is around 39.8 million acres. Natural and regenerated natural pastures, composed largely of C4 and C3 perennial and annual grasses, occupy around 80% of the area. Crop production involves less than 20%, mainly on Argiudols and Vertisols, and is done in rotation with planted grass and legume pastures.

From the times of the Spanish domination, livestock production formed the basis of Uruguayan economy, greatly influencing the national culture. Livestock production has evolved from bovine cattle for leather exploitation to beef and leather production. During the mid nineteen century, sheep for wool and beef were also introduced, and during the twentieth century, dairy cattle became an important component of animal production. Because of the country's climate, all animal production is made in the open field, by direct grazing of natural and planted pastures.

CROPS-PASTURES ROTATION WITH TILLAGE

Field crops production with conventional tillage was used from the times of the European settlement in a relatively small area surrounding the city of Montevideo. Despite its effect on soil degradation due to erosion and soil organic matter loss, the technology of rotating field crops with planted pastures began in the 1960s. The elements that led to the adoption of crops-pastures rotation were the recognition that forage production of natural pastures was limiting the country's animal production, leading to the idea

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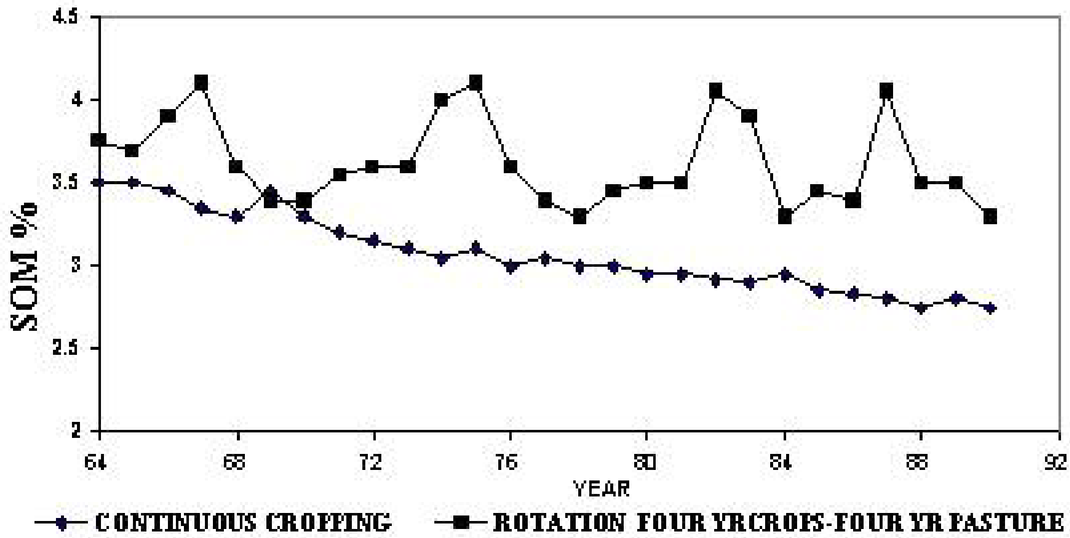

Fig. 1. Evolution of soil organic matter content from 1964 thru 1990, in two contrasting soil use systems with conventional tillage (Díaz Roselló, 1992).

of supplementing natural pastures by planting or interseeding grass and legume pastures to increase forage production, following the New Zealand model. Literature from the UK (Low *et al.*, 1963) presented evidence of improved soil organic matter content, soil nitrogen availability, and soil structure-related properties, after a period of grass and legume seeded pastures, rotated with arable crops, and that these changes had favorable productive effects on the crops that followed.

National programs promoted the planting of grass and legume pastures and the interseeding of legumes in pastures dominated by natural grasses, with the aid of phosphorus (P) fertilization. In the area of predominant natural pastures, the impact of these programs during the 1960s and 1970s was limited, with more interseeding of legumes than planting of new pastures by elimination of natural ones with tillage. Conventional tillage proved to be very risky in terms of soil erosion, and imposed a period of low forage production and utilization because of the slow initial growth of the planted perennial species. But in the smaller area of field crops production, the planting of grass and legume pastures was progressively adopted, in order to recover the productivity of soils degraded by years of continuous cropping. The performance of the planted forage legumes was generally good, because despite the degradation caused by tillage, the continuous cropped soils had higher P availability, due to moderate fertilization of crops. Consequently, the leading farms began to combine field crops production on soils where fertility was recovered after a period of planted pastures, with beef cattle fattened on these productive pastures. The technology of planting the pastures together (in the same planting operation) with the last crop of the crops cycle became very successful because of the savings of time, cost, and soil degradation.

Long-term experiments supported these processes. The oldest one started in 1962 at the Experimental Station INIA-La Estanzuela; it is still in operation, with changes during the 1980s to include reduced tillage and no-till. Reviews were done at the beginning of the 1990s (Dìaz Roselló, 1992; García Préchac, 1992a; Fernández, 1992). The total grain production of the period 1963-1989 in the crops-pastures rotation was between 59 and 63% of the ones in continuous cropping. As the crops cycle in the rotations occupies half the time, it means crop productivity per acre was increased between 18 and 26%. The higher crop productivity is a consequence of better soil quality, as seen in Fig. 1. It shows a continuous decline of the Ap horizon's soil organic matter content in continuous cropping, but in the crops-pastures rotation the soil organic matter content lost during the arable cropping cycle is recovered during the planted pastures cycle, despite a small trend of soil organic matter content decline in the long term. The soil organic matter recovery in the pastures cycle improves N availability (reducing the need of nitrogen (N) fertilizers) and soil structure. The last was documented in 1978 by soil bulk density measurements (García Préchac, 1992a) that increased from 1.12 to 1.28 Mg m^{-3} from the first to the fourth crop of the crops cycle, and decreased back to 1.2 Mg m^{-3} after 3 years of seeded pastures.

The reduction of tillage operations by half in the crops-pastures rotation than in continuous cropping, and less need of N fertilizers, translated to lower average cost during the period 1963-1989 (Fernandez, 1992). As the gross income was similar or higher in crops-pastures rotation than in

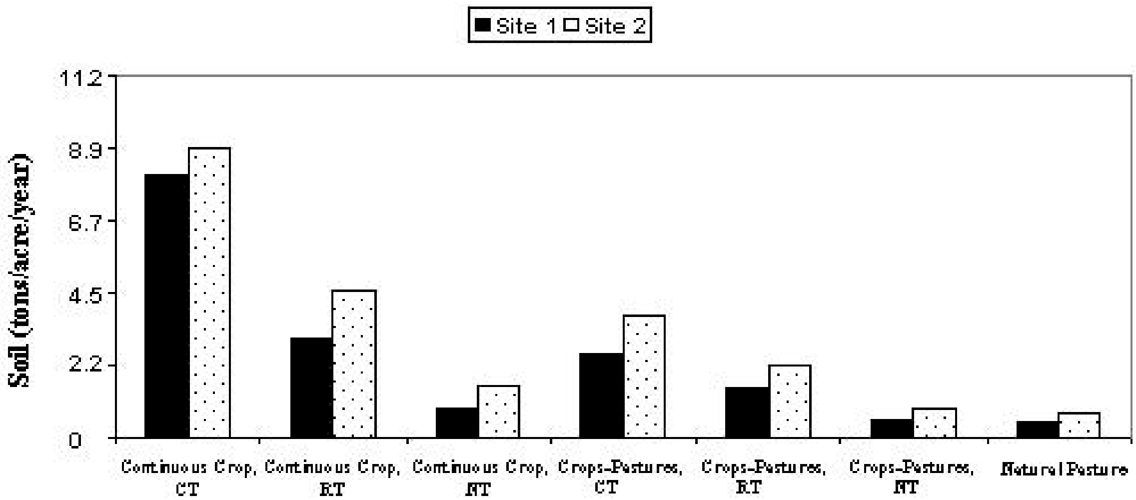

Fig. 2. Annual mean soil erosion of contrasting cropping intensities (continuous crop and crops-pastures rotation) and soil tillage [no-tillage (NT), reduced tillage (RT) and conventional tillage (CT)] in two locations, measured in Wischmeier runoff plots. Site 1, La Estanzuela, from 1984 to1990, (Sawchik and Quintana, cit. by García Préchac, 1992b); Site 2, Palo a Pique, from 1993 to 2000, (Terra and García Préchac, 2001).

continuous cropping, because of higher crop productivity and the addition of beef production, the gross margin of the crops-pastures rotation was higher (in 1990, CPR: $ 120 per acre vs. CC: $70 per acre). Also, because of greater product diversity (grain and beef vs. only grain), the crops-pastures rotation is economically a more buffered system than continuous cropping (Gross Margin Coefficient of Variation: CPR 73% vs. CC 95%), and is better able to support inter annual variations in prices of products and inputs.

Annual average soil erosion, measured in two soils during 6 years with runoff plots (Fig. 2), show the great soil conservation benefits of the crops-pasture rotation, independent of tillage intensity (García Préchac, 1992b; Terra and Garcìa Préchac, 2001). Nevertheless, the need to reduce erosion that is generated during the crops cycle with conventional tillage is important to farmers and technicians, even when contour cropping is used. The switch from conventional tillage to reduced tillage improves the soil conservation level, but the use of no-till combined with crops-pastures rotation generated soil erosion results similar to pristine natural pasture, being the state-of-the-art in terms of soil conservation during the last decade.

CROP - PASTURE ROTATION WITH NO-TILL

The use of no-till became important in Uruguay in the early 1990s and has been growing in percent of farms participating (Ernst *et al.*, 2001; Scarlato *et al.*, 2001). Driving this process were pioneer farmers concerned with soil erosion and degradation during the arable crops cycle of the crops-pastures rotation; as they became interested in conservation tillage they formed AUSID, an organization pro no-till that started contacts with similar organizations in the region (Brazil, Argentina, Chile and Paraguay), shared their experiences, and demanded research on the new technology. Roundup's® patent ended and the competition with other glyphosate-based herbicides lowered the price of this vital input to no-till. Brazilian and Argentinean no-till planters appeared in the market at competitive prices. Research was developed to solve the problems of the new technology inside the particular ecological and productive conditions of Uruguay. But undoubtedly, the increasing adoption is being boosted by the lower total cost of no-till (between 10 and 30%, according to FUCREA, a national Farmers non-governmental organization), because the reduction in tillage, machinery, and operative costs compensates for the need to use more herbicide.

Among the differences of the Uruguayan production systems with the ones in most countries with no-till experience is the crops-pastures rotation, including direct grazing, and therefore soil surface compaction by cattle trampling. Also, in the more intensive animal production systems like dairy production, not only the pastures are grazed, but also most of the crops, in particular during winter when soil water content is high. In addition, the crops that are not grazed are harvested for hay or silage, leaving very little residue on the soil surface. Thus the sustainability of these intensive animal production systems, even under no-till, is in the pasture's return of biomass to the soil during its cycle in the crops-pastures rotation (Terra and García Préchac, 2002).

Figure 3 gives insight into no-till use of different crops

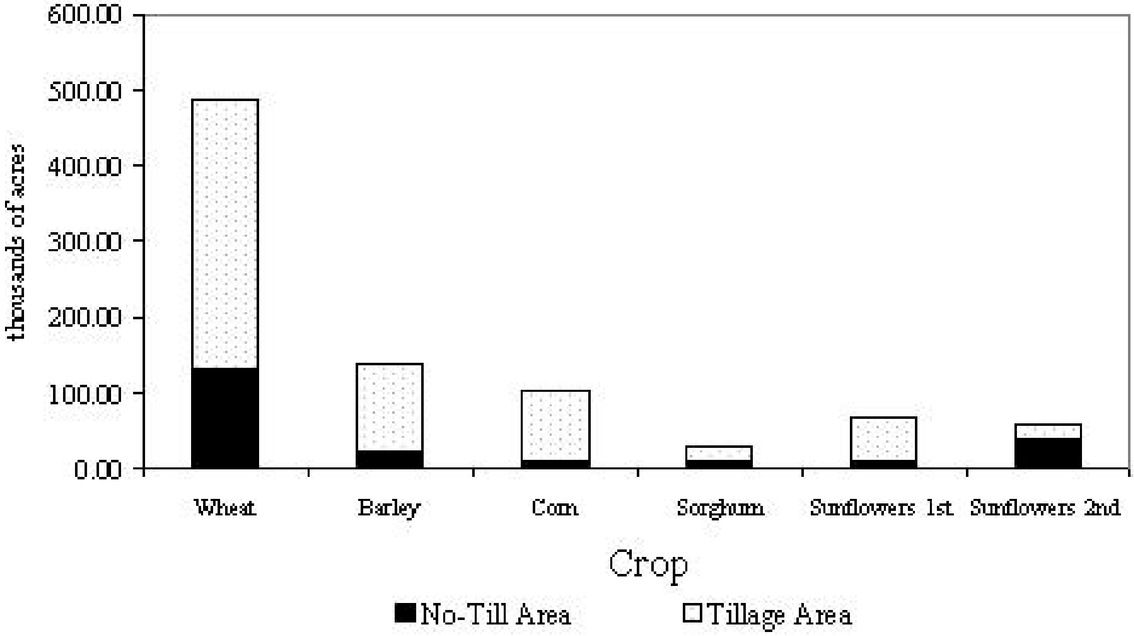

Fig. 3. No-tillage use in different crops during the 1999-2000 cropping season in Uruguay (20% of the population sampled in 2000, DIEA, 2001).

planted in 1999-2000. The main winter crop is wheat (*Triticum aestivum* L.); it shows higher no-till utilization than barley (*Hordeum vulgare* L.), the second crop in importance. The difference between these crops is that barley production is financed by the malt industry, which also dictates the technology to be used by farmers. As the industry has doubts about barley's no-till production performance, it has not yet recommended no-till as the main soil management procedure to be used.

Among summer crops, there is a striking difference in no-till use between full season crops, corn (*Zea mays* L.) and sunflower (*Helianthus annuus* L.) first, and second crops (sunflower 2nd) in an annual double-cropped sequence. Full season crops are planted in the spring, and in Uruguay they share some of the problems known in the U.S. Corn Belt, related to lower soil temperature and N availability early in the spring season. But in the case of corn, most of it is planted for silage in the crops-pastures rotation on dairy farms. In the cropping sequence used on these farms, corn is planted following an annual winter crop for direct grazing of dairy cows. Usually, as winter is the most limiting forage-producing season, dairy farmers continue using winter crops up to the beginning of the spring. This leads to: 1) low soil cover, 2) low soil-available N and water, 3) surface compacted and trampled soil, and 4) short time in fallow to recover water and N availability and to improve soil tilth.

It follows that no-till is being used both as occasional and as integral soil management technology. The latter is the case on farms where the whole operation is done using no-till. The study by Scarlato *et al.* (2001) was in the area of the country where crop production is concentrated. The use of no-till included 35% of the farms, but when referring only to crop-producing farms (there are also livestock farms, based only on pastures), the use of no-till is 52.5%. But only 10% of these farms were using no-till as integral soil management strategy. In a study by Ernst *et al.* (2001), 25% of dairy farmers used no-till, but 15% were using it as part of an integral management system. In the study by Scarlato *et al.* (2001), the planting of pastures in the crops-pastures rotation was done in 80% of the cases using no-till. Thus, the available information indicates that the use of no-till in Uruguay has been easier in systems where full season summer crops are less used in the crops cycle of the rotation. Actually, the study by Ernst *et al.* (2001) on dairy farms showed less use of corn for silage in the integral no-till farms than in the rest of the farms studied.

The Transition

The transition from conventional tillage to no-till is the most difficult period for the adoption of the new technology. Farm and research results from the first half of the 1990s (Fig. 4) indicated lower crop yield with no-till than with conventional tillage or reduced tillage during the transition period (Ernst, 2000). No-till inherits the problems of conventional tillage in the areas of the country where crops and dairy production are concentrated. In the crops-pastures rotation with conventional tillage, the end of the pasture cycle is mostly determined by bermudagrass (*Cynodon dactylon* L. Pers.) infestation. This weed is a perennial rhizome C4 grass, introduced to the country to stabilize

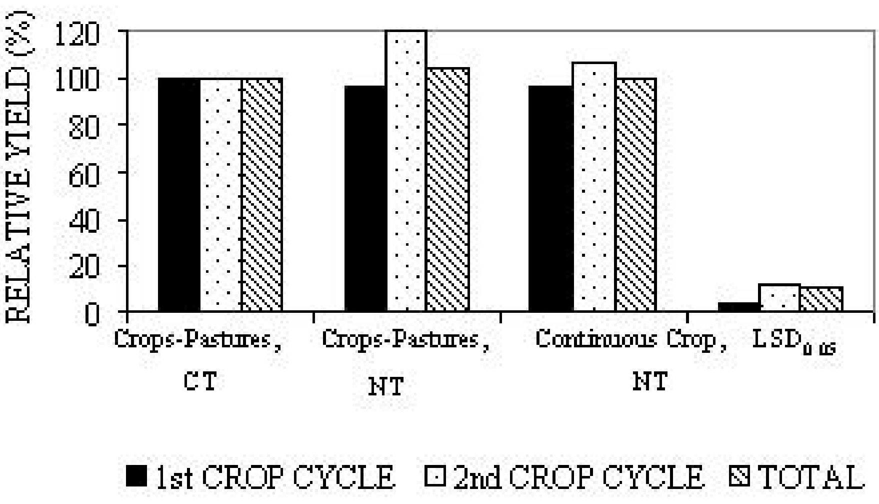

Fig. 4. Difference between conventional (CT) and no-tillage (NT) relative crop yields in the transition period (1st. Cycle); after the systems with no-tillage are more stabilized (2nd. Cycle), and mean of two cycles (Ernst, 2000).

railroad slopes at the end of the 1800s. It occupies the N enriched niches in the pastures left by death of legumes during summer droughts, and competes successfully with most of the commonly used species in the pastures. Its productivity is low because most of its biomass is dedicated to producing subterranean organs, and because the aerial part is killed by the first winter frosts. Bermudagrass, when present, is very competitive with all crops and pastures from the spring thru the fall. Tillage is effective in reducing its presence, as are glyphosate applications, but the amount of growing points underground saves bermudagrass from being totally controlled by any means. No-till farmers experience, as well as long-term experiments, demonstrate that repeated herbicide application and crops competition for light, progressively reduces this weed's presence in no-till systems. But in the transition from conventional to no-till systems, particularly when crops begin to be no-till planted on bermudagrass-invaded pastures (the most common situation), its huge underground biomass with high C:N ratio takes a long time to decompose and sequesters a lot of soil N in the process. Also, this underground biomass holds together soil aggregates; this effect, together with surface compaction due to grazing, results in poor soil tilth.

Figure 4 shows that the yield trends in the first cropping cycle of the rotations were reversed in the second cycle. Despite the fact that the second cycle reflects the effect of less bermudagrass, one reason for this is that during the first cropping cycle, results indicated the need of enough fallow time between the first and heaviest glyphosate application to the pasture and the crop planting, especially when an old pasture with bermudagrass is treated. If the herbicide treatment is to be effective, an important chemical fallow time is needed for the decomposition of the underground biomass, in order to free fixed soil N and to have soil aggregates separate, resulting in good soil physical condition.

Ernst (2000) reported no differences between wheat yields in the following contrasts in an experiment: 1) no-till in crops-pastures vs. continuous cropping, 2) corn vs. soybean (*Glycine max* (L.) Merr.) as previous crop, 3) no-till vs. conventional tillage, averaged over continuous cropping and crops-pastures. But when the contrast was between long or short chemical fallow of herbicide-treated old pastures (treatment on March 10 vs. April 23), the yield of no-till wheat planted on June 15 was significantly higher in the long fallow period (2779 vs. 1334 lbs per acre). Terra and Garcìa Préchac (2001) reported that, after perennial pastures, soil NO_3-N content in the upper 6 inches of soil at oat (*Avena sativa* L.) planting, was significantly higher in no-till plots with 70 days of chemical fallow (35 ppm) compared with no-till plots with 15 days of chemical fallow (10 ppm), and did not differ with tilled plots (33 ppm) with the same fallow time.

One common compaction problem in soils under conventional tillage is the presence of plowpans. The transition to no-till inherits this problem. The problem is eventually eliminated with time because root growth into the compacted layer generates channels, deposits organic matter, and attracts biological activity. Experimentally, the use of the paraplow has been very effective in alleviating soil compaction for no-till planting (Martino, 2001). This researcher found positive response in 11 out of 14 experiments conducted, with crop yield increases of 102, 36, 29, and 14% in corn, sunflower, barley, and wheat, respectively.

When no-till technology began, information in the literature indicated that N fertilizer application with no-till would be more than with conventional tillage, because of lower N mineralization and higher losses in no-till. A long-term experiment was started in 1995 on a pasture very close to natural conditions, but with some bermudagrass infestation (Terra and García Préchac, 2001). The experiment compared no-till with reduced till and conventional tillage, keeping the same treatments in the same plots for 5 years, planting forage crops in an annual double cropping system for direct grazing or total harvesting (hay or silage). The results did not show significant production differences

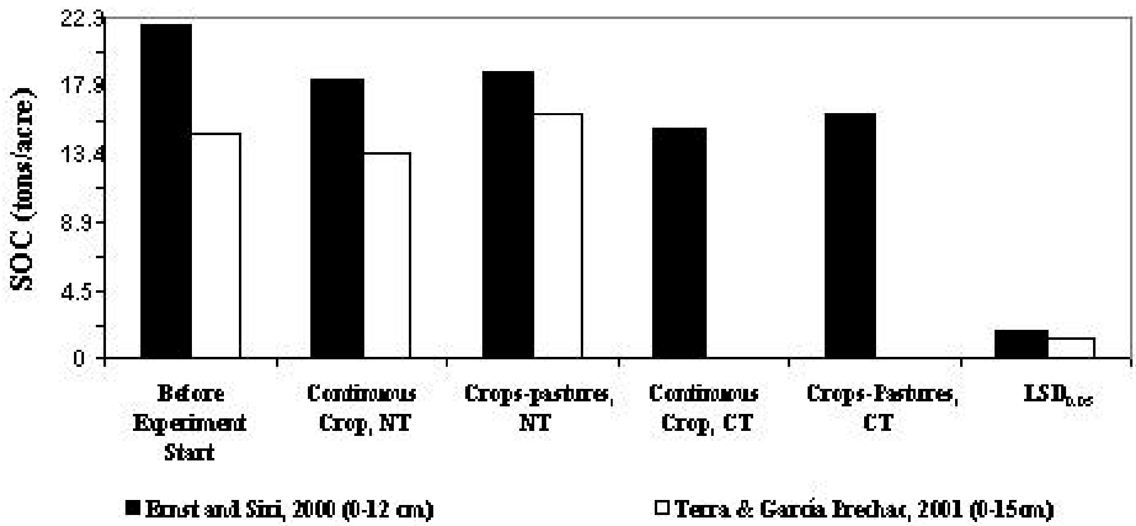

Fig. 5. Soil organic carbon (SOC) content of two experiments after one cycle of crops-pastures rotation vs. continuous cropping; in one case comparing no-tillage (NT) vs. conventional tillage (CT), and in both cases comparing to values before experiments started.

between tillage treatments or significant interaction between the tillage treatments and four rates of fertilizer N. Soil NO_3-N evolution during this period showed that the main factor generating variation was climate, with low levels during wet periods and higher levels during dry periods.

Soil Compaction

Soil compaction has been a matter of concern as it relates to no-till technology. A history of tillage use has created the impression that the only way to deal with soil compaction is tillage. Nevertheless, scientific information indicates that the main cause of soil compaction (among other consequences of soil degradation), in the medium and long term, is tillage. For example, as the crops cycle of the crops-pastures rotation advances, with more crops and tillage operations, the state of the physical properties is progressively deteriorated (García Préchac, 1992a). Conversely, as the soil is not tilled and it recovers soil organic matter content, the expectation is to have better soil structure.

If no-till is compared with conventional tillage in the short term, the soil close to the surface is more compacted under no-till (Terra and García Préchac, 2001). But at the bottom of the tilled layer, soil compaction is greater in the tilled treatments. In terms of traffic from animal grazing, and therefore, for forage utilization, this situation favors no-till. The authors report that the forage was between 10% and 30% better used by animals in no-till, compared with conventional tillage, depending on the winter soil water excess. Tillage treatments were equally grazed during winter, and the ground was prepared for no-till planting of a summer crop late in the spring. However, the results of the summer crop (grain sorghum (*Sorghum bicolor* (L.) Moench) did not show significant differences.

Two years of no-till experiments comparing the effects of different sheep stocking rates as applied to the winter forage crops, on the production of the following summer crops (sorghum and foxtail millet (*Setaria italica* L.)) did not show significantly different production, despite the differences in soil strength that were found after the winter grazing period (Terra and García Préchac, 2001).

Summarizing the results it can be said: 1) no-till planted winter forage crops can be better utilized by animals than conventional planted ones; 2) if soil is tilled for the winter forage crops, the winter grazing eliminates the effects and the following no-till summer crops are not benefited; 3) with the range of winter grazing pressures used in these experiments, no differential effects were found on the performance of the summer crops that followed.

Soil Quality

Soil organic carbon content is well known as the main soil quality indicator (Reeves, 1997). Figure 5 presents the results of two experiments. The one by Ernst and Siri (2000) started in 1993 on a very fertile Argiudol with a previous long history of use under crops-pastures rotation with conventional tillage. The SOC content of this soil at the beginning was around 12% below its content under natural pasture. The crops were harvested for grain, leaving the residues on the surface (no-till) or buried by plowing (conventional till). The experiment by Terra and García

Préchac (2001), started in 1995 on an Argiudol of low fertility, with SOC similar to the same soil under natural pastures due to insignificant crop history of 5 years in the 1980s and long-term pasture after that. The crops were directly grazed [oat-annual ryegrass (*Lolium multiflorum* Lam.) mixture] or harvested for hay (foxtail millet) or silage (corn, grain sorghum); thus, the biomass return is much lower than in the first experiment.

Results in the Ernst and Siri (2000) experiment show that under no-till the SOC remained close to the original value, while with conventional till, continuous cropping lost 20% and crops-pastures 14% of the original value; the difference between the last two systems, the expected one, was not significant. Thus, the conclusion after 7 years is that with no-till, independent of rotation with pastures, the original SOC content is maintained. It should be pointed out that the crops-pastures rotation in this case is 3 years of crops and 3 years of pastures. In the Terra and García Préchac (2001) experiment, after 4 years, continuous cropping with no-till lowered the original SOC content 7.5%, while crops-pastures rotation with no-till had 6% more SOC than the original content (more details in Terra and García Préchac, 2002).

Sustainability

Sustainability of agricultural production systems depends on control of soil erosion and the level of soil organic carbon. We conclude that crops-pastures rotation with no-till are sustainable soil use and management systems under the Uruguayan ecological and productive conditions, even when most of the aerial biomass production is harvested and exported by direct grazing or as hay or silage. When crops are harvested only for grain and residue is left *in situ*, despite some soil erosion (about half of the soil loss tolerance of 3.5 tons $acre^{-1}$ yr^{-1}), SOC indicates that continuous cropping with no-tillage could be possible. Consideration should be given to other benefits of the crops-pastures rotation, such as a more diversified system, with more buffer power against climatic and economic inter annual variations. Also, the use of agrochemicals and their potential environmental impact can be greatly reduced, as the crops-pastures rotation uses them only during the crops cycle, this is half the time, as compared with continuous cropping.

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