INTERNATIONAL
SOIL AND WATER
CONSERVATION RESEARCH

Experiment of "no-tillage" farming system on the volcanic soils of tropical islands of Micronesia

Mohammad H. Golabi[1], S. A. El-Swaify[2], and Clancy Iyekar[3]

Abstract

The soils of southern Guam are formed from very deep; well-drained Saprolite derived from volcanic based tuff and tuff breccias. These soils suffer severe erosion as the result of rapid overland flow, wind and intensive rain events typical of southern Guam. An integrated approach to control the accelerated soil erosion was designed to include conservation tillage, crop rotation with leguminous plant, and residue management for soil surface cover.

The objectives of this study are; 1) to evaluate the use of crop rotation and tillage management for increasing organic-matter content to improve the overall quality of these severely eroded soils, 2) to evaluate the effect of conservation practices on harvested yield and crop productivity of these eroded soils and, 3) to assess the effects of conservation techniques including no-tillage systems on water runoff and infiltration. This paper discusses the effect of conservation strategies and techniques on these severely eroded soils of southern Guam.

Key Words: Conservation agriculture, No-Tillage system, Volcanic soils, Micronesia, Guam

1 Introduction

Accelerated soil erosion, often as a consequence of poor soil quality, degrades the soil resource and degrades the downstream environment in Guam. These threats are manifested most seriously in the southern part of the island. The challenge facing soil and agricultural scientists is, therefore, to develop soil conservation strategies that restore the health and resilience of the soil, and improve soil quality for crop production and maintain the integrity of the environment.

This research, therefore, evaluates the effectiveness of certain conservation techniques in controlling runoff and reducing soil erosion on these highly degraded volcanic soils of southern Guam. These include soil management systems such as conservation tillage (no-tillage and reduced-tillage), and crop rotations with leguminous sunn hemp (*Crotalaria juncea*) with maize (*Zea mays*). These techniques are intended to maintain surface cover before the subsequent cultivation of the main crop (maize). The sunn hemp also serves as green manure to improve the quality of the soils due to its high organic matter content upon its incorporation to the soil.

Plant cover intercepts and dissipates the energy of raindrops before they strike the soil, enabling the water to infiltrate the soil surface and prevent over flow. Furthermore, the resulting buildup of plant stems, roots, and organic matter act to improve soil quality (El-Swaify et al., 1988) hence makes the soil more resistant to erosion. Although many soil-conservation technologies can be combined to reduce erosion rates, reduced-tillage can play a key role in reducing soil erosion, decreasing weed pressure through maintenance of surface mulch, and enhancing soil productivity through crop residue and organic-matter maintenance. The principal method of controlling rapid surface runoff and the resulting soil erosion is to maintain adequate vegetative and/or crop residue cover on the soil surface at all times. The greater water infiltration and reduced evaporation afforded by

[1] Professor of Soil Sciences, College of Natural and Applied Sciences, University of Guam. Corresponding author: E-mail: mgolabi@uguam.uog.edu

[2] Emeritus Professor of Soil Sciences, Division of Soil, College of Agriculture, University of Hawaii

[3] Research Associate, College of Natural and Applied Sciences, University of Guam

crop residue results in more water available for crop use under such management (Hargrove, 1985; NeSmith et al., 1987).

One of the immediate benefits of conservation tillage is the increased population of earthworms (Golabi et al., 1995). The passageways dug by earthworms allow plant roots to penetrate deeper into untilled soil than they do into conventionally plowed soils (De Quattro, 1997). Golabi et al., (1995) have reported that earthworm passageways also increase water infiltration and consequently moisture content of the soil.

In addition to rapid surface runoff due to inadequate surface cover, conventional (traditional) farming practices involving frequent plowing and tilling in preparation of the seed bed have also shown to be highly destructive of soil quality, hence reducing the soil's long term production capacity (Dumanski and Peiretti, 2013). Therefore, in order to protect the soil resources and prevent land degradation, the traditional approaches with conventional tillage must be replaced by conservation farming practices based on continuous soil surface cover by using appropriate procedures such as reduced tillage, minimum tillage and other conservation techniques. These may include no-tillage systems that would maintain continued soil surface cover and help sustain soil productivity and maintain the integrity of the environment, if adapted to the site ecosystem. Although these concepts already exist and have shown much promise towards achieving a more sustainable agriculture, they are also highly knowledge dependent and require management skills for agricultural sustainability and long-term economical well being (Dumanski and Peiretti, 2013). For example, under no-tillage farming systems, soil disturbance is virtually eliminated. This has been shown to be the most effective technology in mitigating many of the negative on-farm and off-site effects of conventional tillage, principally erosion by surface runoff (Dumanski and Peiretti, 2013). The adoptability of the procedures however, may differ from place to place based on the climate as well as other ecosystem conditions. Unlike other conservation farming practices, the no-tillage technique is more management intensive and its success or failure is knowledge based with respect to the soil as well as other ecosystem conditions where no-till is practiced. Also, no-tillage systems normally require four to five years or more of continuous no-tillage, complemented with crop rotations and leguminous cropping, for the soils to become stabilized (Golabi et al., 1995) and hence maintain a sustainable, economically viable productivity for small scale farmers. No-tillage farming requires much education and knowledge and innovative farmers who are able to adjust to the evolving conditions and ensure the sustainability of their farming operations within their limited means and resources. As stated by Dumanski and Peiretti (2013), the various approaches to soil conservation, including no-tillage systems, are not separate concepts, rather components of a continuum of conservation approaches applicable at different conditions and adoptability levels. Also, local farmer's knowledge, innovation and adoptability, research backstopping, as well as the support of the community and farmers association are all necessary elements of adoption for any new technique and innovative agricultural practices such as no-tillage and conservation farming.

Considerable research has been published on the various components of conservation-tillage practices and reduced-tillage systems (Carter and Rennie, 1982; Blevins et al., 1983; Mielke et al., 1986; Radcliffe et al., 1988; Golabi et al., 1995; El-Swaify, 1999; El-Swaify, 2001). As numerous workers have reported, no-tillage and reduced tillage practices can increase site productivity through soil-erosion control and improvement of soil properties such as enhanced organic matter content, structural improvement, water-holding capacity, nutrient availability, and Cation Exchange Capacity (Hargrove et al., 1982; Groffman, 1985; House and Parmelee, 1985; Groffman, et al., 1986). It has also been reported (Al-Kaisi and Yin, 2005) that conservation tillage is regarded as one of the most effective agricultural practices for reducing soil CO_2 emission to the atmosphere from agricultural soils. Increased atmospheric carbon dioxide (CO_2) has been considered a major contributor to global warming (Al-Kaisi and Yin, 2005). Carbon loss from soil to the atmosphere as either CO_2 or other gases has been exacerbated due to inappropriate tillage practices (Al-Kaisi and Yin, 2005). Otherwise, the soil can function as a net sink for sequestering atmospheric CO_2 through appropriate soil and crop management (Al-Kaisi and Yin, 2005). However, the total soil carbon (TC) storage capacity and carbon dynamic is complex and often variable, especially during the first stages of conservation tillage systems or within a short-term no-tillage practices when the soil matrix is not yet stabilized (Al-Kaisi and Yin, 2005).

The greatest challenges for conservation-tillage production therefore, is providing an economical nitrogen supply for non-leguminous crops, as well as dealing with severe weed problems. The relatively long growing season and adequate rainfall in Guam and the islands of Micronesia permit continuous growth of legumes for supplying nitrogen to subsequent crops. Hargrove and Frye (1987) have reported that a well-adopted legume crop can replace from 60 to 120 kg N ha^{-1} for subsequent crops of corn or grain sorghum. Furthermore, El-Swaify et al. (1988) have reported that a drastic reduction in runoff and soil loss resulted from intercropping with legumes. They also reported that excellent cassava yields were obtained where leguminous (*Stylosanthes)* crops had been grown earlier as a ground cover, and that yields of cassava intercropped with legumes without application of additional nitrogen were comparable to those obtained with an application of 200 kg ha^{-1} of nitrogen.

Lack of soil disturbance and maintenance of surface crop residue (mulch) have also been shown to reduce small-seeded annual weeds in reduced-tillage production systems (Bridges and Walker, 1985). According to the agronomist J. Smart (as reported by De Quattro, 1997), "Every time you till or plow to control weeds, you're also planting more weed seeds as well as making the soil more vulnerable to erosion, our most significant environmental contaminant." Because of the wide spectrum of potential weed species and the long growing season in Guam, Smart (1997) anticipated that limited chemical weed control would still be needed.

Disadvantages that may be associated with conservation tillage systems, such as no-tillage, include higher herbicide application. Also, for imperfectly drained soils, no-tillage may aggravate the drainage problem in the short-term, before macro pores are developed as the result of earthworm activities and crop root channeling (Blevins et al., 1993). The resulting wet soils in a no-tillage system tend to be lower in oxygen content of the soil during early stages (3 to 4 years) of no-tillage production systems (Blevins et al., 1993). Furthermore, crop residue mulches left on the soil surface cause slower warming of soils during the spring, a problem identified in certain regions of the United States (Blevins et al., 1993).

Some of these problems, however, may be less significant under the tropical conditions of Micronesia. It has been reported that the surface-residue mulch that may delay germination and early growth in temperate regions, often becomes a positive factor in the tropics by reducing the high temperatures that adversely affect plant growth, thereby increasing germination and growth (Lal, 1982; as cited by Blevins and Frye, 1993).

2 Defining the problem

Both in term of soil quality as well as the environment, water erosion and sediment transport are serious problems for southern Guam (GEPA, 1986). In the badlands of southern Guam, transport of sediment from a badland basin into a new sedimentary system promotes a spectrum of environmental and ecological changes ranging from wetlands formation and river turbidity to coastal modification and habitat destruction (Lewis, 1999). These processes impact the quality of life for residents and the viability of the tourism industry. Both are severely altered by unchecked badlands formation (Lewis, 1999).

The badlands of southern Guam are located within the confines of several of Guam's most important watersheds, including the Ugum, Fena, and La Sa Fua watersheds (Fig. 1). The origin of badlands in southern Guam is related to annual wild and/or set fires (Fig. 2), forest clearing, military action, recreational off road

Fig. 1 A typical badland (degraded soils) in southern Guam

Fig. 2 Farmers and hunters burn natural vegetation for clearing purposes (This process however leads to soil erosion and degradation of the natural resources in southern Guam.)

vehicles, and grazing of wild animals (Lewis, 1999). These badlands are a significant source of sediments in the La Sa Fua watershed, and currently, they are increasing in number and size (Lewis, 1999). The overall extent of the badlands is currently unknown, but their association with non-point source pollution from runoff is certainly measurable at the mouth of and within the La Sa Fua River (Lewis, 1999).

3 Materials and methods

3.1 *The soil*

The soil under investigation is located at the University of Guam's research station in the Ija region of southern Guam. This soil is; a very fine, kaolinitic, isohyperthermic Oxic Haplustalfs. These soils (Fig. 3) are formed from weathered volcanic rocks where depth to bedrock is 50–100 cm (Young, 1988). Being formed from volcanic rock, these soils also contain considerable amounts of aluminum (Al) and iron (Fe) oxides, and are very acidic, measured pH as low as 4.2, in their natural condition (Young, 1988).

3.2 *Field experiment*

A set of 12 field plots (each 9 m×11 m) were set up to evaluate soil management technologies for mitigating or reducing the impact of soil management.

Initial chemical and physical properties of soil samples were determined (Table 1) prior to first planting of corn (Maize) in 2013. Because rainfall in the area tends to be irregular, irrigation lines were laid before the corn was planted. An attempt was made to plant irrigated corn during the dry season and sunn hemp (Crotalaria juncea) during the wet season.

The experiment included corn plantings under four conditions, conducted on different plots: 1) Conventionally Tilled (CT) was used as control plots. 2) Conventionally tilled but rotated with sunn hemp (CT/SH) before the subsequent main crop (maize) was planted as a separate treatment. 3) Reduced tillage (RT), and finally 4) the no tillage (NT) treatment were among the techniques practiced in these studies. All plots/treatments were randomly assigned and replicated three times.

Sunn hemp (Crotalaria juncea) is a leguminous cover crop adapted to tropical or subtropical areas that generate much biomass, and produces 150 to 165 kg ha^{-1} of N under favorable conditions (Koon-Hui Wang et al., 2011). When incorporated into the soil, sunn hemp amendments also enhance the abundance of free-living nematodes that play important roles in nutrient cycling, and result in higher soil nutrient content, organic matter, especially in soils low in organic matter (Koon-Hui Wang et al., 2011). Under favorable soil conditions, sunn hemp could be an adequate fertilizer to meet most of the N, P, K nutrient requirements for many vegetable crops. Since most of the N and other macronutrients are found in leaves and flower heads, use of sunn hemp as a mulch or green manure would be most beneficial at the early- to mid-flowering stages (Koon-Hui Wang et al., 2011).

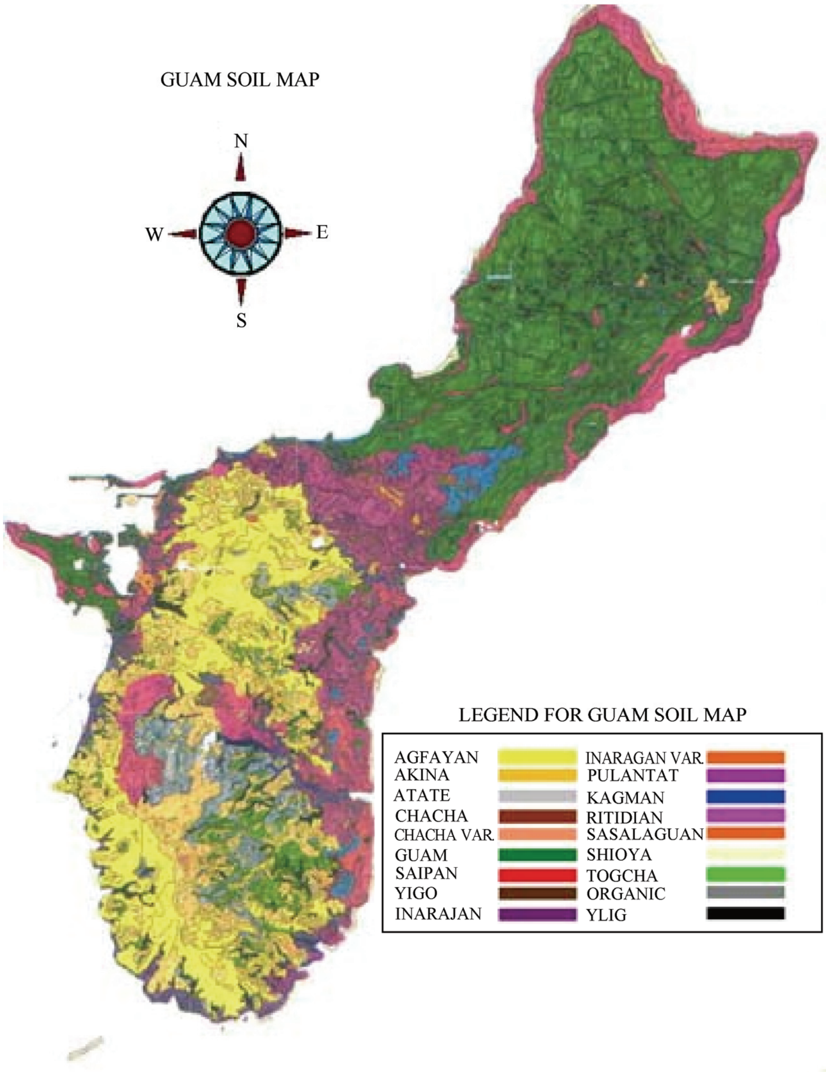

Fig. 3 Soils of Guam showing up-to-date soil series (Young, 1988)

The "Conventional tillage" treatments consisted of plowing, tilling, and disking before planting. The plots were tilled again immediately after harvest with a roller tiller in order to incorporate the plant residue into the soil surface. For this treatment (CT), the soil surface therefore remained exposed to rain and wind after the post harvest tilling and before the subsequent cropping of corn (maize). The CT treatment therefore was assigned as the control for erosion measurements and other parameters monitored during the investigation. In the CT/SH plots, the sunn hemp (Crotalaria juncea) was grown between successive main crops (maize) as a rotating plant. The sunn hemp was then mowed and incorporated into the soil with a tiller, and then plowed and disked just before planting the subsequent main crop (maize). In the NT plots, the field plot was never tilled or plowed and the soil surface remained undisturbed at all times. For this treatment (NT) corn seeds were drilled directly into the soil with the existing plant residue from the proceeding crop and/or vegetation. In the NT plots, however, the standing residue from the previous crop was maintained while the growing weeds were killed using appropriate herbicides a week prior to planting. In the Reduced-tillage (RT) plots, however, the soil surface was left undisturbed after the harvest with the remaining crop residue on the soil surface. The plots were only plowed and tilled for seeding preparation just before the subsequent planting of the main crop (maize).

Yields of the corn crop (maize) were measured after the harvest only occasionally due to the lack of manpower and equipment. Soil samples were also collected and analyzed for occasional soil-property evaluation (Tables 2 and 3).

In order to evaluate the effect of different treatments on infiltration rates, a portable rainfall simulator (Fig. 4) was also used to measure runoff, two years after the establishment of the no-tillage system. Hence a sixty minute rain event was conducted on each treatment plot for this purpose. The rainfall simulation was performed using high-pressure spray nozzles mounted on a frame (Fig. 4) five meters above the $1m^2$ subplots (enclosure). Three sides of the frame were covered with a heavy tarp to reduce the wind effects during the rainfall simulation (Fig. 4). The rainfall simulator was placed on a metal enclosure (1 m × 1 m × 30 cm high), and a 500 gallon portable water tank and a midsize generator were carried on the university vehicle (not shown in the picture) and were used to provide water and power for rainfall simulation throughout the study. Two third of the enclosure's height was forced into the ground by using a hydraulic backhoe. A small submerged pump was located at the lower end of the enclosure for collecting the runoff during the rainfall simulation events. The runoff was collected within 10 minute intervals for a total of sixty minutes. The collected runoff was then measured using a graduated cylinder (Fig. 4) for calculating the infiltration rate during each rainfall event.

Fig. 4 Rainfall simulator was placed over a metal enclosure for measuring the runoff and determining the infiltration rate for each treatment

4 Results and discussion

As shown in Table 1, the pH of the soils was initially low and highly acidic in almost all plots. Lime was applied in order to correct the pH of the soil to an acceptable level of pH 6.5. However, despite the liming treatment, the pH of the soils remained relatively low throughout the study (Tables 2 and 3). This was probably due to the frequent and intensive rainfall events that occur within the area. It is possible, that this resistance to pH change was also due to the high aluminum (Al) and iron (Fe) oxide saturation of these volcanic soils. In a comparable study on similar soils, it was observed that the application of composted organic waste corrected soil acidity more efficiently than liming (Golabi et al., 2006).

Table 1 Soil characteristics (0–24 inches below the soil surface) from the study plots before 2003 cropping of corn

Treatment*	pH	Bulk density ($g\ cm^{-3}$)	OM (%)	Org PO_4 ($mg\ kg^{-1}$)	NO_3 ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)
CT	4.4	1.6	3.4	1.5	0.64	299	1,857	2,709
CT/SH	5.3	1.5	3.5	1.7	0.68	319	1,867	2,645
RT	5.1	1.6	3.6	1.9	0.69	327	1,904	2,227
NT	4.5	1.5	3.7	1.8	0.78	347	1,808	2,033

*Treatments: CT, conventional tillage (control); CT/SH, conventional till with sunn hemp rotation; RT, reduced tillage; NT, no tillage; OM, organic matter.

Soil quality indicators and changes were measured, as shown in Tables 2 and 3. The soil pH increased slightly between 2003 and 2007, but other fertility parameters indicated poor soil quality throughout the study (Tables 2 and 3). Organic matter increased in the NT, RT, as well as the CT/SH treatments compared to the 2003 measurements (Table 1). Bulk density, on the other hand, increased slightly under NT, indicating some compaction of the no-till soil during the experiment. Furthermore, the earthworm activities in these very acidic soils are minimal to none which would otherwise be conducive to reduced compaction in no-tillage treatment on soils with higher pH level. Other parameters remained relatively unchanged (Tables 2 and 3) and no fertility management strategies were practiced in order to minimize variability.

Table 2 Soil characteristics (0–24 inches below the soil surface) on the study plots after the 2005 corn harvest

Treatment*	pH	Bulk density ($g\ cm^{-3}$)	OM (%)	Org PO_4 ($mg\ kg^{-1}$)	NO_3 ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)
CT	5.4	1.4	3.2	1.7	0.63	312	1,897	2,809
CT/SH	5.3	1.3	3.6	1.9	0.71	321	1,868	2,745
RT	5.3	1.5	4.1	2.3	0.78	334	1,947	2,298
NT	5.5	1.6	4.5	2.8	0.80	367	1,878	2,128

*Treatments: CT, conventional tillage (control); CT/SH, conventional till with sunn hemp rotation; RT, reduced tillage; NT, no tillage; OM, organic matter.

Table 3 Soil characteristics (0–24 inches below the soil surface) on the study plots after the 2007 corn harvest

Treatment*	pH	Bulk density ($g\ cm^{-3}$)	OM (%)	Org PO_4 ($mg\ kg^{-1}$)	NO_3 ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)
CT	6.4	1.5	3.6	1.8	0.64	351	1,886	2,718
CT/SH	6.1	1.2	4.1	1.7	0.76	359	1,879	2,803
RT	5.7	1.4	4.7	1.6	0.60	340	1,855	2,221
NT	5.4	1.7	5.1	1.2	0.40	336	1,781	2,203

*Treatments: CT, conventional tillage (control); CT/SH, conventional till with sunn hemp rotation; RT, reduced tillage; NT, no tillage; OM, organic matter.

Data from the 2003, 2005, and 2006 harvests showed (Fig. 5, 6, 7, and 8) overall low crop productivity due to the inherent poor fertility conditions of the soils under study. However, as it is shown, the RT and CT/SH treatments produced the highest yield throughout the study, followed by the CT treatment. The NT treatment produced the lowest yields during the entire study period (Fig. 5, 6, 7, and 8). However, none of the differences were statistically significant at the 0.05 confidence level.

The higher yields in the CT plots were attributed to the absence of weeds (due to frequent plowing and tilling), and to better aeration. On the other hand, the low yield from the NT treatment was due to lower aeration, higher compaction (as indicated by the increased bulk density), and also due to the aggressive weed growth typical of the tropical areas where high rain and high temperature favors aggressive vegetation growth.

It should be noted that the study is relatively short term, and the NT plots are expected to perform better as the system becomes more stabilized (Isro Ismail et al., 2014). This has also been shown conclusively (Calegari Ademir et al., 2008; Lal, 1976) in other tropical areas in Brazil and Nigeria (Calegari Ademir et al., 2008; Lal, 1976). Furthermore the objective of the study was changed after 2008 and is now focused on the carbon content and carbon sequestration of the soils under the aforementioned study. The results from the carbon sequestration and additional yield data from the study are expected to be submitted for publication later.

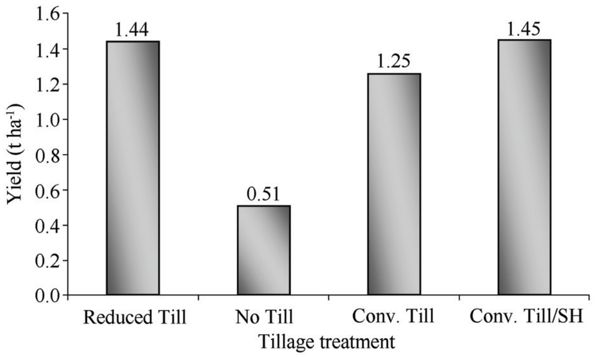

Fig. 5 Corn yields from the 2003 harvest (Bars represent treatment means based on Fisher's t-test. Treatments did not differ significantly at the 0.05 levels.)

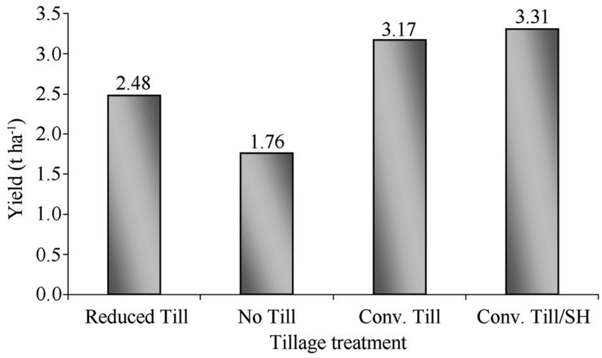

Fig. 6 Corn yields after 2005 crop harvest (Bars represent treatment means based on Fisher's t-test. Treatments did not differ significantly at the 0.05 levels.)

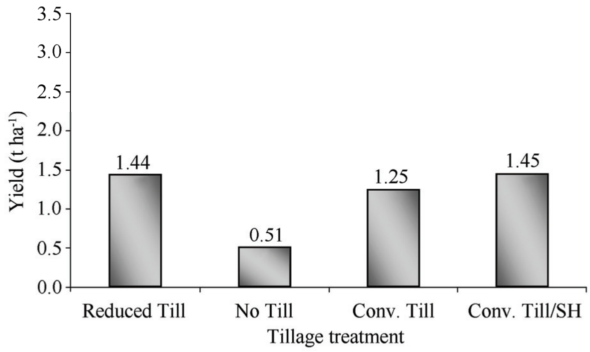

Fig. 7 2006 average corn yields
(Bars represent treatment means based on Fisher's t-test. Treatments did not differ significantly at the 0.05 level.)

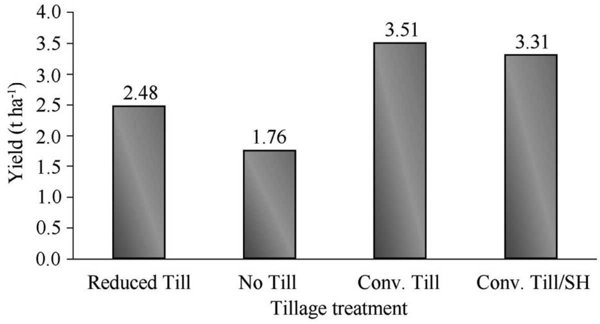

Fig. 8 2007 corn yields
(Bars represent treatment means based on Fisher's t-test. Treatments did not differ significantly at the 0.05 level.)

Fig. 9, 10 and 11 show infiltration rates during one-hour simulated rain events. As shown in Fig. 9 the first infiltration measurement was conducted two years after the no-tillage treatment was initiated. As shown, the infiltration rate remained relatively high for the NT treatment during the entire 60 minutes rain event. This was because residue from previous crops intercepted the rain, hence protecting soil aggregates and eliminating soil particle detachment and preventing surface crusting.

However the infiltration rate decreased gradually for the CT plots after about 10 minutes of continuous rainfall (Fig. 9), producing much runoff during the event. This gradual decrease in infiltration was attributed to soil particle detachment and crust formation as the rain impacted on the bare soil surface (Golabi et al., 1995). Consequently, the falling rainwater turned into overland flow with little or no infiltration below the soil surface in the CT plots. The overland flow washed away the detached soil particles causing soil erosion as was indicated by the murky runoff (Fig. 4) collected from the CT plots during the 60 minutes rainfall event.

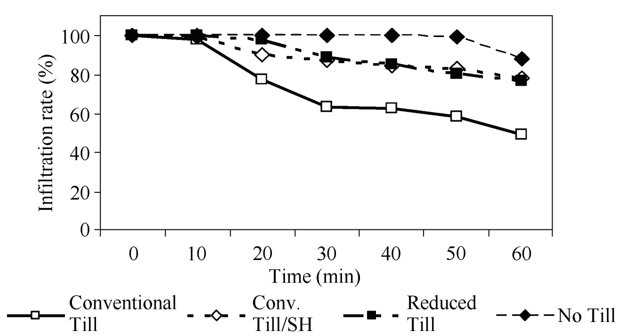

Fig. 9 Infiltration (%) measured under different tillage treatments during a one-hour simulated rain event in 2005

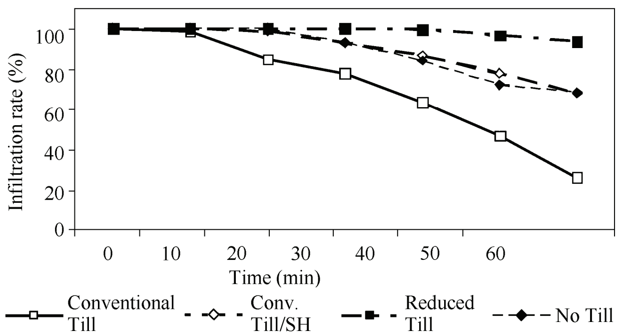

Fig. 10 Infiltration (%) measured under different tillage treatments during a one-hour simulated rain event in 2006

The infiltration rate for the RT, on the other hand, remained high throughout the rainfall events (Fig. 9, 10, and 11). This was possible because the remaining residue from the previously harvested crop intercepted the rain and reduced its impact on soil particle detachment. Furthermore, less tillage on the RT plot allowed the remaining roots and residue from the previous crop to protect the soil aggregates and resist crust formation. In addition, the RT plots were less compacted and hence more aerated as compared to the NT plots. Plowing just before each planting stirred the soil below the surface providing more pathways for rainwater to infiltrate. This was also facilitated by the presence of decaying roots which remained from the previous crop, as compared to more disturbed soils in the CT plots which were tilled immediately after harvest. It is reported, however, that NT is the most effective at reducing runoff and improving higher infiltration on the soils of temperate regions (Golabi et al., 1995). On the CT plots rotated with leguminous sunn hemp (CT/SH), the infiltration rate was also high during the rainfall event and remained comparable to the infiltration rate on the NT plots. This was contributed to the higher organic matter content of the soil (Tables 2 and 3) due to the incorporation of the sunnhemp into the soil as green manure before the subsequent main crop (maize) was planted (CT/SH).

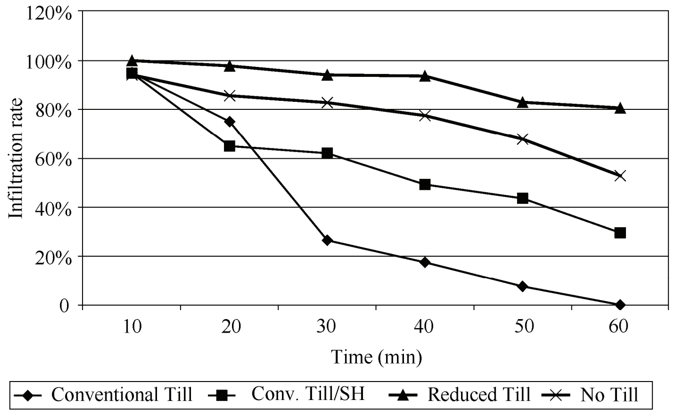

Fig. 11 Infiltration (%) measured under different tillage treatments during a one-hour simulated rain event in 2007

5 Conclusions

An integrated approach was designed to evaluate the effect of no-tillage and other conservation tillage practices, such as crop rotation with a leguminous plant for organic matter build-up, and residue management for soil rehabilitation and restoration of the eroding land in southern Guam. The reduced, as well as the no-tillage practices, proved to be effective techniques for controlling runoff, as indicated by the measured infiltration rates. However, yields on the NT (no-tillage) treatment plots were lower than any other treatments evaluated in this study. This indicates that, unless NT systems are practiced for longer periods of time thereby allowing the system to stabilize and develop the benefits of improved soil conditions, they will not be attractive to farmers in the Micronesian islands who have to deal with similar soils. On the other hand due to high soil acidity and poor fertility conditions inherited from the volcanic parent material in this region, practicing no-tillage farming on the soils of southern Guam may prove to be a major challenge for traditional farmers in this region.

A useful compromise, however, was the reduced-tillage (RT) treatment, which produced higher yield than NT, but also was quite effective in increasing infiltration rates which will reduce runoff and erosion by reducing overland flow rates and runoff volumes. Conventional tillage (CT) rotated with leguminous crop (sunn hemp) (CT/SH) also produced higher yields as well as reducing the runoff hence reducing soil erosion. This was as the result of sunn hemp acting as a green manure, and improving the organic matter content and soil quality which in turn will help resist soil loss from the treated plots.

References

Al-Kaisi, M. M., & Yin, X. (2005). Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn–soybean rotations. *Journal of Environmental Quality*, *34*(2), 437-445.

Blevins, R. L., & Frye, W. W. (1993). Conservation tillage: an ecological approach to soil management. In D. L. Sparks (ed.), *Advances in agronomy*, *51*, 33-78.

Blevins, R. L., Thomas, G. W., Smith, M. S., Frye, W. W., & Cornelius, P. L. (1983). Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. *Soil and Tillage Research*, *3*(2), 135-146.

Bridges, D. C., & Walker, R. H. (1985). Influence of weed management and cropping systems on sicklepod (Cassia obtusifolia) seed in the soil. *Weed Science*, 33, 800-804.

Carter, M. R., & Rennie, D. A. (1984). Nitrogen transformations under zero and shallow tillage. *Soil Science Society of America Journal*, *48*(5), 1077-1081.

Calegari, A., Hargrove, W. L., Rheinheimer, D. D. S., Ralisch, R., Tessier, D., de Tourdonnet, S., & de Fatima Guimarães, M. (2008). Impact of long-term no-tillage and cropping system management on soil organic carbon in an Oxisol: A model for sustainability. *Agronomy Journal*, *100*(4), 1013-1019. Retrieved from http://my2.ewb.ca/site_media/static/attachments/group