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Conservation Tillage for the Protection of Soil Quality and Sustainability

G.R. Mari and JI Changying

Department of Agricultural Mechanization Engineering,
College of Nanjing Agricultural University, Postal Code 210031, Nanjing, China

Abstract: The need for land management technologies and policies that provide long-term sustainability as well as high levels of productivity is generally accepted in the World, but this will have to operate within the constraints of market conditions and political and social expectations. However, acceptable methods of assessing sustainability of farming practices are often questioned by the farming community. Therefore, development of broadly applicable framework for evaluation of sustainable land management needs urgent attention by the researchers and policy makers and the assessment techniques need to take into account the widely varying factors influencing sustainability in different farming systems.

Key words: Soil quality · agricultural sustainability · crop production · tillage system · organic matter · agricultural practices

INTRODUCTION

The movement for sustainable agriculture is growing in momentum throughout the world and the Pacific region is no exception. It exhibits widely varying climatic conditions from arid through warm and cool temperate to tropical; and soil ranging from volcanic to loess. Soil erosion, crop production and pasture improvement and their management flexibility and moisture conservation are sufficient incentives to keep sharp focus on soil conservation technologies. The provision, therefore, of biologically tolerant crop production technologies capable of adaptation to a wide range of soil and climatic conditions is an important prerequisite to the large-scale change from tillage to conservation tillage technology [1].

The report of the World Commission on Environment and Development Brundtland [2] has defined sustainability as that development which meets the needs of the present without compromising the ability of future generations to meet their own needs. While this ideal originates from environmental concerns, it assumes that farmers would accept such a challenge without considering financial impact on their profit margins.

The enactment of New Zealand's [3] was aimed to promote the sustainable use and management of natural and physical resources. The sustainable management in the act included, managing the use, development and protection of natural resources and physical resources in a way, or at a rate, which ensures that, in providing for the social and economic well-being of people and communities and their health: (a) the potential of the natural and physical resources to meet the reasonably foreseeable needs of future generations is sustained; (b) the life-supporting capacity of air, water and soil and ecosystems is safeguarded; and (c) any adverse effects of activities on the environment are avoided, remedied, or mitigated.

Similarly, the Australian sustainable development strategy has the framework using, conserving and enhancing the community's resources so that ecological processes, on which life depends are maintained and the total quality of life, now and in the future, can be increased [4].

The overall objectives of above the strategies are that indicators of agricultural sustainability should be used as tools for early warning of deleterious environmental and other changes for trace-back enquiries on causation and for better comparisons between farming practices, management decisions, or system's performance.

While agricultural practices that give rise to soil erosion, ground water pollution, acidification, salinization, weed, pest and disease infestation and long-term retention of pesticide residues in the soil are commonly recognized as being unsustainable, the un-sustainability of continuous and untimely cultivation of many of soils for grain production is not as widely appreciated [5].

Corresponding Author: Dr. JI Changying, Department of Agricultural Mechanization Engineering, Engineering College of Nanjing Agricultural University, Postal Code 210031, Nanjing, China

Farmers, as they become aware of the adverse effects of excessive tillage and soil nutrient stripping through continuous cropping of lands, are increasingly acknowledging past mistakes and are recognizing the need for conserving the natural resources of land and water.

SURFACE RESIDUE MANAGEMENT

Much of agriculture land revolves around rotating pastures with crop production on poorly drained, easily compacted soils. The presence of crop surface residues and/or chemically-desiccated pasture mulch has an apparent conflicting role in crop establishment. Traditional tillage practices buried organic residues, to slow down their decomposition and thus influence the microbial population for a longer period. Surface residues, while modifying soil temperature and moisture, have shorter life in consequence, with all the associated effects.

Evidence also suggests that crop residues left intact on surface have an adverse effect on seed germination under no-tillage conditions where suitable seed drills were not available [1]; yet straw mulching was practiced successfully in Australia McCown [6] and North America [6-8] found that toxic acids were produced in harmful amounts only under moist soil conditions, while stubble mulching under dry warm conditions was important in aiding moisture retention and preventing wind erosion. Other attributes of surface residue included nutrient return, control of certain weeds, improvement of soil structure and the pasture legume sward which volunteers from hard seed, is allowed to form an under-story in the main crop. Under moist temperate conditions the harmful effects of residue included the build-up of diseases such as mildews, rusts, leaf blotch and take all. Pests, particularly slugs, also tended to accumulate under straw. In Australia and New Zealand, crop residues are often grazed and trampling of low-quality residues is encouraged by the over sowing of fodder crops.

Soil organic matter: Soil organic matter is of great importance because of its influence on soil physical, chemical and biological properties and on creating a favorable medium for biological reactions and life support in the soil environment. Biological activity is generally greater and both microbial and soil fauna populations are higher under zero-tillage regimes relative to conventional tillage [9, 10]. Earlier research suggests that cropping with conventional tillage in New Zealand has almost always found to be accompanied by a decline in soil organic C and microbial C, particularly coming out of pasture [11]. Organic carbon content and soil respiration were found to be higher in the pasture field. Compared to the biodynamic ally and conventionally cropped fields.

In another long-term experiment [12] on a silty clay loam and silt loam, continuous cultivation for up to 11 years decreased C content in the top 20 cm of soil by 21 and 49%, respectively compared with the levels under long-term permanent pasture. These authors also found that there was a strong linear relationship between the decline in the proportion of stable aggregates and the loss of organic C and microbial C in the top 10 cm of cultivated soil. On the other hand, when restored to pasture after cropping, the microbial C content recovered more quickly than the total organic C. Management and tillage techniques rather than total organic matter status appeared to have had a greater effect on soil physical structure and this view was confirmed by the fact there was no clear relationship between the recovery of soil aggregate stability and the build-up of organic C.

Microbial and microbial activity: The microbial biomass has an important role in nutrient transformation and thus impacts on the fertility status and nutrient supplying potential of soils. The microbial biomass of a soil is a comparatively labile pool of soil organic matter [13] and a substantial pool of soil nutrients [12] and can be used as an index of the biological status of the soil fertility [12]. It is also used as an indicator of management-induced changes brought about by tillage practices, incorporation of crop residues, N fertilization, crop rotation sequence and changes in soil moisture regimes [15]. Consequently, loss of organic matter during cultivation and especially loss of the soil microbial component, can adversely affect both the physical, biological and nutrient status of soils [16].

Cultivation usually results in a marked decline in the organic carbon content of soils compared with soils under pastures or forests because of the decomposition of existing organic matter. Consequently, loss of organic matter resulting from excessive cultivation can have adverse effects on the physical and biological and nutrient status of soils. Microbial biomass C content of surface soil has been shown to be a more sensitive indicator of changes in soil organic matter than total organic matter and was also more closely related to the proportion of water-stable aggregates [12]. A decrease in microbial carbon of 0.76 mg g^{-1} was noticed after 11 years of continuous maize production on a poorly-drained Kairanga silty clay loam (Typic Haplaquept). Similar large declines in organic C (40- 50%) have been reported by Ross *et al*. [17] in the Waikato region of New Zealand where the decline in C content was attributed to the decreased C input under arable farming compared with pasture and enhanced mineralization of organic C caused by cultivation. Conversion to cropping with conventional tillage from permanent pasture resulted in a 45, 53 and 51% decline in microbial N, K and P, respectively, at 0-5 cm soil depth [18]. As the continued application of tillage will lead to a further decline in microbial biomass nutrients, this is likely to affect crop yield in the longer term. Total nitrogen was significantly higher in the pasture fields, mostly because of their higher.

Clover content, than the cropped soils: Overall, these studies have indicated that adoption of no-tillage can protect soils from physical [19, 20] and biological degradation and enhance soil quality as compared with conventional tillage management. Furthermore, these studies suggest that no-tillage with appropriate crop rotation can be used as an effective tool to maintain and enhance soil productivity while promoting agricultural sustainability at a level similar to that in clover-based permanent pastures.

The extent of soil tillage, crop rotation and soil amendments impact on soil microbial biomass. Conventional tillage reduced microbial activity while soils where crops were sown in rotation, or which had application of green manure or liquid farm slurry, had enhanced such biological activity. Land rehabilitated from open cast coal mines has been shown to have low percentage of microbial C in total organic C for at least three years in restored soils. Conversion from pasture to cropping with tillage reduced earthworm populations by 74% whereas no-tillage cropping had only a minimal effect [18]. Therefore, changes in microbial nutrients and earthworm activity can bring marked changes in soil fertility status, which are often reflected in crop performance.

Greenhouse gases: In New Zealand, as a result of the Resource Management Act [3] and growing environmental awareness, the effects of land management on soil degradation and on water and air quality are important issues for farmers, regional councils and researchers. Recent strategies in reducing CO_2 emissions have focused on the likelihood of introducing a carbon tax. Major land uses include indigenous and exotic forests, unimproved and permanent pastures, arable crops, wetlands and scrubs. Research on the reduction of CO_2 emissions from the agricultural sector has been a recent phenomenon and the planting of trees to absorb and store CO_2-C emissions has been a major focus. However, no emphasis has been placed on measuring CO_2 emissions from arable crops sown by conventional tillage.

CO_2 emissions were related to biomass turnover and these indicators were useful in assessing long-term sustainable practices. Conventional tillage stimulates microbial activity, as shown by increases in the rate of soil respiration. Such stimulation results from disruption of soil aggregates and exposure and aeration of their biodegradable material. A flush of CO_2 immediately after ploughing has been reported in number of publications by Reicosky and his colleagues in the USA [21]. Conversely, Roberts and Chan [22] concluded that increases in microbial respiration due to tillage were probably not a major factor causing losses of soil organic matter in the soil under intensive cultivation. Choudhary *et al*. [19] have suggested that no-tillage limits soil disruption and leaves crop residue on the surface thereby limiting contact residue decomposition rates.

Soil CO_2 emissions and C sequestering are likely to be affected under various land uses. Soil C levels were maintained when pasture land was converted to cropping with no-tillage but markedly reduced with cropping and tillage. The tillage practices had, in general, little or no effect on CO_2 emissions during the growth of crops. These experiments demonstrated that freshly cultivated land may slightly enhance CO_2 emissions as compared with untilled soil. However, once the cultivated seedbed was re-compacted, CO_2 emissions were akin to those in untilled soils.

CONSERVATION TILLAGE SYSTEMS

Rotation of permanent pastures with forage crops using conventional tillage is a common practice. Establishment of crops using conventional tillage is popular. However, such operations are not sustainable because of the decline in soil physical, chemical and biological properties, there is a growing acceptance of conservation tillage as an efficient method of crop establishment [1], but its application is mainly limited to use with establishing pastures and forage crops. This has been partly because some conservation tillage research shown that no-tillage is associated with higher soil bulk density, soil strength, aggregate stability [23-27].

The more positive aspects such as increased surface organic matter content, plant-available water, high soil hydraulic conductivity and earthworm populations, reduced risks of erosion and sustainability aspects have not been adequately promoted. More recent research has highlighted the vitally important aspects of the long-term development of conservation tillage in the preservation of the non-renewable soil resource. Collectively the research has demonstrated that the habitat of seeds under conservation tillage together with their resulting seedling environments, are pivotal to yield and are influenced by micromanagement of the soil, surface residues and soil fauna in the sown environment. These parameters are themselves influenced by the action and the design of seed drill openers. Soils under sustained conservation tillage systems, involving organic matter return, often together with reduced carbon dioxide diffusion potential are largely unmatched by tilled soils.

LEY FARMING

Management of surface residue and weeds is crucial in the development of appropriate soil management systems for the development of mixed dry land crop and animal production. Surface mulches are important for ameliorating soil surface moisture, temperature and fertility. In the semiarid tropics, soil management practices such as conservation tillage and ley farming play a significant role in determining the economic benefits to the farmers through mulch retention between the soil and associated micro-organisms reducing and increased yields and sustainability of the farming systems.

Research programs on mulch farming and conservation tillage were initiated in 1970's by the CSIRO in the semiarid tropics with the aim of ameliorating soil crusting, improving crop establishment and reducing soil erosion problems resulting from traditional cultivation. Similarly, on loamy red earths where soil sealing impeded seedling emergence, mulch retention by no-tillage resulted in an average maize yield increase of 18% [6]. Other studies have related such increases in yields to lower soil temperatures, increased moisture, more organic matter and surface accumulation of N, P, K nutrients and more soil stability with no-tillage [28].

Adoption of conservation tillage in the semi-arid tropics is consistent with the principles of sustainable agriculture as these minimize deleterious effects on soil erosion, water quality, biodiversity and is in harmony with natural ecosystems [29]. Ley farming and no-tillage combination have four features.

These include: Self-regenerating legume ley pastures grown in rotation with maize or sorghum. Cattle graze native pastures during the green season and legume pastures and crop residues in the dry season; Crops are planted directly into pasture residues following killing of pasture at, or shortly before, sowing by non-residual herbicide and the pasture legume sward which volunteers from hard seed is allowed to form an under-story in the main crop.

Provision and management of surface pasture or residue mulch and control of weeds and pests is crucial if no-tillage is to be successful to sustain cropping in ley farming systems in the tropics [30, 31]. Similarly, the field nutrient management is important as N contents vary considerably within fields. Fertilization regimes based on the average N contents of the heterogeneous fields, would result in under- and over fertilization with the corresponding effects of water pollution as a result of soil erosion and leaching of excess fertilizer and suboptimal growth.

Australian experience with conservation tillage in conjunction with mulch farming is consistent in terms of yields with other warmer climates where soil moisture conservation is a critical issue [32]. Production results from both short- and long-term experiments show that comparable or higher yields with no-tillage are possible as compared with conventional tillage [28, 33]. In drier years, crop yields were significantly higher particularly when surface was covered with mulch.

SUMMARY

The principal objective of any farming practice is sustained profitable production and farm income stability. Environmental concerns are often associated with adverse economic implications. In production agriculture, for instance, environmental laws often focus on reducing the adverse effects of fertilization or biocide application. These laws are perceived by farmers to be associated with increased costs and reduced profit margins. However, hidden environmental costs are not included in economics of products.

The need for land management technologies and policies that provide long-term sustainability as well as high levels of productivity is generally accepted in the World, but this will have to operate within the constraints of market conditions and political and social expectations. However, acceptable methods of assessing sustainability of farming practices are often questioned by the farming community. Therefore, development of broadly applicable framework for evaluation of sustainable land management needs urgent attention by the researchers and policy makers and the assessment techniques need to take into account the widely varying factors influencing sustainability in different farming systems and regions.

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