HISTORICAL REVIEW OF NO- TILLAGE CULTIVATION OF CROPS

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ABSTRACT

No- tillage and reduced tillage have been used since ancient times by indigenous cultures, simply because man has not the muscle force to till any significant area of land to a significant depth by hand. The ancient Egyptians and the Incas in the Andes of South America for example, used a stick to make a hole in the ground and put seeds by hand into unprepared soil. In modern, mechanised agriculture, no- tillage cultivation of crops was attempted long time ago, but it was not until the advent of modern herbicides that the technique could be put into practice. Back in the 1940s Edward Faulkner induced a change to eliminate tillage by the plough and reduce tillage in his famous book "Plowman's Folly" (1943).
According to Phillips and Phillips (1984) attention was diverted to reduced tillage in the late 1940s with the introduction of plant growth regulators developed during World War II. Klingman, in North Carolina in the late 1940s reported on no-tillage practice. In 1951, K.C. Barrons, J.H. Davidson and C.D. Fitzgerald of the Dow Chemical Co., reported on the successful application of no- tillage techniques. In the 1960s M.A. Sprague, in New Jersey, reported on pasture renovation using chemicals as a substitute for tillage. L.A. Porter, New Zealand, reported on strawberry production without tillage in the early 1960s, followed by A.E.M. Hood, and R.S.L. Jeater at Jealott's Hill, England, for small grain (Phillips and Phillips, 1984).
The invention of Paraquat in 1955 and its commercial release in 1961 led the Imperial Chemical Company, ICI, and others, to initiate intensive no-tillage research in the UK, the USA and elsewhere. In 1961 and 1962 demonstration trials were run in several farms in the United States. These demonstration plots led Harry and Lawrence Young from Herndon, Kentucky, to apply the novel technology on their farm and became one of the first mechanised farmers in the world to use modern no- tillage crop production.
No- tillage trials in Latin America were first started in 1971 by the Instituto de Pesquisas Agropecuarias Meridional, IPEAME, in Londrina, Paraná State, Brazil, in co- operation with a GTZ (German aid) project. This project set up demonstration plots in the farm of Herbert Bartz, a Brazilian farmer of German descent, in Rolandia, Paraná. After seeing the results of these plots, Herbert Bartz visited the UK and the USA, carried out research on the advances of this technique, visited ICI in Fernhurst and Harry Young in Kentucky, bought a no-tillage planter in each country, and started seeding his first soybeans under no-tillage in 1972. Thus Herbert Bartz became the first farmer to apply the technology in Latin America and to use it continuously until the present.
Compared to the Americas, no- tillage practice is much less adopted in Europe, Africa and Asia, and in many countries this soil-conserving sustainable production system is virtually unknown. Despite a wealth of research information generated at IITA, Nigeria, since the seventies, the total area under no-tillage in Africa is still very small.

INTRODUCTION

No- tillage is defined in this paper as the planting of crops in previously unprepared soil by opening a narrow slot, trench, or band only of sufficient width and depth to obtain proper seed coverage. No other soil preparation is performed (Phillips and Young, 1973). We also refer here to permanent no-tillage rather than not tilling the soil occasionally. No- tillage is the term used in North America while direct-drilling or zero tillage is used in the United Kingdom and Europe. Aerial seeding is of course the ultimate form of zero tillage.
When I was invited to present this paper on "Historical review of no-tillage cultivation of crops" at the 1st JIRCAS Seminar on Soybean Research I thought that I could accept the task, since I have witnessed an important part of this history myself. But when I tried to obtain information on what had happened outside the main no-tillage countries, information became very scarce and due to the short time frame to prepare this paper, I have not been able to gather enough information to give a comprehensive picture on the historical development of this production system. Therefore I was forced to restrict this paper to the countries where data were more readily available or where colleagues and friends provided me with information. It is very difficult to be always fair to all who have contributed over the years to the history and development of no-tillage farming over the world. Therefore I would like to apologise to those not mentioned in this paper. Also, at this point I would like to thank everybody that took his time to provide me with facts and figures on the history of no-tillage cultivation in different parts of the world. Despite the difficulties , the task of writing this paper has been a worthwhile experience and has opened my eyes to the fact that probably about 95% of the practical application of no-tillage by farmers world-wide takes place in the Americas. Therefore, a greater effort has to be made to transfer this truly sustainable production system mainly to the tropics and warmer areas of Africa and Asia. The reason for this, is that "no technique yet devised by

mankind has been anywhere near as effective at halting soil erosion and making food production truly sustainable as no-tillage" (Baker et al., 1996).
The ploughing system is considered to be an inefficient use of time and fuel and causes much "wear and tear" to the machines (Waydelin, 1994). Power requirements for soil tillage are considerable. In modern agriculture this may be a technical challenge or an economic problem, but formerly this meant hard, long-lasting labour for a large percentage of all the people that ever lived on earth. Forces required are so great that animals were used very early to make the physical stress endurable (Kuipers, 1970). But a small farmer ploughing his field with animal traction has to walk 30 to 40 km behind his plough for each hectare in which he is preparing the soil. Therefore, the reduction of tillage to the minimum necessary to produce a crop, has probably been in the minds of many farmers for a long time. But when the tractor appeared, where effort is reduced because the operator is sitting, the tendency went the other way and farmers started believing that the more tillage you do, the more yield you get. Truth was, that the more tillage you do the more erosion and soil degradation you get, especially in warmer areas.

A SHORT HISTORY OF TILLAGE

The plough has been developed in early days of agriculture and was first pulled by man and later by animals. The use of the plough is often mentioned in the Bible and one of the best known citations is "they shall beat their swords into plough shares" (Isaiah 2. V. 4.). But the plough of biblical times had nothing to do with modern ploughs of the 19th century. In those days a plough was nothing else than a branch from a tree that scratched or scarified the soil surface without mixing the soil layers. Ploughs that inverted the soil layers and thus gave a better weed control were not developed until the 17th century. Only in the 18th and 19th century did ploughs become more and more sophisticated. But it was not until the end of the 18th century that German, Dutch and British developments of this tool led to an almost perfect shape of the mouldboard, that turned the soil by 135° and was very efficient in weed control. It is this plough that avoided famine and death at the end of the 18th century, since it was the only tool that could effectively control quack grass (Agropyron repens), a weed that had spread all over Europe and could not be controlled with "conventional" tools. Because the modern plough saved Europe from famine and poverty it became a symbol of "modern" agriculture and is used as such by many agricultural research institutes, universities, agronomy schools, etc. One of these early ploughs of 1884 is displayed at the agricultural museum of the University of Hohenheim, in Stuttgart, Germany, and in a festival is taken around the city of Hohenheim each year, to commemorate the invention of this implement. By knowing the history of this tool, it becomes understandable why Europeans and especially Germans are often such fervent advocates of the plough, which has turned to be the most often used symbol of agriculture world- wide.
Against this background, the colonial powers took the plough to America, Asia and Africa, where it became an important tool for the development of newly cultivated land. But it took many decades to discover that the same tool that brought food and wealth to Europe, would bring soil erosion and degradation to the warmer environments.
Often the experts mainly from Europe have spread the concept that tillage makes the soil fertile and therefore cannot be replaced. They have not understood the significance of soil erosion, as well as intensive weathering under hot, humid conditions. This has resulted in the widespread distribution of poor, badly eroded, infertile soils all over the tropics and subtropics. Economic interests and the lack of experience of some of the expatriate experts have led, first the colonial countries and later the aid donor countries, to spread the culture of the plough in developing countries, while the so called "primitive technologies" have been classified as backward and unproductive.

EARLY CULTIVATION WITHOUT TILLAGE

No- tillage and reduced tillage have been used since ancient times by the so called "primitive cultures" for the cultivation of crops, simply because man has not the muscle force to till any significant area of land to a significant depth by hand.
The Incas in the Andes of South America and probably also most indigenous cultures around the world, have used a stick to make a hole in the ground, put seeds in the soil by hand and cover the seeds with the foot. Even today hundreds of thousands of farmers in Central and South America seed their crops using the same technology. Moreover, millions of hectares of land have been (and are today) traditionally sown with a hand jab planter without tilling the soil, after burning, in the shifting cultivation system in Brazil and neighbouring countries, long before the term no- tillage was introduced into the modern vocabulary. The slash mulch or "tapado" system in Central America and Mexico is another example of no- tillage developed by small landholders which has been used for centuries (Thurston, et al., 1994). In this system the seed is thrown after rain on top of the soil underneath a dense stand of Mexican Sunflower (Thithonia diversifolia) or other voluntary (or seeded) vegetation. Then the plants are cut and left on top of the seeds. After a few days the plants dry out and seeds germinate. In this case no tillage is performed at all.
The first possibility of cultivating crops without tillage on large scale farms occurred when 2,4-D, a broadleaf weed killer, was made available to farmers in the 1940s. Later, also Atrazine and Paraquat

became available, these being the only herbicides accessible to early farmers engaged in no- tillage agriculture.

DEVELOPMENT IN EUROPE

The invention of the herbicide Paraquat in 1955 in the UNITED KINGDOM was the start of modern no- tillage development in Europe and also world-wide. This discovery led the Imperial Chemical Company, ICI, to initiate research without soil tillage. In 1973/74 the area under no- tillage in Great Britain increased to 200,000 ha and 10 years later to 275,000 ha (Table 1), thus the UK had the second largest area under no- tillage in the world after the USA (Derpsch, 1984). Field experiments in England showed that, if well managed, direct-drilling and reduced cultivation could give similar yields of winter cereals to those after ploughing, when straw residues were burnt. However, when restrictions on straw burning were introduced and problems occurred from the build-up of weeds and volunteer cereals many farmers who used these methods resumed the use of the plough and direct drilling almost ceased to be applied (Christian, 1994).

In the NETHERLANDS research on minimum and no-tillage started in 1962, aimed at simplification of field work, saving of time and energy and improvement of farm economy. W.A.P. Bakermans and C.T. de Wit of the Institute for Biological and Chemical Research of Agricultural Crops in Wageningen, were among the first scientists to apply the novel technology. Wind and water erosion is not a real incentive for no-tillage practices in this country. From the early experiences, gained in the period 1962-1971, Ouwerkerk and Perdok (1994) concluded that in Dutch arable farming no- tillage is not feasible.

Stimulated by successful trials abroad, investigations into direct drilling systems started in GERMANY during 1966 (Bäumer, 1970). Despite intensive and long-term research carried out by Bäumer at the Institute of Plant Production of the University of Goettingen (the early experiments are still under way), by Czeratzki in Braunschweig and by Kahnt at the University of Hohenheim (Kahnt, 1969, 1976) that started in the late sixties, it is estimated that not more than 5,000 ha were under permanent no-tillage in Germany in 1997 (Friedrich Tebrügge, personal communication, 1998). On the other hand occasionally no- tillage is being increasingly practised by farmers in this country. In long- term research (18 years) carried out at the University of Giessen (Tebrügge and Böhrnsen, 1997) the authors concluded that no- tillage is a very profitable cultivation system compared to conventional tillage because of the lower machinery costs and lower operating costs. No-tillage decreases the purchase costs, the tractor power requirement, the fuel consumption, the amount of required labour as well as the variable and fixed costs. At the same time no-tillage increases the campaign performance so that it is a very powerful cultivation system. On average since the same crop yields can be achieved by no- tillage compared to plough tillage, the profit will increase. On the other hand lower yields can be accepted without any loss of profit in comparison to the conventional system. Based on the calculation of the total process cost, the relative superiority of no-tillage systems could increase further, if the beneficial environmental effects of no-tillage (e.g. less erosion, less pollution by agrochemicals) were taken into account (Tebrügge and Böhrnsen, 1997).

In FRANCE long-term experiments with different minimum tillage techniques (including no- tillage) were started by INRA and ITCF in 1970, mainly with cereals (Boisgontier et al., 1994). The authors concluded, that a comprehensive range of technical and economic data are now available in France in relation to where minimum tillage can be developed and how it can be implemented.

In PORTUGAL, Carvalho and Basch (1994) concluded that for most of the crops the direct drilling method can be applied.

No- tillage research in SPAIN started in 1982 and on the clay soils of southern Spain no- tillage was found to be advantageous in terms of energy consumption and moisture conservation, as compared to both conventional or minimum tillage techniques (Giráldez and González, 1994). In 1996, 500 no-tillage machines were used and it is possible to estimate that the area subjected to direct drilling in Spain amounts 300,000 to 350,000 ha (Gonzáles, et al., 1997). These areas represent only a small proportion (below 5%) of the area under annual crops. Although the references cited mention no-tillage, it is doubtful that they referred to no-tillage under the proposed definition in this paper. Costa (1996), writes: "It is somewhat disappointing that conservation tillage (no- tillage with 30% of soil covered by crop residues) has received so little public support". Is no-tillage being understood as synonymous of conservation tillage?

First no- tillage trials in ITALY were carried out in 1968, but it is only in the last 5 or 10 years that the technology has experienced a substantial expansion. This is due to the need for reducing crop costs and the greater availability on the Italian market of equipment for sowing on untilled soil, as well as progress in the availability of adequate herbicides. In 1994, it was estimated that this planting system was applied on a surface area well above 30,000 ha for cereals and around 3,000 ha for soybeans (Sartori and Peruzzi, 1994). More recently the no- tillage area has increased to 100,000 ha, i.e. 2% of the agricultural land used for extensive cropping (Sandri and Sartori, 1997).

In BELGIUM Frankinet and Rixhon compared ploughing to direct drilling over a 15 year period from 1967 to 1982. Yields after direct drilling were slightly higher for winter beans, as in the case of winter wheat and spring oats, 15% less for spring barley and maize, and 20% less for sugarbeet (Cannel and Hawes, 1994).

Hawes, 1994).
In SWITZERLAND Vez started research on direct drilling in 1967 showing 15% yield increases in winter wheat as compared to ploughing (Cannel and Hawes, 1994).

DEVELOPMENT IN THE UNITED STATES

Research on conservation tillage with early versions of a chisel plough was started in the Great Plains in the 1930s, to alleviate the damage caused by wind erosion, after the occurrence of the famous "dust bowl". Stubble mulch farming was developed in the Great Plains, as a forerunner of no- tillage.
Edward Faulkner's book "Plowman's Folly", first published in 1943, is probably a milestone in the changes in agricultural tillage practices. He questioned the wisdom of ploughing. Some of his statements are: "No one has ever advanced a scientific reason for plowing"; "There is simply no need for plowing in the fist instance. And most of the operations that customarily follow the plowing are entirely unnecessary, if the land has not been plowed"; "There is nothing wrong with our soil, except our interference"; "It can be said with considerable truth that the use of the plow has actually destroyed the productiveness of our soils". The statements were questioned by both farmers and researchers, because alternatives to ploughing at that time would not allow farmers to control weeds or plant into the residues. According to the Reader's Digest, "probably no book on agricultural subject has ever prompted so much discussion in the United States, at the time it was written". Five editions were printed in the first year of publishing.
Klingman, in North Carolina in the late 1940s reported on no- tillage practice. In 1951, K.C. Barrons, J.H. Davidson and C.D. Fitzgerald of the Dow Chemical Co., reported on the successful application of no- tillage techniques. In the 1960s M.A. Sprague, in New Jersey, reported on pasture renovation using chemicals as a substitute for tillage. (Phillips and Phillips, 1984).
More intensive research on chemical seedbed preparation started in the United States in the early sixties. In 1960, experiments were begun in Virginia, killing bluegrass sod with Paraquat, using Atrazine for residual control and 2,4-D for post-planting cleanup. These experiments were soon repeated in Ohio, Illinois, and Kentucky (Thomas and Blevins, 1996, Blevins et al., 1998).
In 1961 and 1962 demonstration trials were run in several farms in the US. These demonstration plots led Harry and Lawrence Young from Herndon, Kentucky, to apply the new technology on their farm in 1962, and they became one of the first mechanised farmers in the world to use no- tillage crop production. A metal plate at the site remembers the date: "First practice of no- tillage crop production in Kentucky occurred on this farm in 1962. Harry and Lawrence Young of Christian County were among first in nation to experiment with no- tillage techniques which use herbicides in providing seed bed in residue stubble. Conserves soil and water, saves time, labour, fuel and often produces higher crop yields".
Harry Young earned his B.S. and M.S. degrees at the University of Kentucky, and worked for the University before returning to the 500 ha family farm in 1954. He began experimentation with no-tillage on about 1/ 3 ha in 1962. Soon thousands of visitors went to his farm to learn about the new technology (Phillips and Young, 1973). Other farmers joined Harry Young and his brother later and began testing no-tillage corn production. At this time also machinery manufacturers started developing adequate equipment and in 1966 Allis Chalmers introduced the fluted coulter no- tillage planter. As no- tillage enabled to sow seeds immediately after harvest, soybeans produced by the no- tillage method started to be double- cropped after wheat in 1967 (Phillips and Young, 1973).
Shirley Phillips, one of the pioneer researchers of no-tillage in Lexington, University of Kentucky, wanted to prove that no-tillage was not suitable for adequate crop production. But after seeing the results, he became one of the strongest advocates and most successful propagators of no- tillage, not only in the US, but abroad as well. Because of his commitment to the system and his scientific as well as extension and lecture work, Shirley Phillips can be regarded today as the father of no-tillage technology.
Among the earliest research publications on no- tillage crop production we can cite Moody et al., 1961, Free et al., 1963, Triplett et al., 1963, Triplett et al., 1964, Lillard and Jones, 1964 and Jeater and McIlvenny, 1965. A report on a six-year comparison of no-tillage was published by Shear and Moshler in 1969.
In 1973 Phillips and Young published the book "No-Tillage Farming". This publication was a milestone in no-tillage literature, being the first one of its kind in the world. It led other people to apply and carry out research on the technology and was later translated into Spanish.
The area under no-tillage in the United States experienced a steady growth and increased from 2.2 million ha in 1973/ 74 to 4.8 million ha in 1983/ 84 (Table 1) to almost 20 million ha in 1997 (Table 2), but it accounts for only 16% of the total cultivated area of the country.
The new farm laws of 1985 and 1990, which promoted conservation compliance, recognised the vital role of no- tillage as a major means of meeting conservation requirements on highly erodible soils (Thomas and Blevins, 1996) and contributed to a faster adoption of no- tillage.
Despite the impressive increace of no-tillage cultivation in the USA, the expansion has been much slower than anticipated. In 1975 USDA predicted that in the year 2000 about 82% of the planted cropland in the United States could be under conservation tillage and 45% under no- tillage (USDA, 1975, 1985). This prediction may not be realised.

The increase of the no- tillage area in the USA, Canada and the other main countries where no- tillage is applied from 1987 to 1996 is described by Hebblethwaite (1997) from CTIC (Figure 1).

DEVELOPMENT IN LATIN AMERICA

BRAZIL: The first attempt to apply the no-tillage technology was made by the Faculty of Agronomy of the University of Rio Grande do Sul, in Não-Me-Toque, in 1969 (Borges, 1993). With the help of USAID a Buffalo no-tillage planter was imported from the USA, and one hectare was subjected to direct drilling with sorghum in the same year. Unfortunately this machine was destroyed by fire putting an end to this early development.

First no- tillage trials in Latin America were started in April 1971 at the Instituto de Pesquisas Agropecuarias Meridional, IPEAME (later EMBRAPA, Empresa Brasileira de Pesquisa Agropecuaria), in Londrina, Paraná State, in co-operation with a GTZ (German aid) project (Derpsch, 1984). In this project demonstration plots were set up in the farm of Herbert Bartz, a Brazilian farmer of German descent, in Rolandia, Paraná. After seeing the results of these plots, Herbert Bartz visited the UK and the USA, carried out research on the advances of this technique, visited ICI Fernhurst and Harry Young in Kentucky, bought a no- tillage planter in each country, and started seeding his first soybeans under no- tillage in October 1972. This is how Herbert Bartz became the first farmer to apply the technology in Brazil and Latin America and to use it continuously until the present. Another farmer, that imported an Allis Chalmers no- tillage machine together with Bartz, abandoned the system a few years later, after having problems in controlling weeds. The beginning of no-tillage was not easy in terms of area, since the first machines built in Brazil in 1975/76 based on the rotary hoe (Howard Rotacaster) were slow and the only herbicides available were 2,4-D and Paraquat. Hand hoeing saved many crops from failure at this stage. Despite the difficulties at the beginning, the area under no-tillage increased from 1,000 ha in 1973/74 to 400,000 ha in 1983/84 (Table 1) and reached 6,500,000 ha in 1996/97 (Table 2). The Federation of No-till Associations in Brazil FEBRAPDP, estimates that in 1998 the area under no-tillage in Brazil had expanded to 8.4 million hectares (Figure 2).

ICI promoted no-tillage in Brazil from the early times with Terry Wiles starting applied research in Rolandia, Paraná in 1972. First experiments in the State of Rio Grande do Sul were started by ICI in 1973. More intensive and systematic research on no-tillage was initiated at IAPAR, Fundação Instituto Agronomico do Paraná, Londrina in 1976, in a co- operative research effort with ICI, resulting in the first comprehensive research publication on no- tillage in Brazil in 1981 (IAPAR, 1981). Another co-operative research project started in 1977 between IAPAR and the German Agency for Technical Cooperation, GTZ, focused on cover crops and crop rotations under no-tillage. The results were published in German in 1988 and later translated into Portuguese (Derpsch et al., 1991). At present, some research institutions of Brazil such as EMBRAPA (CNPTrigo), in Passo Fundo, Rio Grande do Sul, have decided that all their research programs (varieties, rotations, cover crops, etc.) should be carried out in no- tillage and their goal is to achieve (together with the extension service and the private sector) a 100% adoption of this farming system by farmers.

The first National No- till Conference held in Ponta Grossa, Paraná in 1981 was organized by the "Cooperativa Central Agropecuária Campos Gerais". Two other national conferences in 1983 and 1985 at the same site boosted the area under no- tillage in the "Campos Gerais" of Ponta Grossa to about 200,000 ha in 1986, this being the first large region to be subjected completely to the no- tillage practice in Brazil. Here the pioneer work of Frank Dijkstra and Manoel Henrique Pereira (President of the Federation of No-till Farmers FEBRAPDP, from 1992- 1998), both farmers and leaders in their community, played a major role in the development and diffusion of this method of farming, not only in Brazil, but in all the Latin American countries and abroad. From here the technology spread mainly to the States of Santa Catarina and Rio Grande do Sul in the South of the country where significant progress has been achieved with the use of cover crops and crop rotations, thus reducing fertiliser and herbicide costs. In the 1990s the largest expansion of no-tillage in Brazil (Figure 2) occurred in the Cerrados (savannas of North Central Brazil with only one growing season per year), due to the extensive work of APDC (No- till Association of the Cerrados), which organised the fifth and sixth national no- till conference in Goiania and Brasilia in 1997 and 1998, each one with more than 2300 participants.

As more, better and cheaper herbicides appeared on the market in the 1990s, no- tillage became easier to manage and this together with the development of more diverse and better no- tillage seeding machines, has had a tremendous impact on adoption rates by farmers (Figure 2). Among the chemical companies, probably Monsanto has invested more in the diffusion of no- tillage, because of its interest in marketing the herbicide Glyphosate. Among the no- tillage seeding equipment manufacturers, Semeato has been the leading company in developing seeding machines and supporting no- tillage-related activities. In 1985 already, thirteen no-tillage seeding machine manufacturers were on the market in Brazil (Derpsch et al., 1991).

Main crops under no- tillage in Brazil are soybeans, maize, wheat, barley, sorghum, sunflower, beans and green manure cover crops in rainfed agriculture. Irrigated rice is also increasingly being subjected to no-tillage in southern Brazil. About 270,000 ha of irrigated rice (33% of total area) were under no-tillage in the State of Rio Grande do Sul. In the irrigated rice growing area of south western Brazil,

no-tillage in the State of Rio Grande do Sul. In the irrigated rice growing area of south-western Brazil, north-western Uruguay and eastern Argentina approximately 450,000 ha of irrigated rice were grown under no-tillage in 97/98 (Ivo Mello, personal communication, 1998). Not only traditional crops are now being subjected to no- tillage in this country, but also onions, tomatoes, vegetables, tobacco, etc.

ARGENTINA: First farm experiences with and also research on no- tillage were started in Argentina in 1974. At this time some pioneer farmers began applying no-tillage while looking for a better way to grow soybeans after wheat in a double cropping system (two crops in one year). Several farmers started with the system and then gave up mainly because of the lack of adequate herbicides and machinery which constituted the main constraint for the early adoption of the system. Duperial (ICI) was one of the first private companies to become involved in the diffusion of the system by promoting research activities, meetings and field days. This company also set up a co- operation project with INTA (Instituto Nacional de Tecnología Agropecuaria) (Marelli, 1995). Among other outputs of this project, a National No- tillage Conference was held at the INTA experiment station Marcos Juarez in1977 (INTA, 1977). From that time, INTA developed research and extension no-tillage projects targeted at some productive areas of the country. Heri Rosso from Marcos Juarez was one of the first farmers to apply the technology in Argentina in 1978 and is now using it with increasing success. In 1979 the second National No- tillage Conference was held in Rosario, Santa Fé.
In 1986 AAPRESID (Argentine Association of No- till Farmers) was formed, being a milestone in Argentine diffusion of no- tillage technology. In 1992 AAPRESID organised its first national conference "Congreso Nacional de Productores en Siembra Directa" which more than 1000 farmers attend each year. While in 1987/88 not more than 25,000 ha were under no-tillage in Argentina, the technology expanded to 4.4 million hectares in 1996/97. The availability of machines was the main constraint for the early adoption of no-tillage, but today almost 30 different manufacturers from Argentina, and a few from Brazil, are selling no-tillage seeding machines in this country. Soybeans, maize, wheat and other small grains, as well as sorghum and sunflowers are the main crops being subjected to no- tillage in Argentina.

CHILE: Carlos Crovetto is Chile's no- tillage pioneer. In 1978, he bought an Allis Chalmers planter and planted Chile's first corn under no-tillage in his Chequen farm near Concepción. Today, Crovetto has virtually eliminated erosion, by leaving about 14,300 kg/ ha of corn residues and 6,200 kg/ ha of wheat residues on the surface. On land with 15 to 18 percent slope he obtains remarkable yields, such as 19,600 kg/ha irrigated corn and 10,800 kg/ ha dryland wheat (No- Till Farmer, 1997). Through 19 years of continuous no- tillage practice Carlos Crovetto has added one inch of topsoil, boosted the organic matter content from 1.7 to 10.6% in the first 5 centimetres of soil, improved the bulk density from 1.7 to 1.4 g/ cm3, increased the soil water-holding capacity by more than 100 percent, increased the phosphate content from 7 to 100 ppm and potash from 200 to 360 ppm in the top 5 centimetres of soil, improved the soil's cation- exchange capacity from 11 to 26 milli-equivalents per 100 grams of soil and raised the soil's pH levels from 6 to 7 (No-Till Farmer, 1997). As a farmer and researcher, Crovetto is also the author of the book "Rastrojos sobre el suelo" (1992), which was later translated into English with the title "Stubble over the soil" (1996).
First research reports on the no-tillage practice were published by INIA in 1981 (Del Canto and Ormeño, 1981; Martinez and Novoa, 1981). Despite 20 years of successful no- tillage farming in Chile, the system has not expanded to more than about a 100,000 ha in this country, and many farmers still burn the straw and practice no-tillage into ashes. Wheat, oats and rapeseed are the main crops under no- tillage in Chile (approximately 95%), in addition to barley, triticale, lupins, lentils, and maize.

PARAGUAY: Before any research on no- tillage was performed, farmers from the Cooperative Colonias Unidas, in Itapua, in southern Paraguay, applied the new production system in the beginning of the 1980s. Due to the lack of knowledge on how to handle the new technology and because they imported machines of lower quality based on the rotary hoe, as well as due to the lack of appropriate herbicides on the market, the first experiences failed and soon they resumed conventional tillage. Later, Japanese farmers from Colonia Yguazú, Eastern Paraguay, gave the technology a new try with the backing of the Centro Tecnológico Agropecuario en Paraguay (JICA- CETAPAR). This centre, which was established for extending technical assistance to Japanese immigrant farmers in Paraguay, together with farmers, succeeded in making the system work. Akinobu Fukami, a Japanese immigrant, president of the local co-operative and leader in his community was the first farmer in this country to practice no-tillage successfully and continuously since 1983. With the support of JICA, all the farmers of this co- operative were applying the technology 10 years later and also many farmers in other Japanese colonies. Initial development was slow, and in 1992 only 20,000 ha were under no-tillage in Paraguay. After the Ministry of Agriculture of Paraguay with the assistance of the German Agency for Technical Cooperation, GTZ, initiated a Soil Conservation Project in 1993 that concentrated on no-tillage development and diffusion, the technology expanded rapidly to about 500,000 ha in 1998 (mainly soybeans). About 65% of the soybean- growing farmers in mechanised agriculture were using no-tillage on all or part of their farms in 1998.

BOLIVIA: After visiting Brazil and Argentina, Dr. Jean Landivar started no- tillage on his 2000 ha farm in the lowlands of Santa Cruz in 1986 for the cultivation of sorghum and maize and also for some soybeans. Research started at about the same time but without positive results. In the summer of 1996/97 102,000 ha were under no-tillage in Santa Cruz mainly with soybeans but also maize, rice and some cotton. In the winter of 1996, 35,000 ha of wheat (35% of total area) and also sunflowers were sown by applying the no-tillage practice (Patrick Wall, personal communication, 1997).

MEXICO: At the end of 1997 about 490,000 ha were under no- tillage in Mexico, 100- 200 thousand hectares of which in small landholdings (Ramón Claverán, personal communication, 1997). Other sources indicate that less than 10,000 ha of no- tillage is practiced on small farms in Mexico and Central America (Wall, 1998). This contrasting information is probably due to different definitions of "small farmers".
Most of the other countries in Latin America have started to apply the technology recently, with the no-tillage areas covering less than 100,000 ha.

CAAPAS: An important milestone in the development of no- tillage in Latin America was the foundation in 1992 of CAAPAS, the Federation of American No- tillage Associations for Sustainable Agriculture. Victor Trucco was the first president from 1992- 1998. At first only Latin American countries joined, but in 1998 CTIC (Conservation Tillage Information Centre) has become a member too.

DEVELOPMENT IN AFRICA

Earliest research on no- tillage in Africa was carried out in the late sixties in Ghana (Kannegieter, 1967, 1969, Ofori and Nanday, 1969, Ofori 1973). Research work at the IITA (International Institute of Tropical Agriculture) in Ibadan, Nigeria started in 1970 (FAO, 1993). Rattan Lal has been one of the most prominent researchers and prolific writers on this subject at IITA. First publications by Lal were written in 1973 (Lal, 1973 a, b). Forty one of his publications are listed as references in the IITA Monograph N° 2, which summarises 12 years of work at this Institute (Lal, 1983). Other scientists working at national research institutes and universities in Nigeria also started studies on a range of soils in the 1970s to compare the effect of different tillage methods on soil properties, crop growth and yield (Agboola and Fayemi, Aina, Wilkinson, cited by FAO, 1993). Similar studies were also initiated in other African countries including Liberia by Lal and Dinkins, Ivory Coast by Roose and Senegal by Nicou and Chopart (FAO, 1993). Despite the wealth of research information on no-tillage and mulch farming in Africa, the technology has not spread to a great extent among farmers. Also, there is only little information available on the development of no- tillage in this continent. A study on the potential use of no- tillage in Africa conducted by GTZ (GTZ, 1998), indicates, that the technology is already being used to some extent in the following countries: Angola, Benin, Ghana, Ivory Coast, Kenya, Mozambique, Niger, South Africa, Tanzania, Zambia and Zimbabwe. In most countries in Southeast Africa some work on conservation tillage practices (either at research stations or on farms) is being done and no- tillage is practiced successfully in larger farms. The most common crops being used in no-tillage are maize, sorghum, wheat and cotton.
In mechanised farms no- tillage seeding machines are often imported from Brazil, New Zealand or from the USA, but in Zimbabwe there is also a local production. No- tillage seeding equipment for small farms is manufactured in South Africa for experimental purposes and in some cases imported from Brazil. Also hand jab planters are imported from Brazil (GTZ, 1998).
On the other hand according to the Conservation Tillage Handbook in Zimbabwe (Vowles, 1989) many farmers have modified their planters to enable them to plant row crops directly through crop residues with no previous tillage operation. Although experimentation with zero tillage in many cases began with irrigated crops, it is assumed that under dryland conditions the potential benefits of zero tillage are the greatest.
It should also be mentioned, that permanent zero tillage is practiced only in regions with higher rainfall patterns or when irrigation is available. Minimum tillage is used widely and is the most common form of soil preparation in small farms (1- 2ha).
According to GTZ (1998), traditional land tenure, uncontrolled or communal grazing and lack of sufficient soil cover, as well as socio-economic constraints are the major problems in the spreading of no-tillage in Africa. Research and development as well as diffusion strategies have to be directed towards solving these problems before no-tillage becomes an attractive alternative for farmers in this continent. On the other hand labour constraints at the time of seeding in many regions of Africa may be an opportunity for this system to be adopted among farmers.

DEVELOPMENT IN AUSTRALIA AND NEW ZEALAND

Before no- tillage of crops was applied, pastures were directly drilled in Australia and New Zealand. In 1964 Plant Protection Ltd and ICI Australia Ltd undertook a joint programme on bipyridyls for crop establishment without tillage in Australia (Barret et al., 1972). First experiments were conducted in the Eastern States (Rowell, 1968). Little information could be obtained on the development of no-tillage in

Australia other than that the technology is applied on about 1 million hectares (Hebblethwaite, 1997). Australia has serious erosion problems and this is an important reason why no-tillage is being increasingly used.

In New Zealand, Taylor (1967) from ICI Christchurch, reported that satisfactory yields of winter wheat were obtained by Arnott and Clement in 1962 following the application of chemicals in uncultivated soil. At Massey University in New Zealand many papers have been published in the 1950s and 1960s by M.W. Cross on reseeding, oversowing and overdrilling of pastures. In the 1970s more detailed investigations were conducted on direct drilling of crops (Baker, 1970, Dixon 1972). Intensive research on no-tillage has continued at Massey University until the present. In the book "No-tillage seeding" (Baker et al., 1996), many references of research on direct drilling carried out in New Zealand are listed.

DEVELOPMENT IN ASIA

It has been difficult to obtain information on the development of no- tillage in Asia. According to Table 1 no-tillage is being practiced in Japan, Malaysia and Sri Lanka over a limited area. It was reported that conservation tillage is practiced in India, Indonesia, Korea, Philippines, Taiwan and Thailand. More detailed information could be gathered from Japan.

JAPAN: (Personal communication by Makie Kokubun, 1998) There have been many studies and experiments on the no- tillage system in Japan, from the viewpoint of soil properties, crop performance and labour cost. The advantages and benefits from this system were in many cases observed in terms of labour cost/time, and sometimes in terms of crop performance.

Several types of no- tillage seeding machines have been designed, built and tested by experimental stations and private companies and some of them have been found to be practical. A few machines are ready for commercial sale .

Despite the considerable research efforts for the development of no- tillage, farmers have not been keen to adopt this technology, so that the acreage under this system is statistically negligible in Japan, mainly because soil erosion, which is a strong driving force to introduce no- tillage in South and North America, is not a serious problem in Japan.

Attempts are made to develop the no- tillage system in rice- based cropping systems in paddy fields. In these systems, weed control is performed by water management rather than herbicide application. Similar system was used in rice-pasture cropping systems in Australia.

In some Asian countries where JIRCAS is carrying out collaborative research, the situation is similar to that in Japan. Despite the efforts to confirm the advantages of the no- tillage system, the prevalence among farmers is still at a starting point.

FINAL REMARKS

1. Although there were many early attempts to cultivate crops without tillage, modern no- tillage research started in the 1940s and adoption by farmers in the early 1960s.
2. First conceived as an efficient soil conservation method, no- tillage has evolved to an economic and sustainable production system that not only improves soil physical, chemical and biological characteristics, but also improves the environment for all, by reducing the emission of greenhouse gases.
3. The historical development of no-tillage cultivation of crops and the successful application in mechanised farms has been closely related to the following factors:
    - the availability of appropriate knowledge (research results and farmers' experiences) under different agro- ecological and socio-economic conditions
    - the availability of a variety of efficient low-cost herbicides
    - the availability of appropriate machines at adequate prices
    - the practice of adequate crop rotations including green manure cover crops (this has been the basis of successful application especially in Latin America)
4. The greatest diffusion of no- tillage has occurred in the Americas, while only a small proportion in the rest of the world.
5. Latin America has adopted the practice on more than 14 million hectares virtually without any subsidies.
6. Despite the wealth of research information in Africa showing the benefits of no- tillage, this farming system is not extensively practiced in that continent.
7. The historical development shows that industry and farmers have exerted a major influence on the diffusion of the no-tillage production system.
8. Research, development and diffusion of no-tillage have been accomplished almost exclusively in mechanised medium and large-sized farms. Research on small farms in Brazil started only in 1982, and in most parts of the world no research has been carried out.
9. Adoption of no-tillage in small farms (that do not have tractors) is still very limited on a world-wide basis. Adoption is highest in Brazil with about 25,000 ha, Paraguay with 4,500 ha, and Central America and Mexico with less than 10,000 ha. About 10,000 ha of no- tillage are reported to be practiced on small farms in India, Bangladesh and Nepal (Wall, 1998).

reported to be practiced on small farms in India, Bangladesh and Nepal (Wall, 1998).

10. Reduced cost of production under no- tillage is probably the main driving force in achieving high adoption rates. Production costs per acre of soybeans under no- tillage are reduced by US$ 27.00 in Argentina, by US$ 14.18 in the USA and by US$ 11.50 in Brazil. Similar reductions in the production costs are also achieved with maize (Hebblethwaite and Towery, 1997).
11. No- tillage accounts for less than 50% of conservation tillage practices in the USA, but is almost the only form of conservation tillage practiced in Latin America.
12. It has been generally understood that no- tillage is not a fashion or a transitory trend, but it is a production system that is spreading increasingly because of its evident advantages and also because of ecological and economic pressures.

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Table 1. Area under no- tillage in the seventies and eighties (Hectares)

Country	1973/ 74	1983/ 84
U.S.A.	2,200,000	4,800,000
United Kingdom	200,000	275,000
France	50,000	50,000
Netherlands	2,000	5,000
Japan, Malaysia, Sri Lanka	200,000	250,000
Australia	100,000	400,000
New Zealand	75,000	75,000
Brazil	1,000	400,000

Source: Various sources, cited in: Derpsch, 1984

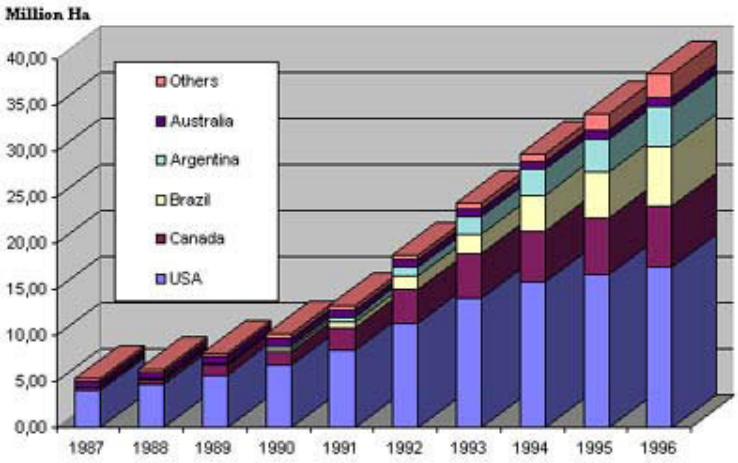
Table 2. Total area under no- tillage in different countries in 1996/ 97 (Hectares)

Table 2. Total area under no- tillage in different countries in 1996/ 97 (Hectares)

Country	Area under no- tillage
Argentina[1)]	4,400,000
Brazil[1)]	6,500,000
Canada[1)]	6,700,000
Mexico[2)]	490,000
Paraguay[3)]	500,000
Uruguay + Chile + Bolivia[5)]	500,000
U.S.A.[4)]	19,400,000
Others[5)]	460,000
Total	**38,700,000**
Australia[1)]	1,000,000

Source: [1)]Hebblethwaite, 1997; [2)]RELACO, 1997; [3)]MAG- GTZ Soil Conservation Project, 1998; [4)]No- Till Farmer, Jan. 1998; [5)]Estimates

Fig 1. Hectares of No-Till in Various Countries



Source Hebblethwaite, 1997

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Top