Intercropping annual fields with perennial plants - A strategy to reduce land degradation in semi-arid regions

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Declaration

I hereby declare that this submission is my own work. I designed all the experiments, applied the field and laboratory work, collected the field data, performed the statistical analysis of the data and wrote the manuscripts by myself. Throughout the research, I was advised by Prof. Dr. Ruediger Prasse, who discussed the results and contributed to advanced drafts and final stages of the manuscript.

I certify that this thesis has not been submitted as dissertation to any other university or institute nor any of its parts.

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Abstract

Soil erosion and declining of soil quality seriously threaten agricultural sustainability worldwide. These processes are especially relevant in semiarid and arid regions which are usually inhabited by poor populations depending mainly on rain fed agriculture for their livelihood. It is well-known that a permanent vegetation cover may reduce the surface runoff and soil erosion and may improve soil quality. However, the application of permanent cover on annual crop production fields is not usually an option due to the loss of some productive area.

In this study an agricultural technique was developed on arable annual production fields, which permits to combine the advantages of a perennial ground cover with the production needs. The developed system is a multi-species intercropping in which strips of useful native perennial plants were used as intercrops. These strips may reduce the surface runoff and erosion as well as the loss of soil fertility. The native plants intercrops used are usually collected by the local population as food, spice or medicine. Therefore, this system allows farmers to apply a meaningful economically conserving technique.

A field experiment from 2004 to 2006 was conducted to test whether it is possible to control soil and water losses and to conserve soil quality with the help of the described method without financial losses for the farmers. The experiment was conducted in semiarid and arid areas in Al-Khalil district, West-bank. Two sites situated along an aridity gradient of different mean annual precipitation (approx. 425 mm and approx. 595 mm) were selected in order to acquire additional information on the influence of climate on the effects of the management strategy.

The results show that both the unproductive water loss by runoff and soil loss by erosion were strongly reduced by intercropping with native perennial plants. Intercropping reduced runoff by 34% - 89% and reduced soil erosion by 45 % -

94%. The positive effects of intercropping were consistent in two consecutive seasons of investigation and in both investigated areas. The effectivity of intercropping in controlling runoff and soil loss was more pronounced at the drier part of the studied rainfall gradient and during the drier season.

The soil parameters tested -soil organic matter content (SOM) and microbial activity- were also improved by intercropping compared to the mono-species control. The results show low level of microbial activity and a rapid decline of SOM in the not intercropped arable fields during the two years of study. By contrast, the SOM content was maintained, and the level of microbial activity was enhanced in the intercropped fields. Species specific effects of intercrops were not observed in conserving water and soil resources.

The developed intercropping system using native perennial plants had minimal negative effect on the yield of the annual crops. The reduction of crop yield was less than may be expected as 10% of the field area was used for the native plants intercrops. The slightly lower annual crop yield in the intercropped fields was compensated for the farmers by the income gained from marketing the native plants. The income gained from the intercropping system with native perennial plants was stable and consistent in the two investigated seasons, while the income gained from the annual crops was proportional with the amount of rainfall received in each season with lower yields in the dry season. This means that, in semiarid regions the income from intercropping system may be more sustainable and reliable compared with the monoculture system. These observations were consistent in the two investigated sites.

This study implies that intercropping with useful native perennial plants is a sustainable economic agriculture management that may help in protection of the existing soil resources. The study shows that intercropping is a suitable technique for semi-arid regions, and may be suitable as a mitigation strategy to cope with the effects of the expected global climatic changes.

Keywords: intercropping, erosion, runoff, organic matter, native perennial plants.

Zusammenfassung

Zwischenfruchtanbau mit ausdauernden Pflanzenarten - Eine Strategie zur Reduzierung von Erosion, Oberflächenabfluss und Bodenfruchtbarkeit auf Äckern in semi-ariden Gebieten

Bodenerosion und der Verlust von Bodenfruchtbarkeit sind weltweit auftretende Phänomene, welche oft die Nachhaltigkeit der landwirtschaftlichen Nutzung gefährden. Die Gefährdung der langfristigen Nutzbarkeit der Böden ist insbesondere in Regionen auffällig, deren Umweltbedingungen schon heutzutage kaum noch Landwirtschaft zulassen und in denen daher eine oft arme Bevölkerung lebt. Es handelt sich z. B. um die von Viehzucht und Regenfeldbau dominierten semi-ariden Regionen im Übergang zu den Wüsten dieser Erde.

Es ist bekannt, dass der Aufbau bzw. der Erhalt einer dauerhaften Vegetationsdecke den Oberflächenabfluss und die Erosion sowie alle damit verbundenen Auswirkungen (Verlust der Bodenfruchtbarkeit etc.) reduzieren kann. Der Aufbau bzw. der Erhalt einer solchen mehrjährigen (perennen) Vegetation auf Äckern ist allerdings üblicherweise eine für den Landwirt nicht umsetzbare Landnutzungsstrategie. Dies insbesondere, da eine mehrjährige Pflanzendecke die auf dem Acker zur Verfügung stehende Produktionsfläche reduzieren würde und der Landwirt mit Produktionseinbußen rechnen müsste.

In der vorliegenden Arbeit wird eine landwirtschaftliche Produktionsmethode entwickelt, welche es erlaubt, die Vorteile einer mehrjährigen Pflanzendecke mit dem landwirtschaftlichen Produktionsbedürfnis zu verbinden. Zu diesem Zweck wurden in mit einjährigen Pflanzen bestellten Äckern, Streifen mehrjähriger Pflanzenarten eingezogen. Diese Streifen sollten den Oberflächenabfluss sowie die damit verbundene Erosion und den Verlust an Bodenfruchtbarkeit reduzieren. Dieses „Intercropping“ wurde mit Pflanzenarten vorgenommen, welche von der lokalen Bevölkerung üblicherweise als Nahrungsmittel, Gewürz oder Medizin gesammelt werden. Dies ermöglicht dem Landwirt,

auch die zur Erosionsverminderung gepflanzte, mehrjährige Vegetation ökonomisch sinnvoll zu verwerten.

In einen Feldversuch wurde von 2004 bis 2006 getestet, ob es mit Hilfe der beschriebenen Methode möglich ist, den unproduktiven Wasserverlust, die Erosion und den Verlust an Bodenfruchtbarkeit zu reduzieren, ohne dass dieses mit finanziellen Einbußen für die Landwirte verbunden ist.

Das Experiment wurde in den trocken-mediterranen bis semi-ariden Regionen der Westbank bei Hebron (Al-Khalil) durchgeführt. Für die Untersuchungen wurden Felder ausgesucht, die in zwei Gebieten mit unterschiedlichen mittleren Jahresniederschlägen lagen (ca. 425 mm und ca. 595 mm). Dies sollte Aussagen über die Effektivität der Maßnahmen unter verschiedenen Umweltbedingungen ermöglichen und Aussagen darüber zulassen, ob das Intercropping mit einheimischen Nutzpflanzen eine geeignete Methode zur Abschwächung der Auswirkungen des zu erwartenden Klimawandels sein kann.

Die Ergebnisse der vorgelegten Studie zeigen, dass ein Zwischenfruchtbau (Intercropping) mit mehrjährigen einheimischen Nutzpflanzen sowohl die Erosion als auch den unproduktiven Oberflächenabfluss stark reduziert. Die erreichte Reduzierung lag für den Oberflächenabfluss bei 34 % - 89 % und für den Bodenverlust (Erosion) bei 45 % - 94 %. Diese Effekte waren in beiden Untersuchungsjahren und in beiden Untersuchungsgebieten zu beobachten. Das Ausmaß des Unterschiedes zu den Flächen ohne Zwischenanbau von mehrjährigen einheimischen Nutzpflanzen variierte jedoch in Abhängigkeit vom aktuellen Jahresniederschlag und der langjährigen mittleren Niederschlagsmenge. Auch die mikrobielle Aktivität und der Anteil organischer Substanz im Boden wurden durch den Zwischenfruchtanbau positiv beeinflusst. Der Anteil organischer Substanz und die mikrobielle Aktivität nahmen auf Äckern ohne Zwischenfruchtanbau im Verlauf der zweijährigen Untersuchungszeit stark ab, während sie auf den Äckern mit Zwischenfruchtabbau konstant blieben oder leicht zunahmen.

Die Wirksamkeit des Zwischenfruchtbaus war für alle Parameter in der trockensten Region und im trockeneren der beiden Untersuchungsjahre am höchsten. Artspezifische Auswirkungen des Zwischenfruchtanbaus wurden nicht beobachtet.

Der vorgenommene Zwischenfruchtbau mit mehrjährigen einheimischen Nutzpflanzen hatte nur minimale negative Auswirkungen auf Ertrag der über die einjährige Hauptfrucht der Äcker erzielt wurde. Dies ist insbesondere bemerkenswert, da die Zwischenfrucht 10% der Fläche der untersuchten Äcker bedeckte und daher mit einer dementsprechenden Abnahme der Produktion zu rechnen gewesen wäre. Hier scheint die Verringerung der Produktionsfläche über einen höheren Wasseranteil im Boden und eine höhere Bodenfruchtbarkeit ausgeglichen worden zu sein.

Das insgesamt per ha erzielte Einkommen lag auf Äckern mit Zwischenfruchtanbau immer höher als auf Flächen ohne Zwischenfruchtanbau. Gleichzeitig blieb der über den Anbau der Zwischenfrucht erzielte Gewinn in beiden Untersuchungsjahren konstant, während das über den Anbau der einjährigen Hauptfrucht erzielte Einkommen stark mit den aktuellen Niederschlägen eines Jahres variierte. Dies bedeutete, dass auf den Flächen ohne Zwischenfruchtanbau in dem trockeneren der beiden Untersuchungsjahre kaum Einkommen erzielt wurde, während auf den Flächen mit Zwischenfruchtanbau noch immer ein signifikantes Einkommen über den Verkauf der angebauten Wildpflanzen erarbeitet wurde.

Die vorliegende Untersuchungen belegt deutlich, dass ein Zwischenfruchtbau mit mehrjährigen einheimischen Nutzpflanzen eine nachhaltige Landwirtschaft unter Schutz der vorhandenen Ressourcen ermöglicht, ohne dass dies mit negativen wirtschaftlichen Auswirkungen für die Landwirte verbunden wäre. Eine Umstellung auf diese Form des Landbaus wird großflächig zum Ressourcenschutz in semi-ariden und ariden Gebieten beitragen und erlaubt gleichzeitig eine Abschwächung der erwarteten Auswirkungen des globalen Klimawandels.

Schlagworter: Zwischenfruchtanbau, Erosion, Oberflächenabfluss, Bodenfruchtbarkeit, Wildpflanzen.

Contents

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Synopsis

Introduction

Land degradation is a serious problem in arid, semiarid and dry sub-humid zones. Globally around 47 per cent of marginal rain fed croplands and a significant percentage of irrigated croplands are currently being degraded (Gisladottir and Stocking 2005). Soil degradation results in reduced crop yield and decline species diversity (Tengberg et al. 1997, Lal 1998). These processes are especially relevant in semiarid and arid regions which are usually inhabited by poor populations depending mainly on rain fed agriculture for their livelihood (Altieri 2004). In addition, accelerated soil degradation may enhance other important global problems especially climate change through biophysical processes such as carbon reduction in soils and loss of below-ground biodiversity (Lal, 2001& 2003).

Several forms are recognized for land degradation such as soil erosion, declining in soil quality and loss of biodiversity. Soil erosion is the major feature of land degradation and the principal threat to agricultural sustainability especially in arid and semi-arid (Tengberg et al. 1997, Lal 1998, 2001, Chappell et al. 1999, El-Swaify 2001). The degradation of soil quality includes the decline in organic matter, soil compaction, poor internal drainage, salinisation and soil acidity. These forms of soil degradation, serious in themselves, usually contribute to accelerated soil erosion (Lal 2001). Depletion of plant nutrients in soil especially organic matter also contributes to adverse impacts on soil productivity (Wischmeier & Mannering 1969, Roose & Barth’es 2001). Soil organic matter as a major determinant of soil quality affects almost all important soil physical, chemical and microbiological properties

(Arias et al. 2005, Magdoff and van Es 2000, Fontaine et al. 2003, Chen et al. 2003). Therefore, complementary strategies to control the various forms of land degradation should have the priority attention from researchers and policy makers.

The various forms of land degradation are highly sensitive to climate conditions (Yang et al. 2003, Nearing et al. 2004). Furthermore, the global climatic change scenarios predict increased severity of soil degradation in the semi-arid regions in the future (O'Neal et al., 2005). Climatic change scenarios predict increased temperatures, greater variability in monthly precipitation, and increased frequency of large storms (Zhang and Nearing, 2005). Subsequently, a decrease in the vegetative cover is expected mainly due to the increased temperatures (O'Neal et al., 2005). However, changes in crop management due to the effects of climate change and economic pressures may in future increase the magnitude of land degradation even more (O'Neal et al., 2005). Therefore, climate change and its effects on land-use strategies and economics needs to be taken into account while developing strategies for sustainable water resource management.

Although soil degradation processes are naturally occurring they are affected by crop managements and accelerated by human activities (Lal 2001). Among the serious activities that threaten agricultural sustainability and accelerate land degradation, land-use change has the most immediate effect (Vandermeer et al., 1998). This includes the switch from natural vegetation to cultivation and the more incremental changes associated with agricultural intensification. The modern high intensive agriculture depends on monocultures and crop varieties of narrow genetic base. The crop varieties used in intensive agriculture are high performance crops but with low drought adaptation. Consequently, consumes lots of water through artificial irrigation which is often not available in semiarid regions. These features of modern agriculture accelerate soil degradation processes and result in other environmental problems mainly declining agro-biodiversity especially in transitional areas, like semiarid regions (Vandermeer et al., 1998, Altieri 1999b, Darkoh, 2003). Therefore, biodiversity is among the most urgent of the issues that need addressing when developing new agricultural techniques especially in dry lands. In addition, new ways are needed to increase farm productivity that not only benefit the rural poor under marginal agricultural conditions, but also conserve and regenerate the soil resources.

As management strategies for these problems, several authors suggested diversifying the agricultural systems and the application of permanent ground covers (Lal 1995, Vandermeer et al. 1998, Altieri 1999, 2002, Jackson et al. 2007). One of the recommended multi-species agriculture systems for semi-arid areas is intercropping (Altieri 1999). Several environmental and economical advantages are supposed to result from diversified intercropping systems. Intercropping systems are expected to be less susceptible to erosion process (Nelson et al. 1998, Barton et al. 2004) and may contribute to improvement of soil fertility (Altieri 1999b, Ghosh 2004). The multi-species intercropping systems may enrich the soil with greater variety of organic matter residues and improve soil microbial activity (Altieri 1999b). In addition, some studies indicate that diverse agricultural systems as intercropping are indeed more productive than simple systems (Vandermeer 1998, Hallam et al. 2001, Ghosh 2004, Yildirim & Guvenc 2005, Alene et al. 2006, Ghosh et al. 2006). Therefore, intercropping systems are possible management practices to mitigate many of the ecological and economical problems. However, the application of permanent vegetation cover is usually not an option for farmers of annual crops, since they will lose some of the productive area for the perennial cover. Therefore, new ways of production are needed that combine the advantages of permanent ground cover with the production needs of the farmers.

Domestication of useful native perennial plants and planting them as strips in annual crop fields may contribute to financial reward for the farmer while serving as a partially permanent cover that help in soil protection. By marketing the useful native perennial plants a new source of field income will probably be available for the farmer, the manager of the system. In addition, the domesticated native plants may help the agroecosystem to partly mimic the natural ecosystem and acquire some of its benefits (Vandermeer et al. 1998, Jackson et al. 2007). The perennial life history of many native species may contribute to reduce overland flow (Dunj'o et al., 2004). Therefore, the perennial cover provides sediment traps and enhances water efficiency by minimizing un-productive water losses (surface runoff). In addition, it may also help to increase the quantity of soil organic matter by frequent addition of plant residues to the soil. Consequently, positive effects are expected on other soil properties such as soil microbial activity and aggregate stability.

The use of native perennial plants as intercrops may benefit biodiversity also by reducing the collection pressure of local population on the wild stands of these plants especially the threatened species. The endangered species are commonly collected from the wild to be used as food, spices, and for medicinal purposes. Such species need conservation precautions. Planting these perennial plants in arable fields as intercrops may help to conserve these species in addition to there possible benefits in soil conservation. Therefore, intercropping with useful native perennial plants is supposed to contribute to soil and biodiversity conservation without economic losses.

Many useful native perennial plant species are adapted to grow in semiarid-arid regions. However, these species vary considerably in their morphology and the vegetation growth period, which may contribute to various effects on runoff, erosion and soil properties. Thus, to derive conclusions about species specific effects in the mitigation strategy which use native perennial plants, it is important to test several species.

This study introduces an intercropping strategy for annual production fields that uses the domestication of useful native perennial plants to enhance agrobiodiversity and to mitigate land degradation problems in semiarid-arid areas. The native perennial plants that used as intercrops were: *Majorana syriaca, Salvia fruticosa* and *Salvia hierosolymitana*. It is assumed that intercropping systems using native perennial plants may help to control water and soil losses, and improve soil quality. The yield and financial income from the intercropped fields is likely to be by marketing the native plants as normal crops. Therefore, the study includes evaluation for the economic value or the yield productivity of this intercropping system. In particular the study aimed to evaluate the potential of intercropping arable fields of annual crops with useful native perennial plants as means to reduce land degradation under semiarid-arid conditions.

Thesis objectives and organization

This study attempts to examine the following hypotheses:

1. the application of intercropping with native perennial plants will reduce unproductive water-losses due to surface-runoff,
2. the application of intercropping with useful native perennial plants will reduce soil erosion,
3. the intercropping systems with useful native perennial plants will increase the retention of water in soils, and consequently increase water efficiency,
4. the advantages of intercropping with native plants in reducing runoff and erosion are consistent in areas and seasons with different rainfalls,
5. the efficiency of the intercropping with useful native perennial plants in reducing runoff and erosion is not species specific,
6. the application of a permanent ground cover, as it is partially present in intercropping with native perennial plants, maintains and/or improves the soil organic matter,
7. the efficiency of a permanent ground cover in improving SOM is not species specific,
8. the efficiency of a permanent ground cover in improving SOM is consistent under different climate conditions,
9. a partially permanent ground cover, as it is partially present in intercropping with native perennial plants, will improve the soil microbial activity,
10. the efficiency of intercropping with native perennial plants in improving microbial activity is consistent under different climate conditions,
11. the effect of intercropping with native perennial plants on microbial activity is not species specific,
12. The annual crop's yield will not be affected by the intercropping system,

13. The farmer’s financial income will increase due to the additional income from the production of marketable native perennial plants,
14. The farmer will gain a more sustainable and reliable income from intercropping system if compared to the income from not intercropped fields,
15. The observed effects of intercropping are independent of the mean annual rainfall.

This thesis is organized in four chapters written as independent manuscripts aiming to test a group of the above hypotheses to convey a specific message to the international audience. This approach results, regrettably, to a certain repetition of some parts of the manuscripts, namely the introduction and methods. The four chapters are organized as follows:

- Chapter one: Intercropping with useful native perennial plants reduces surface runoff and soil erosion in traditional agricultural systems in Palestine. In this chapter the hypotheses 1-5 were tested.
- Chapter two: Managing soil organic matter by intercropping arable fields in Palestine with native perennial plants. In this chapter the hypotheses 6-8 were tested.
- Chapter three: Soil microbial activity response to intercropping with native perennial plants. In this chapter the hypotheses 9-11 were tested.
- Chapter four: Intercropping annual fields with native perennial plants as management strategy that reduces socioeconomic risks. In this chapter the hypotheses 12-15 were tested.

Key Results

The influence of intercropping with useful native perennial plants on surface runoff and soil erosion

The study showed that considerable amounts of water and soil are lost from the arable field in the region (223 m^3 – 288 m^3 of water /ha = 4%-7% of the annual precipitation, and 3.2-5.6 ton/ha of soil). However, both total runoff and erosion were strongly reduced when the annual crops were intercropped with useful native perennial plants. The intercropping reduced the runoff by 34% - 89% and the soil loss by 45 % - 94%. The positive effects of intercropping were observed in two consecutive seasons of investigation, while the magnitude of the effect varied with season and along the rainfall gradient. The effectivity of intercropping in controlling runoff and soil loss was more pronounced at the drier part of the studied rainfall gradient and during the drier season. The effect on erosion and runoff was not species specific.

The influence of intercropping with native perennial plants on soil organic matter

The study show a rapid decline of soil organic matter (SOM) in the not intercropped arable fields during the two years of study, while the level of SOM in intercropped fields was maintained. Conserving SOM by intercropping was not species-specific. The intercropping practice show higher SOM improvement at the drier part of the studied rainfall gradient.

Soil microbial activity response to intercropping with native perennial plants

The results indicate that intercropping with native perennial plants can enhance soil microbial activity. The change in microbial activity was generally accompanied with positive changes in soil organic matter. All the native perennial plants species tested may enhance soil microbial activity. Additionally, there are some trends of species-specific effects on the magnitude of microbial activity enhancement. These results were consistent at all investigated sites which have different mean annual precipitations.

Intercropping with native perennial plants as resilience to socioeconomic risks

The study show that intercropping with native perennial plants had minimal negative effect on the yield of the annual crops, while the overall financial income were higher on intercropped plots if compared to the income from fields with annual monocrops. There was a tendency toward lower annual crop yield in the intercropped fields if compared to the non intercropped plots. However, for the farmer that reduction was compensated by the income gained from the native plants. The income gained from the annual crops in the dry season (2005/6) was lower than in the wet season (2004/5), while a stable consistent income was gained from marketing the native plants in both seasons. This means that, in semiarid regions the income from intercropping system may be more sustainable and reliable compared with the monoculture system. These results were consistent in semi-arid and arid sites.

General Discussion

The main objective of this study was to develop a land use strategy that mitigates soil problems with feasible crop production in semiarid-arid regions characterized by short rainy season, low annual rainfall and high inter-seasonal variations. Therefore, we introduced intercropping annual crops in arable fields with useful native perennial plants. The practice proved to be efficient in soil conservation and economic mechanism.

Our study implies that water loss due to runoff and soil erosion can be effectively controlled by a partially permanent plant cover in the form of native perennial plant intercrops. Water and soil losses in the surface runoff could be reduced significantly by intercropping. Reduction of total runoff by intercropping ranged from 34% to 89%. This means that intercropping may annually save quantities of water ranged from 100 $m^3 ha^{-1}$ to 264 $m^3 ha^{-1}$, which is of high important especially in area suffering from natural shortage in water due to low mean annual precipitation. The amounts of water saved in this technique are sufficient to produce 350 kg ha^{-1} to 900 kg ha^{-1} of grain according to the estimation of water use efficiency for the study area (Al-Juneidy and Isaac 2001). As runoff is reduced, the infiltration rate will be increased which may help in increasing ground water resources. In addition, intercropping was also effective in reducing soil loss by 45 % to 94% compared with no intercropping treatment. The estimated amount of annually saved soil by intercropping is almost 5 ton ha^{-1} of soil. These are some environmental benefits provided by the proposed intercropping system which are also of economic values.

The greatest erosion control benefit from the native perennial plants resulted from their ability to reduce the soil concentration in the runoff. The protection action of intercropping is likely to occur by impeding surface runoff between native plant rows, thereby reducing runoff velocities and erosion potential (Dunj'o et al., 2004). The sediment was more likely to be redeposited behind the next native plant strip down slope, because of reduced runoff velocity. Therefore, the native plant strips are particularly important for surfaces that completely devoid of any form of protective covering after crop harvesting that characterize the annual production fields in semiarid-arid areas. By contrast, the not intercropped fields of such area are highly susceptible to erosion especially in early winter periods when the most erosive rain storm occurs before the presence of any type of vegetation. The study therefore, confirms the importance of vegetation in erosion control as documented by several authors (e.g., Seeger 2007, Neave & Rayburg 2007).

In addition to the direct effects of aboveground intercropping plants on reducing runoff and erosion, there were some indicators for indirect effects of the native perennial plants intercrops that reduce soil erodability. The results of this study indicate that SOM was conserved or improved in the intercropping treatments. The improvement of SOM probably occurs by the frequent incorporation of organic matter in soils via root depositions and plant residues. Additionally, intercropping reduced the rates of nutrients and organic matter losses through runoff and erosion. These benefits were absent in monocrop fields therefore, a rapid decline of SOM content was recorded in the not-intercropped fields. Therefore, the study indicates that intercropping may help in improving soil structure especially increasing soil organic matter. By longer term application, the increase of SOM may result in increased aggregate stability and reduced soil erodability. Increasing soil organic matter means additional nutrients are available for plants after decomposition.

The results confirm that intercropping may enhance other soil quality parameters mainly microbial activity. The microbial activity indicator (dehydrogenase enzyme activity) in the intercropped fields was elevated up to two times of that found in the monocrop fields. The higher level of microbial activity was generally accompanied with the increase in soil organic matter. Therefore, it is possible to suggest that the higher level of microbial activity under the native plant strips was mainly a response to the increase input of nutrients. This is in consistent with results obtained by some authors (e.g., Balota et al. 2003 & 2004, Hassett & Zak 2005). In addition, the greater variety of organic matter residues derived from long-term intercropping may allow more efficient organic matter utilization by soil microbes as compared to the more uniform input from monoculture plots (Insam et al., 1989), which may enhance the activity of several soil microbial populations. The microbial activity was relatively lower in the monoculture fields, which means that agriculture of mono-species in semiarid soils may have a negative effect on microbial activity. Therefore, intercropping with native perennial plants may preserve soil resources and maintain healthy productive soil.

Little information is available in literature about particular plant species effects in soil conservation (Loranger-Merciris et al. 2006, Potthoff et al. 2006). Therefore, the species-specific effects on the conservation action are uncertain. However, the results indicate some evidence that different plant species may contribute to different magnitudes of improving soil parameters especially microbial activity. The microbial activity level under the various species intercrops was ordered as *Salvia hierosolymitana* > *Salvia fruticosa* = *Majorana syriaca*. While no significant differences were between these species in improving SOM. Therefore, the variation in microbial activity may be due to the presence of non-easily decomposable organic matter (Garcia et al., 2005) and/or due to allelopathic release of some substances from *M. syriaca* and *S. fruticosa*. The highest level of microbial activity was in the plots of *S. hierosolymitana* which is characterized by producing good vegetation. Therefore, there are some insights into various effects of plant species on microbial activity although some gaps are still in our understanding of the linkages between plant species and microbial activity.

Since there was no observed species specific effect on soil conservation and maintaining SOM, other native perennial plant species may be suitable for the conservation technique. However, it must be noted that the magnitude of their effectivity is not always equal. Therefore, it is important to determine the conservation priority. If the priority is for improving soil quality mainly the soil microbial characteristics, it is important to use a species that produce good vegetation with minimal negative allelopathic effects on soil microbial community. But if the aim is to conserve the soil base and/or to protect a specific useful plant species, simply this aim may be achieved by planting the plant species widely as intercrops in annual crop fields. Several useful native perennial plants in the research area and other semiarid-arid areas are considered endangered species because of the collection stress from local people (Applied Research Institute, 1997). These species may be used for intercropping in annual production fields. Planting such species as intercrops will probably decrease the pressure on their wild populations. Thus, this technique may help in biodiversity conservations. The choice of the native plant species for the intercropping practices may therefore, depends mainly on local needs in terms of economic and biodiversity conservation.

The results indicate that intercropping with native perennial plants is a suitable soil protective management for semiarid-arid areas. Furthermore, there are evidences that the impacts of this agricultural management vary according to climatic conditions and may be suitable with more aridity. The magnitudes of reducing runoff and erosion, and improving SOM by intercropping were more pronounced at the arid part of the study gradient. Higher reduction of runoff and erosion by intercropping was also found during the drier season than in the season with normal rate of rainfall. In addition, comparing these results with previous data from other regions provide additional evidence about the suitability of this technique for semi-arid regions. For example, the activity of intercropping in controlling soil erosion in the semi-arid area of this study was higher than intercropping in mild areas as reported by Barton et al. (2004). Therefore, the results encourage intercropping with native perennial plants as a mitigation strategy in other semiarid-arid regions. Further, since the observed effects were consistent in two geographical sites with different means of rainfall, we conclude that this agricultural scheme is a suitable strategy to cope with the effects of expected climate change especially the reduction in mean annual precipitation.

A farming system is considered sustainable if it conserves the natural resources base and continues to satisfy the needs of farmers, the managers of the system (Hobbs, 2007). This study proves that intercropping with useful native perennial plants satisfy these conditions. In addition to the conservation effect of intercropping as discussed above, it was economic also. There was a tendency toward lower amounts of the annual crop's yield in the intercropped fields due to the lower plant population of the annual crops. However, the total financial income from the intercropped fields was higher than the income from monocrop treatments. The total income from intercropping fields was 74% -464% higher than the monocrop fields. Therefore, intercropping did not result in economic losses for the farmers as may be expected for usual agriculture conservation strategies which use some of the field area for the conservation purposes. Some mitigation strategies were able to control soil degradation in semiarid areas but fail to maintain crop yields such as a combined system of crop rotation, perennial hedgerow and grass strips (Kinama et al., 2007). Therefore, the simplicity and productivity of intercropping with native perennial plants may encourage adaptation of this strategy by the local farmers.

The yield and income from the annual crops were highly affected by the shortage in the rain fall in the second season while the yields of the native plants were stable. The intercropping system using marketable native perennial plants proved to be more sustainable and reliable despite the inter-seasonal fluctuation of rain fall amounts. Given that droughts of unpredictable intensity frequently occur in semiarid-arid regions, the farmers of annual monocrops in these areas frequently suffer from economic losses due to yield failure. However, the economic losses may be reduced and/or compensated as financial rewards to the farmers by practicing intercropping with native perennial plants. The native plants of semiarid-arid regions are adapted to drought conditions. Therefore, the income gained from them was sustainable in the two seasons. Marketing the native perennial plant intercrops may guarantee some income even if the annual crops failed. In this case, the income from native perennial plants may represent the resilience to socioeconomic risks and provide the substitute income for farmers in dry seasons.

The intercropping practice using native perennial plants is simple and economic mechanism. The native perennial plants intercrops are planted once with relatively very low cost. The native perennial plants may not need additional application of fertilizers because of high return of nutrients to soil. In addition, application of pesticides for these plants is not expected to be necessary since many native plants have developed it own defense means such as producing toxic materials (Reales et al. 2004, Kaileh et al. 2007, Aburjai et al. 2007). However the advantages of this system are permanent in terms of sustainability and conservation. The intercropping system which uses marketable native perennial plants may minimize the risk of crop loss in dry season, stabilize the income over the long term, and promote biodiversity by decreasing the pressure on the wild populations of the intercropping species. Furthermore, intercropping with native perennial plants is effective in soil protection and water efficiency enhancement. Thus, we strongly recommend intercropping the traditional arable fields with useful native perennial plants as a promising option for sustainable rain-fed agriculture and soil resource conservation in semiarid-arid areas.

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Chapter one

Intercropping with useful native perennial plants reduces surface runoff and soil erosion in traditional agricultural systems in Palestine

Abstract

Surface runoff and erosion are regarded as major contributors to soil degradation worldwide. These processes are especially relevant in regions with spares vegetation cover, low annual precipitation but often intense rainfall events. Palestine is situated in an area with - despite of low overall precipitation - sometimes heavy rainfall events (especially during the early growing season when vegetation cover is still scarce). However, little quantitative information is available for this region on soil losses by erosion and unproductive water-losses by runoff on agricultural lands. Consequently, land management practices that may help to mitigate these problems must be introduced. Therefore, a 2-year, experiment was set up to assess soil loss and unproductive water loss on arable fields in Palestine and to test for the mitigating effects of intercropping arable fields with useful native perennial plants. The experiment was conducted in two sites situated along an aridity gradient from 425 mm to 595 mm to test the possible influence of the different means of annual precipitation on the proposed mitigation strategy. Three useful native plant species were used as intercrops, *Majorana syriaca, Salvia fruticosa* and *Salvia hierosolymitana*. All these species are commonly collected from the wild as food and spice.

The results of the study showed that considerable amounts of water and soil are lost from the arable fields in the region (223 m^3 – 288 m^3 of water/ha = 4%-7% of the annual precipitation and 3.2-5.6 ton/ha of soil). However, both total runoff and erosion were strongly reduced when the annual crop was intercropped with useful native perennial plants. The intercropping reduced the runoff by 34% - 89% and the soil loss by 45 % - 94%. The positive effects of intercropping were observed in two consecutive seasons of investigation, while the magnitude of the effect varied with season and along a rainfall gradient. The effectivity of intercropping in controlling runoff and soil loss was more pronounced at the drier part of the studied rainfall gradient and during the drier season. Additionally, it was possible to show that intercropping enhanced infiltration and retention of water after rainstorms. The effect on erosion and runoff was not species specific.

Our study implies that intercropping with useful native perennial plants can effectively reduce runoff and soil erosion in semi-arid regions.

Introduction

Soil degradation is a serious natural biophysical process. However, it is enhanced by human activities through alteration of land cover and disturbance of soil structure by agriculture (Lal 2001). About 80% of the world's agricultural land suffers from moderate to severe erosion and world-wide about 12 Million hectare of arable land are abandoned or destroyed annually as a result of non-sustainable farming practices (Ritchie et al., 2003). The present global average value of soil erosion is estimated to be 10.2 ton $ha^{-1} year^{-1}$, of which 60% are induced by human activities, and this amount is estimated to have increased by about 17% due to the fast development of cropland in the last century (Yang et al., 2003).

Soil erosion is the principal threat to agricultural sustainability especially in arid and semi-arid regions due to reduction of top soil depth and losses of essential plant nutrients (Tengberg et al. 1997, Lal 1998 Chappell et al. 1999, El-Swaify 2001). Furthermore, soil erosion is predicted to increase in future because of the greater variability in monthly precipitation, and the increased frequency of large storms predicted by global climatic change scenarios (Zhang and Nearing, 2005). Soil erosion may also increase as a result to the decrease in the vegetative cover which is predicted to occur due to the increased temperatures (O'Neal et al., 2005).

However, changes in crop management due to effects of climate change and even economic pressures may in future increase the magnitude of erosional impacts stronger than predicted from the direct influence of the climate change (O'Neal et al., 2005). Therefore, climate change and its effects on land-use strategies and economics need to be taken into account while developing strategies for sustainable water resource management.

It is known that certain physical factors define the erodability of soils (Wischmeier & Mannering 1969, Duiker et al. 2001, Rhoton et al. 2002). However, these effects may vary according to local conditions. Soils with high content of organic matter, high aggregate stability, and high infiltration capacity are relatively resistant to erosion. Recent studies indicate that the influence of these soil factors on runoff generation and erosion is uncertain and highly variable in space and time (Seeger, 2007). Therefore, additional factors maybe involved. One of these factors - known to strongly affect runoff generation and erosion - is the structure and density of the vegetation cover (Barton et al. 2004, Adekalu et al. 2006, Seeger 2007). Adding vegetation cover by mulching or intercropping was found to reduce runoff and soil loss (Gafur et al. 2003, Barton et al. 2004, Dunj'o et al. 2004, Adekalu et al. 2006, Neave & Rayburg 2007). The importance of vegetation in erosion control is attributed to two main effects: on one hand, the direct mechanical protection of the soil surface by the canopy and litter covers that intercept rainfall and consequently reduces the detachment of soil particles caused by raindrop impact at the soil surface, and on the other hand the indirect improvement of the soil physical and chemical properties, especially by the incorporation of organic matter (Dunj'o et al., 2004).

In arid and semi-arid regions agricultural fields stay bare of vegetation for a long period of the year including the time of the first rain events. During this period the soil is left in a physical condition that makes it prone to both wind and water erosion. Therefore, successful techniques to prevent or reduce runoff and erosion in arid-semiarid region must maximise the area of permanent vegetation cover. Only such a permanent vegetation cover will efficiently work as a sediment trap during the early and often strong rainfall events.

In order to avoid or reduce the described problems for human livelihood, it is necessary to develop land-use strategies that will mitigate runoff and erosion and allow a sustainable land-use, even under changing climatic conditions. The fast implementation of such strategies is especially important in transitional zones, like semiarid regions, where the effects of the expected global climatic change will be most obvious. So far the cropping systems that have been suggested and/or tested as mitigation strategies are mulch, rotation and intercropping of annual crops with various tillage combinations (Lal 1995, Vandermeer et al. 1998, Altieri 2002, Barton et al. 2004, Adekalu et al. 2006). E.g., mulch and intercropping of annual crops with conventional tillage reduced erosion rates by 4% - 35% in mild climate of steep lands in Yunnan (Barton et al., 2004). From a simulated rainfall experiments, Adekalu et al. (2006) predicted that 85% mulch cover is enough to prevent runoff and soil loss under rainfall intensity of 100 mm/h. A crop rotation system of selected crops and perennial grass species (>50%) reduced erosion on upland regions in temperate zone of Lithuania by 77–81% (Jankauskas and Jankauskiene, 2003). A complex system of grain crop rotation with perennial shrub hedges and mulch with and without grass strips was used to control soil runoff and erosion on sloping land in semiarid Kenya (Kinama et al., 2007). The system was effective in controlling runoff but failed to maintain crop yields (Kinama et al., 2007). Intercropping was suggested by some authors as mean to control runoff and soil erosion sense it may provide efficient vegetation sediment traps and infiltration zones (Lal 1995, Vandermeer et al. 1998). Despite that intercropping is already practiced as a mean to conserve soil quality in some semiarid areas of East Africa and Latin America (see reviews of Vandermeer et al. 1998, Altieri 1999, 2002, Tengberg et al. 1998), the attribution of intercropping to controlling runoff and erosion was not quantitatively evaluated. In addition, the experimental evaluation of the possible effect of various climate conditions on intercropping as mean to control runoff and erosion got less attention from researchers. Therefore, the quantitative information on the efficiency of intercropping in controlling soil erosion in semiarid-arid regions is scanty. The presented study attempts to contribute to fill that gap.

Dunj'o et al. (2004) found that the natural vegetation of perennial herbs and shrubs in arid-semiarid regions was effective in controlling runoff and erosion more than annual cropping. That effect is partially attributed to the perennial ground cover of many native species which prevents overland flow in rills and gullies sinks (Dunj'o et al., 2004). Therefore, the cultivation of useful native perennial plants as intercrops in annual crop fields could be a possible management strategy to reduce soil erosion and deserve evaluation. Several native plants species are adapted to grow in semiarid-arid regions. However, these species vary considerably in their morphology, growth period and vegetation density. Therefore, these variations may contribute to some effects on runoff and erosion. Thus to derive conclusions about species specific effects in the intercropping practice it is important to test several species.

The presented study aims to test if intercropping with native perennial plants will mitigate land degradation and reduce unproductive water loss under present and future climate conditions. We assume that intercropping systems using native perennial plants may help to control soil erosion by providing sediment traps and enhance water efficiency by minimizing un-productive water losses (surface runoff). In addition we assume that intercropping with native perennial plants will increase infiltration and retention of water in soils. In particular we aimed to study the potential of intercropping traditionally used agricultural crops with useful native perennial plants in reducing runoff and erosion under semiarid-arid conditions. We want to examine also the possibility of using different alternatives of native species in the intercropping system. Specifically, this study attempts to examine the following hypotheses:

(1) the application of intercropping with native perennial plants will reduce unproductive water-losses due to surface-runoff,

(2) the application of intercropping with useful native perennial plants will reduce soil erosion,

(3) the intercropping systems with useful native perennial plants will increase the retention of water in soils, and consequently increase water efficiency,

(4) the advantages of intercropping of native plants in reducing runoff and erosion are consistent under different mounts of precipitations of sites and seasons, and

(5) the efficiency of the intercropping with useful native perennial plants in reducing runoff and erosion is not species specific.

Methods

Selection of the study area

The hilly slopes of the West Bank, Palestine were selected as a suitable area to study our hypotheses. The area suffers from severe land degradation problems - mainly soil erosion - due to the low vegetation cover and scarcity of available water (Isaac and Maurice 1999). The low water availability is related to natural shortage of water resources and the increasing demand for water by a rapidly growing human population. Additionally, due to economic pressures, a shift from traditional rain-fed agricultural systems to modern irrigated agriculture is observed, which enhances the pressure on the available water resources even more.

The study area has a Mediterranean climate characterized by long, hot, dry summers and short, cool, rainy winters, with often intense rainfall events (ARIJ, 1995). Climate changes scenarios predict for 2071 to 2100 for the area a rise in temperature of about 3℃ - 5 ℃, and a decrease annual precipitation of about 10% - 30% (Alpert et al., 2006).

The study was conducted in vegetable fields at Al-Khalil district in the southern part of the West Bank (Figure 1). This district is located between 100 m and 1011 m a.s.l. The monthly average temperature ranges from 7.5 ^{o}C in winter to 22 ^{o}C in summer. The district is mostly semi-arid – Mediterranean (250 mm to 600 mm) with the wettest parts in the north and an increasing aridity towards the south (Negev desert) and east (Jordan Valley). Most of the precipitation is received between December and February (ARIJ, 1995). Rainfall of high intensities occasionally occurs particularly early in the season when soil cover that may diminish raindrop impacts, is still low. Seasonal rainfall and rainfall distribution over the season are highly variable. The dry period of the year can be as long as 7 months (April-October).

In order to test the influence of changes in climatic conditions on our proposed mitigation strategy we conducted our experiments at two sites differing in the received mean annual precipitation (Figure 1):

- Al-Dhahriya (further referred to as Site A) located 15 km to the south of Al-Khalil city, (31º 26’ 46.2” N, 34º 58’ 18.3” E), receives a mean annual precipitation of 425 mm, and is situated at 610 m above sea level. Four arable fields were at this site for our experiment.
- Halhul (further referred to as Site H) consisted of three fields: H1 (situated at 31º 35’ 41.3” N, 35º 06’ 06.2” E), H2 (situated at 31º 35’ 18.1” N, 35º 05’ 08.9” E), and H3 (situated at 31º 34’ 07.2” N, 35º 06’ 12.0” E), receives a mean annual precipitation of 590 mm and located between 910 m a.s.l. and 960 m a.s.l. Because of the local conditions at site H the distances between the experimental fields were larger than at site A. However, the distances between fields at each site were always shorter than the distance between sites.

The selected fields for our experiments share comparable features. They were located on moderate slopes with inclination between 8% and 10%. The soil of the investigation sites is classified as brown Terra Rossae (Land research Center 2002). All sites were used for rain-fed annual vegetables and field crops farming since decades (traditional agriculture). The basic soil physical and chemical characteristics of the experimental fields (Table 1) were determined using standard methods: pH by pH electrode in 1 : 1 soil-water suspension, Mg and Ca by atomic absorption, Na & K by flame photometer, Total N and total P by Kjeldahl methods, Electrical conductivity (EC) was determined on 1 : 2 saturation extract with conductivity meter, soil texture following the methodology of Kettler et al. (2001), Soil organic matter (SOM) was measured by wet oxidation using H_2SO_4-$K_2Cr_2O_7$ (Weber 1977).

To test our hypotheses, we conducted an intercropping experiment. Annual vegetable crops were intercropped with useful native perennial plants. The efficiency of native perennial plant intercrops in reducing runoff and soil erosion as well as increasing water retention was measured in intercropped experimental fields and compared to results from not intercropped fields (controls).

In order to test whether or not the results obtained are species specific we used three species of useful native perennial plants. The experiment and the measurements were repeated in two repetitive rainy seasons to test for the effect of inter-annual variation in precipitation on the efficiency of native perennial plants intercrops to reduce runoff and erosion as well as to enhance water retention.

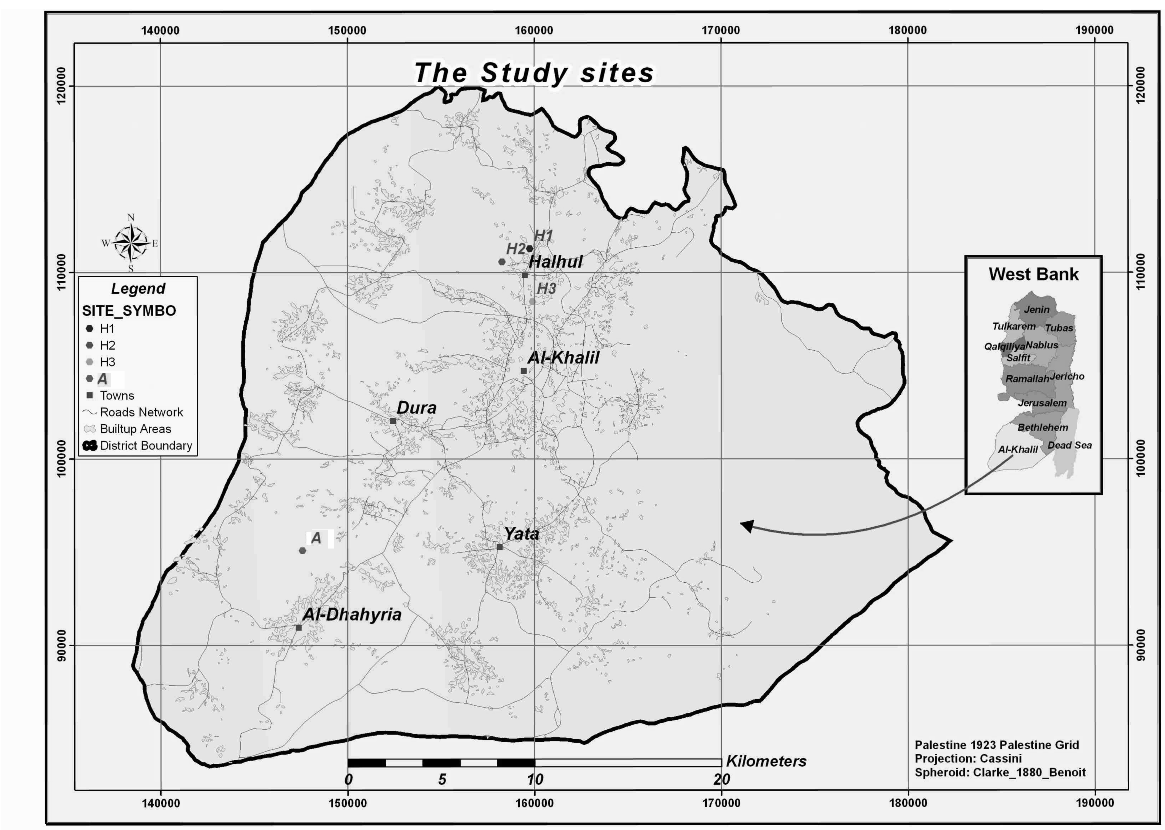


Figure 1: The location of study sites in Al-Khalil district, West Bank, Palestine.

Table 1: Soil characteristics of the experimental fields in two sites (A: Al-Dhahirya and H: Halhul):

Site	Field No.	Texture			Mg^{+2}	Ca^{+2}	Na	K	EC	pH	Total N	Total P	%OM
		Sand%	Silt%	Clay%	mg/g	Mg/g	mg/g	mg/g	mS/cm				
A	1	54	23	23	0.014	0.075	0.055	0.037	0.306	7.4	0.342	0.041	2.93
	2	52	23	25	0.015	0.092	0.063	0.033	0.311	7.4	0.424	0.043	2.49
	3	56	23	21	0.022	0.120	0.084	0.035	0.510	7.4	0.710	<0.001	2.40
	4	51	25	24	0.015	0.084	0.059	0.035	0.298	7.4	0.376	0.044	2.66
H	1	50	36	14	0.022	0.064	0.060	0.005	0.413	7.6	0.480	<0.001	2.52
	2	38	50	12	0.018	0.082	0.046	0.016	0.356	7.5	0.017	0.003	2.44
	3	42	42	16	0.017	0.056	0.046	0.006	0.348	7.6	0.370	0.036	3.17

Experimental design

A block design was used with 4 blocks in site A and 3 blocks in site H. Each block contained three intercropping treatments and a control (Figure 2). Each treatment plot was 110 m^2 (5 m wide x 22 m long). In the intercropping treatment parallel strips of the native perennial plants were planted across the path of overland flow. The width of each strip was 0.5 meter. The strips were planted with a distance of six meters in order to allow the machinery and other treatment necessary for agriculture in the field. The native plants covered 10% of the total area of each treatment plot. Spaces of 1 m -2 m were left untreated between bordering treatments to reduce edge effects. The arrangements of the different treatments in each block were randomised. Each experimental block covered about 1000 m^2 or 0.1 ha.

The decision for the cash-crop used was left to the local farmers involved in the project. Therefore, the crop rotation followed the local tradition: Snake cucumber (*Cucumus melo, var. flexuosus*) in the first year (2004/5) and bean (*Phaseolus vulgaris*) in the next year (2005/6) of study.

As native perennial plants for the experiment we selected *Majorana syriaca, Salvia fruticosa,* and *Salvia hierosolymitana* (in the following referred to as *M. syriaca*, *S. fruticosa* and *S. hierosolymitana*). These native plants were chosen because they are commonly collected from the wild as food, spice and/or for medicinal purposes and because they have perennial life history. *M. syriaca* is herbaceous/shrub plant which shows weak stems with small leaves in early autumns, which cover around 30% of the strip area. When the first rain falls, the plant starts growing slowly until the plants cover 100% of the strip area in February. After cutting stems for consumption, the stem base (10-20 cm high) still exist in the fields with very slow growth until the rain season. *S. fruticosa* is a shrub plant of well developed stems and leaves in all periods of the year. Stems with leaves are usually cut 20-30 cm above ground for consumption. The existing parts in the fields cover almost 50% of the strip until autumn. When rain fall the plant starts growth again until it covers 100% of the strip area. *S. hierosolymitana* shows residues of dry above ground stems with small green ground leaves at the early autumn. In this period the plants cover less 10-20% of the strip area. The plants start to grow rapidly after rain fall and cover 100% of the strip in January. The flesh leave are usually picked for consumption every 10-15 days in the growing period but the left stems and leaves are still sufficient to completely cover the area of the strip until midsummer.

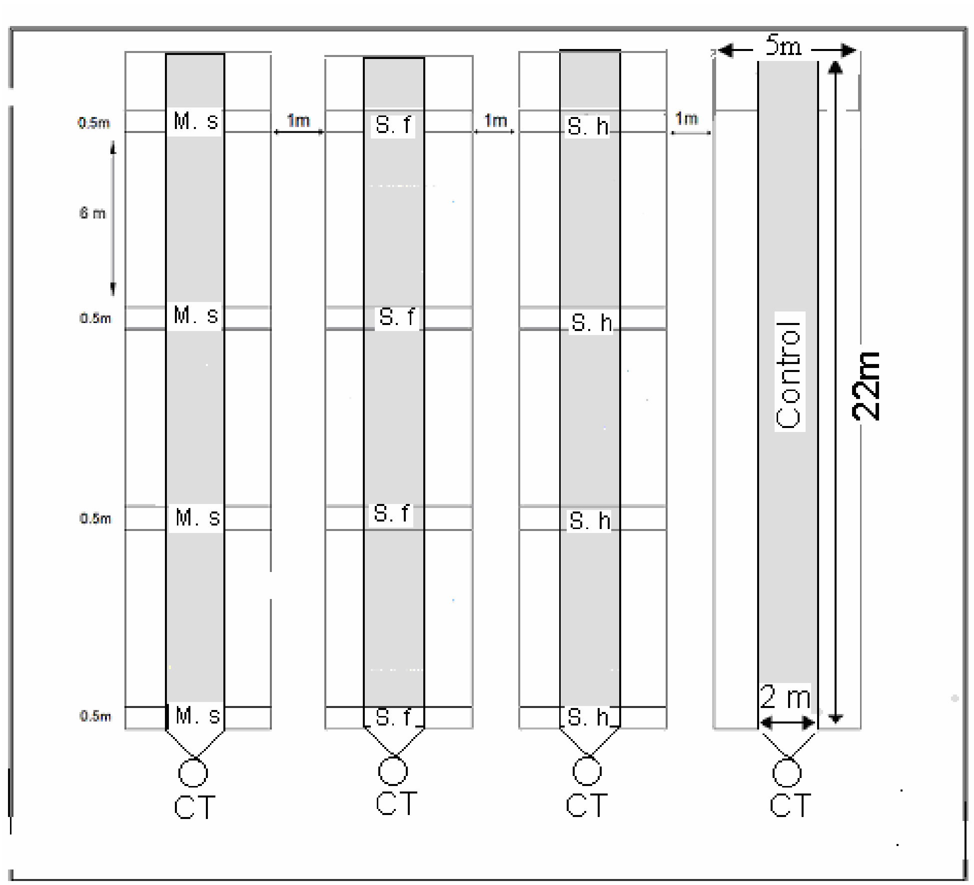


Figure 2: The experimental design and the spatial distribution of vegetable crops and the intercropped native plants in a block of the experiment. The position of the erosion plots are marked as dark areas (22 x 2m). The arrangement of different treatment plots is randomised (therefore, the graph gives only an example). M.s.: *Majorana syriaca, S.f.: Salvia fruticosa* , *S.h.*: *Salvia hierosolymitana.* CT : Sediment Collection Tank.

The seedlings of the three native plants were acquired from a local nursery and transplanted into the field in the 3rd week of Feb. 2004 at site A and in the 4th week of the same month at site H, 9 months before the erosion measurements. Three rows of the seedlings were planted in each strip of intercrops with a distance of 25 cm between rows and 50 cm between adjacent seedlings. The seeds of the annual crop (snake cucumber/bean) were planted in the middle of April at site A and in the middle of May at site H. These planting times follow the beginning of the warm season (following the cold rainy period). Since the beginning of the planting season varies according to the geographic location, planting started at site H one month later than at site A.

Measurements

Rainfall

Rainfall amounts were monitored in the two seasons of investigation, first to calculate the percentage of rainwater is lost by runoff in the various treatments. In addition, to test if the intercropping effectivity is influenced by variations in the rain fall between sites and during the rainy season, and to detect some of the inter-annual variation in precipitation and to test if the intercropping effectivity is influenced by inter-annual variations. The amount of rainfall was measured after each rain event at each site from one simple rainfall gauge. The total accumulative amount was used for the subsequent calculations. The total amount of rain water received per hectare was used to calculate the amount of water losses by runoff as a percentage of rainfall.

The influence of intercropping on runoff

The accumulative runoff volume over each rainy season received from intercropping plot was measured and compared with the volume received in the control plots. Runoff was measured using field erosion plots as described by Morgan (1995), Albaladejo et al. (1999), and Bagarello and Ferro (2003). The plots were 22m x 2m, and set-up in the centre of each experimental plot (Figure 2). Each plot was bordered by sheet-wood strips embedded about 5 cm into the ground and extended 15 cm above the soil surface. The surface runoff and total sediments were intercepted at the down slope end of the plot and routed to a cylindrical collecting tank (capacity 200 litres). Runoff volumes were measured in all plots right after each erosive rain event or occasionally, after a series of events if these were separated by only short intervals without precipitation. The depth of the water collected in each tank was measured and used to calculate the volume of runoff. The total runoff volume over the rainy season was measured as litre per plot (44 m^2). Then the measurements were converted to litre per hectare (L/ha). Water loss was calculated as a percentage of total rainfall amount received during the measuring period. Measurements were taken in two repetitive rainy seasons (2004/5 and 2005/6).

The relative differences in runoff volumes between the different treatments (species used for intercropping) were calculated to allow to test for species-specific effects and for the influence of mean annual precipitation on the effects of intercropping.

The influence of intercropping on soil erosion

The soil erosion over each rainy season was measured in the same experimental set-up as described before. After each rainfall event in two repetitive rainy seasons 2004/5 and 2005/6 a sample of the runoff was taken from each of the collecting tanks. Prior to taking the sample the water in the tank was stirred intensively with a wood stick. After thorough stirring up all the sediments in the tank three aliquots of 0.5 l were taken from different depths (upper, middle and lower parts of the tank) with 0.5 l beaker. The three aliquots were merged in a 2 l container. The sediment concentration in each of the merged samples was determined within 24 hr after collection. Two sub-samples of 0.5 l from the 2l aliquots were filtered through filter paper (Whatman No. 1). The sediments on the filter papers were oven-dried at 105 °C for 24 hours, and weighed. A mean of the measured concentration from the two sub-samples was calculated and this mean was used to calculate the amount of soil loss. The amount of soil erosion of each plot was calculated by multiplying the sediment concentration by the volume of collected runoff from each rain storm. Then the total soil loss in the whole season was used to calculate soil erosion as kilogram dry soil per hectare (kg/ha). The relative differences in soil erosion between the treatment plots were calculated to test for species-specific effects and for the influence of mean annual precipitation on the effects of intercropping.

The influence of intercropping on the water retention

To test the influence of intercropping on the retention of water in the soil, soil moisture content was measured in all plots after rain storms and the results from the treatment plots were compared to the results from the control plots. We measured the soil moisture three days after the rain storms since the soils of the area usually become very muddy and it is impossible to access the fields directly after a rain-storm. The weather of the area is usually cold and cloudy in rainy periods, and therefore, the loss of water by evaporation can be neglected. During the 1st rainy season soil moisture was measured five times (five longer breaks between the rain-storms). In the 2nd season, erosive rain events were less frequent than in the first season and therefore, soils moisture could be measured only three times.

For the measurements one composite soil sample (about 1kg, from 0 cm - 20 cm depth) was taken at different locations (upper slope, centre of slope and lower part of slope) which include the area between strips and under the native plants strips in each plot. 50 g of the each composite sample was oven dried over night at 105 °C and weighed. Percent soil moisture by weight (% Moisture content) was calculated by

$$\% \text{ Moisture content} = 100\% * [(W_f - W_{od}) / W_{od}$$

where W_f = fresh weight of soil sample and W_{od} = oven dry weight of soil sample.

Statistical analysis

To test for the effects of intercropping on runoff (hypothesis 1) we employed a 3-way ANOVA using the whole data set. In that ANOVA runoff (L/ha) was used as dependent variable and the four treatments (intercropping with *M. syriaca*, *S.*

fruticosa, *S. hierosolymitana* and a control), the two sites (A: Al-Dhahriya and H: Halhul) and two seasons of investigation (2004/5 and 2005/6) as independent variables. Separate one-way ANOVAs on the data obtained from each site and in each season alone were used to analyze the inter-treatment differences and Scheffe post-hoc tests ($p < 0.05$) was used to test for differences among treatments within each site and season.

To determine the influence of intercropping on soil erosion (hypothesis 2) the same statistical analysis as described above were conducted with the dependent variable soil erosion (kg/ha).

To test for the influence of intercropping on the retention rate of water in soils (hypothesis 3), the soil moisture content was used as dependent variable and the treatments (4), the sites (2) and the seasons (2) were used as independent variables in a 3-way ANOVA.

The influence of rainfall amount on the effects of intercropping with native plants (hypothesis 4) we calculated two parameters for the effects of intercropping on runoff and erosion which represents the relative differences between intercropping treatments and the control (% reduction of runoff and % reduction of erosion). Then these parameters were used as dependent variables in separate the 3-way ANOVAs. The independent variables in that ANOVAs were intercropping treatment-types (3 species), the two sites (A: Al-Dhahriya and H: Halhul) and two seasons of investigation (2004/5 and 2005/6).

To test for species-specific effect on runoff and erosion (hypothesis 5) the relative differences between intercropping treatments and the control (% reduction of runoff and % reduction of erosion) was used as dependent variables in the separate ANOVAs mentioned in the previous section.

The whole data-set and all needed sub-set satisfied the assumptions for ANOVA. All statistical analyses and graphical presentations were done with the help of the SPSS software package.

Results

Rainfall

The total amount of rain received in the first season (Oct. 2004 to April 2005) was 422 mm (4220 m^3 ha^{-1}) at the fields of site A and 572 mm (5720 m^3 ha^{-1}) at site H. In the second season of investigation (2005/6) total amount of rainfall was 248 mm (2480 m^3 ha^{-1}) at site A and 367 mm (3670 m^3 ha^{-1}) at site H. The monthly distribution of rainfall of the two seasons shows that in the 1st season the area faced extremely high rainfall in Nov (Table 2). The rainstorms with high rainfall intensity were only few in the second season. The differences between the two seasons are within the typical inter-annual variations known for the region.

Table 2: Monthly rainfall at the two experimental sites in Al-Khalil District during two repetitive rainy seasons

Month	**Al-Dhahirya (Site A)**			**Halhul (Site H)**		
	2004/5	**2005/6**	**Long-Term Average**	**2004/5**	**2005/6**	**Long-Term Average**
Oct	12	8	13	4	9	15
Nov	118	42	43	203	44	67
Dec	44	71	91	45	87	116
Jan	119	21	105	136	74	134
Feb	77	62	89	117	94	142
Mar	41	10	59	55	15	91
Apr	11	34	24	12	34	25
Total	**422**	**248**	**425**	**572**	**357**	**590**

The influence of intercropping on runoff

Total runoff in all intercropped treatments was significantly lower as compared to the control in all seasons of investigation and at all sites. Runoff volume in the control of site A was 287934 l ha^{-1} in 2004/05 and 185375 l ha^{-1} in 2005/06. Runoff was decreased in the intercropping treatments to 176487 l ha^{-1} and 38768 l ha^{-1} in the two seasons respectively. At site H the runoff volume in the control was 223100 l ha^{-1} in 2004/05 and 30173 l ha^{-1} in 2005/06 and decreased in the intercropping treatments to an average of 138067 l ha^{-1} and 13823 l ha^{-1} in the two repetitive seasons (Figure 3).

The monthly runoff volumes were correlated with monthly amount of rainfall (Correlation coefficient = 0.695, $p < 0.001$) in all cases. The linear regression analyses between runoff and rainfall shows that intercropping decreased the slope of the regression. The contribution to runoff of all treatments varies hierarchically with rainfall characteristics. The amount of runoff was usually accompanied with the amount and severity of rainfall. For the smallest storms, it is mainly the bare plots that produce runoff and its amount increased with the increase of rainfall. As rainfall amounts increase in the single storm, the runoff increased in the control and the intercropped plots started to contribute to runoff (Figure 4). The intercropping system was effective in reducing runoff during the extremely rain events in Nov of the 1st season. The reduction of water loss in the intercropped plots was observed even already in the early rain events of autumn when only the root systems and residues of semi-dry aboveground parts of the native plants were present in the case of *M. syriaca* and *S. hierosolymitana*.

Out of the amount of rain received about 6.8% and 7.5% were lost by runoff from the control plots at site A in the two seasons respectively. The loss of water was lowered in the intercropped plots in this site to 4.2% in the 1st season and 1.6% in the 2nd season. At site H the water loss in the control was 3.9% and 0.8% of the rainfall in the two repetitive seasons. The average loss of water in the intercropping treatments at this site was 2.4% and 0.4% in the two seasons respectively (Figure 5). The reduction of total runoff volumes in intercropped plots compared to the control plots was 34% - 41% in the 1st season and 52% - 89% in the 2nd season of investigation.

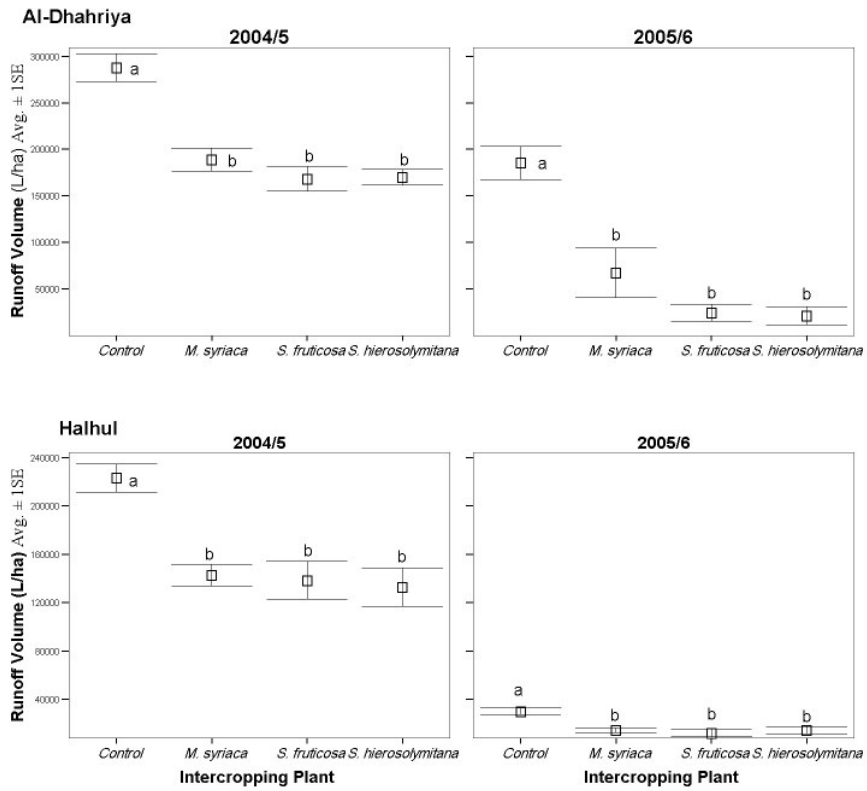


Figure 3: The runoff volumes (Avg. + 1SE) in two sites in Al-Khalil district under four different treatments in two seasons of investigation. Error bars with similar letter in each site and season are statistically not different (Scheffe test, $p < 0.05$).

The influence of intercropping on soil erosion

Total soil erosion in all intercropped treatments was significantly lower as compared to the control in all seasons of investigation and at all sites. Soil loss in the control of site A was 5625.4 kg ha^{-1} in 2004/05 and 1919.9 kg ha^{-1} in 2005/06. Soil loss in this site was reduced in the intercropping treatments to 2381.8 kg ha^{-1} and 221 kg ha^{-1} in the two seasons respectively. At site H soil loss in the control was amounted to 3158.7 kg ha^{-1} in 2004/05 and 319.8 kg ha^{-1} in 2005/06 and reduced in the intercropping treatments to 1533.2 kg ha^{-1} and 73.1 kg ha^{-1} in the two repetitive seasons respectively. That effect was consistent for all investigated sites and all studied seasons (Figure 6). The reduction of soil loss was 45% - 68% of the amount recorded in the control in the first season and 74% - 94% in the second season.

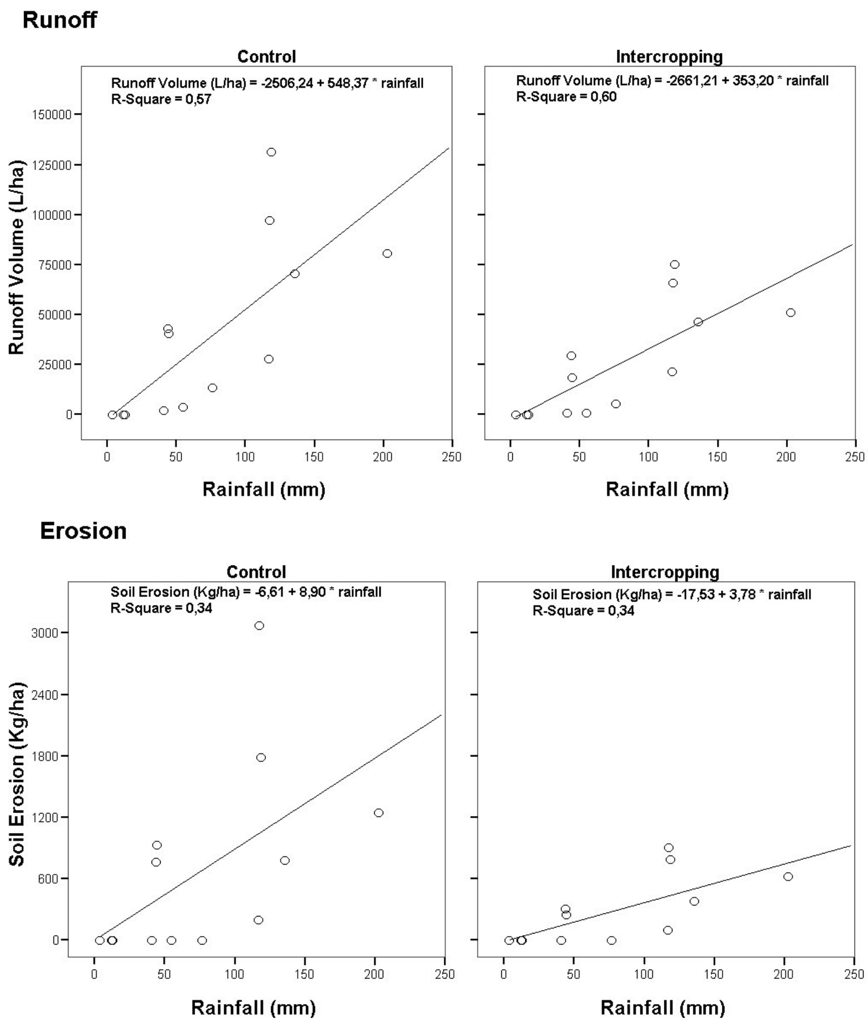


Figure 4: The linear regression of monthly runoff volumes (A) and monthly soil erosion (B) with the monthly amounts of rainfall under intercropping treatments using three native plant species as intercrops and control (no intercropping) for two sites.

The soil loss was proportional with the rainfall amounts. Almost 50% of the soil erosion occurred in Nov in which extreme high rainfall event occurred. The linear regression analyses between soil and rainfall shows that intercropping decreased the slope of the regression. Even during the high intensive rain events there was high reduction of soil loss by intercropping treatments (Figure 4). In addition, it was observed that sediment concentration in the collected runoff of the intercropping treatments in the late period of the rainy season was much less than its concentration in the early period (data not shown).

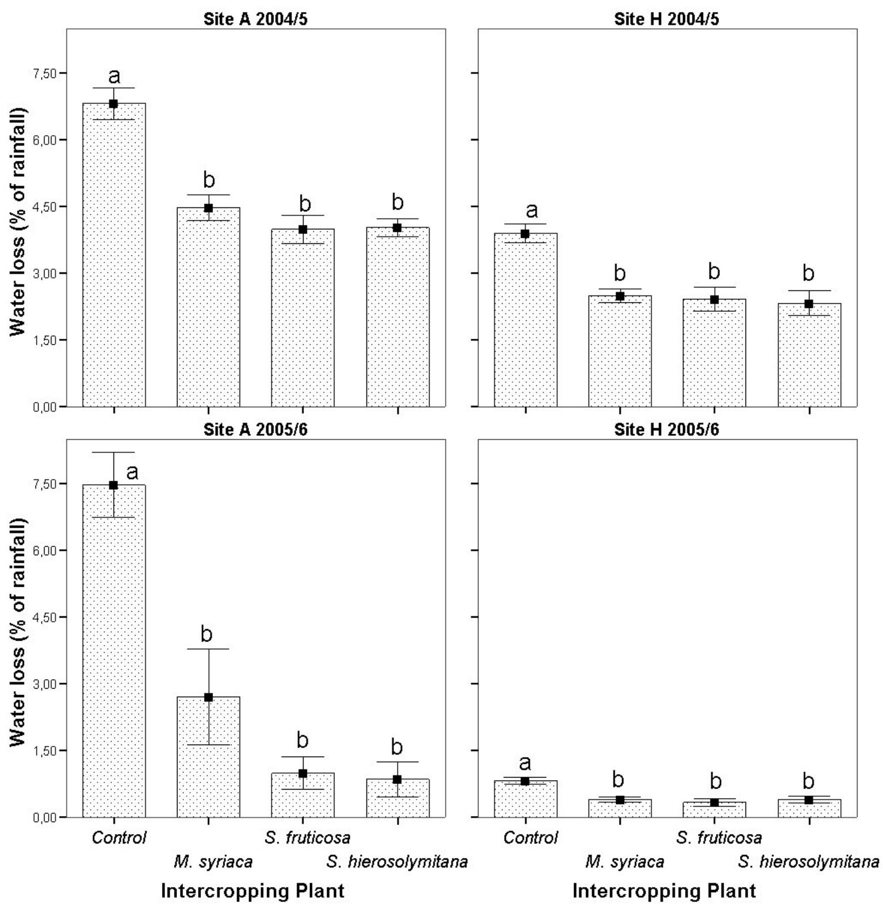


Figure 5: The average annual water loss (Avg. + 1SE) presented as percentages of rainfall in four different treatments in two seasons. Error bars with similar letter in each site and season are statistically not different (Scheffe test, $p < 0.05$).

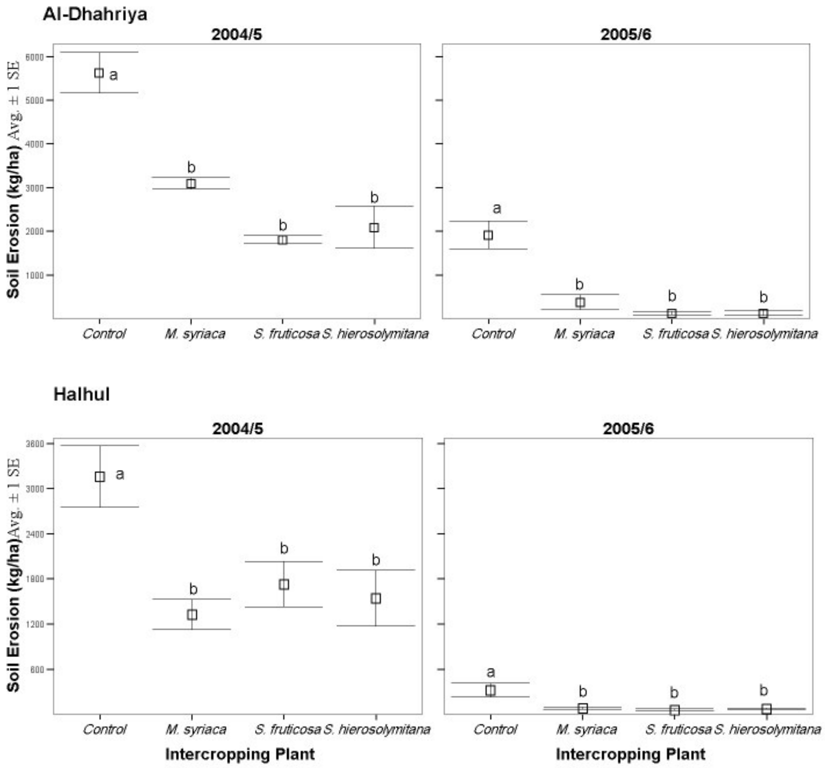


Figure 6: The amount of soil erosion (Avg. + 1SE) in two sites in Al-Khalil district under four different treatments in two seasons of investigation. Error bars with similar letter in each site and season are statistically not different (Scheffe test, $p < 0.05$).

The influence of intercropping on the retention of water in soils

Soil moisture in intercropped treatments with the three native plants was greater than in the bare treatment (control) in the first season only (Figure 7). The average soil moisture content in the control was 21.9% and the average in the intercropping plots was 24.6%. In the second season there was no significant difference of soil moisture content between different treatments. The average soil moisture content in the control was 22.2% and the average in the intercropping plots was 24.6%.

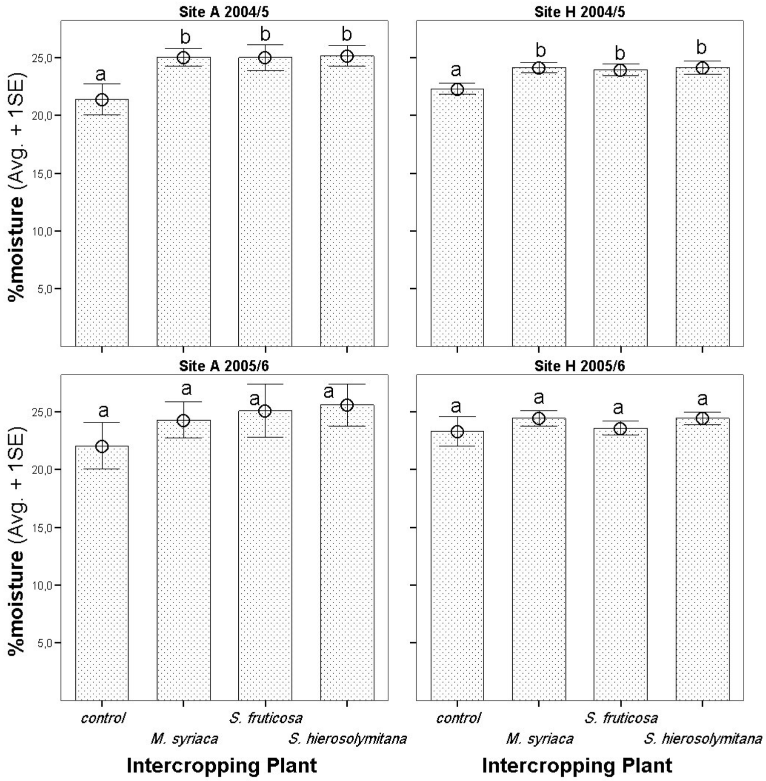


Figure 7: Soil moisture content (Avg. + 1SE) in two sites in Al-Khalil district under four different treatments. The values are means of 5 samplings after rain events in 2004/5 and means of 3 samplings in 2005/6. Error bars with similar letter in each site and season are statistically not different (Scheffe test, $p < 0.05$).

The influence of rainfall amount on the effects of intercropping

The amounts of runoff and soil erosion were lower than in the controls independent of the geographic location of the experiment and independent of the inter-annual variation. However, geographic location and season determined the magnitude of the difference. The reduction of runoff and erosion by intercropping treatments was more pronounced at site A (the drier site) than site H. The runoff was reduced by 59% at site A and by 46% at site H. The soil loss was reduced by 73% in site A and 64% in site H (Figure 8). In addition, the reduction of runoff and erosion by intercropping treatments was also higher in the 2nd season (the drier season) than the 1st season in all sites. The runoff was reduced by 38% in the 1st

season 2004/5 and the percent was 68% in the drier 2nd season. The soil loss was reduced by 55% in the 1st season and 83% in the 2nd season (Figure 9).

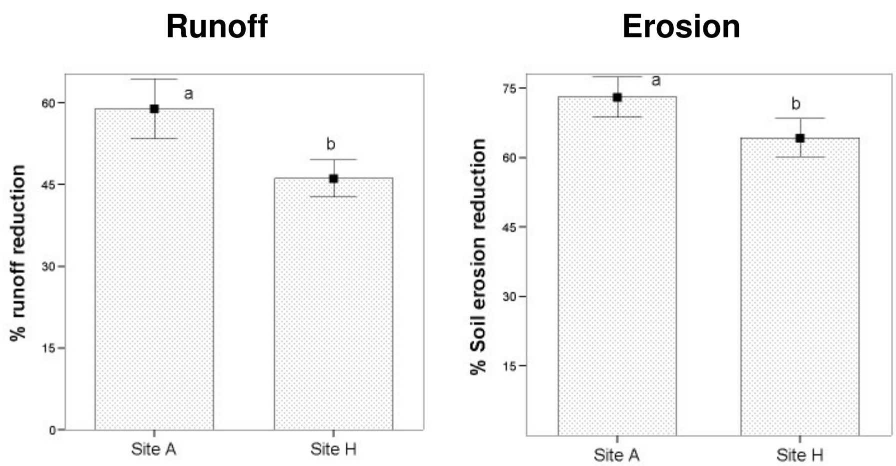


Figure 8: The influence of different geographical sites of different mean annual rainfall on the effects of intercropping in reducing of runoff (Avg. + 1SE) and soil erosion (Avg. + 1SE). Error bars with different letters are statistically different.

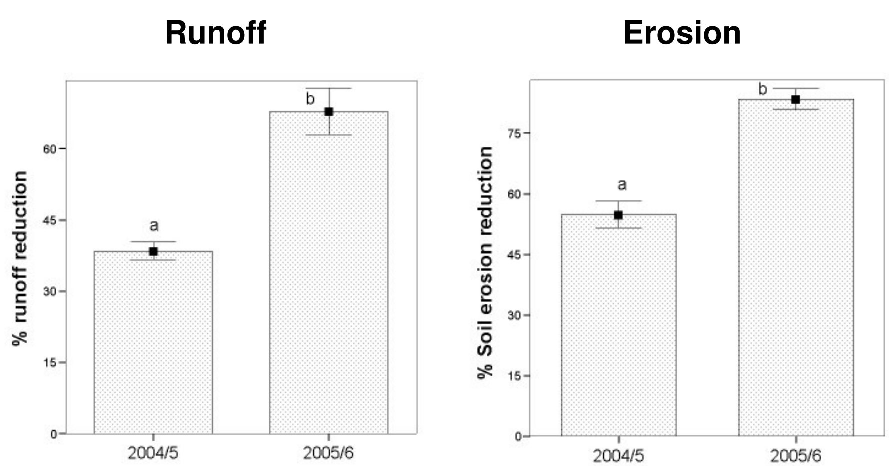
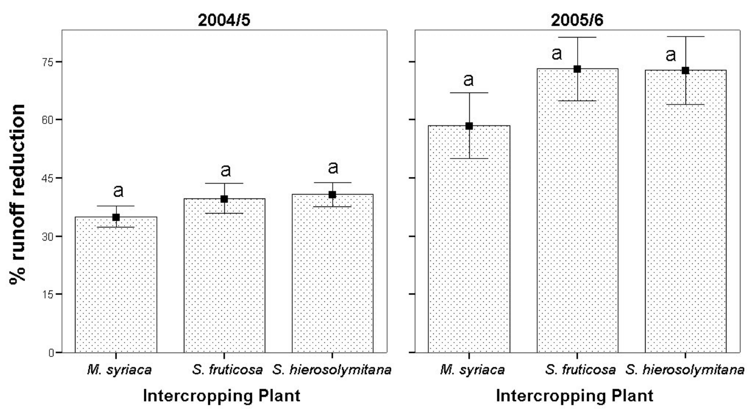


Figure 9: The influence of inter-seasonal variation of rainfall on the effects of intercropping in reducing runoff (Avg. + 1SE) and soil erosion (Avg. + 1SE). Error bars with different letters are statistically different.

Species-specific effects of intercropping

All used native perennial plants intercrops reduced the average runoff volumes and soil losses in all seasons (Figure 3, 6). The strongest reduction was observed in plots intercropped with *S. fruticosa* and *S. hierosolymitana*. The average reduction in runoff was 56.4% for *S. fruticosa* and 56.8% for *S. hierosolymitana*. The average reduction in soil erosion was 71.8% for *S. fruticosa* and 71.9% for *S. hierosolymitana*. The lowest reduction was measured in plots intercropped with *M. syriaca* with an average reduction in runoff by 46.8% and in soil erosion by 64.1%. However, the differences between different intercropping treatments were never significant (Figure 10).

Runoff



Erosion

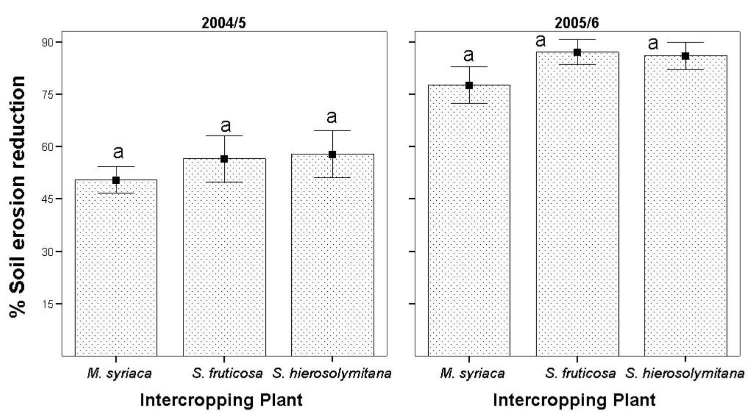


Figure 10: The species specific effects on the percentage reduction of runoff (Avg. + 1SE) and the percentage reduction of soil erosion (Avg. + 1SE) in the intercropping managements. Error bars with different letters are statistically different.

Discussion

The influence of intercropping on runoff

Our results show that the area of study is suffering from a serious problem of unproductive water losses from arable fields. The amount of water loss by runoff measured in bare plots without intercropping in this study was 7% of rainfall at the drier site A and 4% at the wetter site H. If these values will continue to be lost annually then the annual water loss will be equivalent to 297 m^3 ha^{-1} at site A and 238 m^3 ha^{-1} at site H. The estimated water use efficiency for the study area is 3.47 kg grain per one cubic meter of irrigated water (Al-Juneidy and Isaac 2001). Thus, the water lost by runoff in bare plots is sufficient to produce almost 770-1000 kg grain per hectare. This study shows that these amounts of water loss can be minimized by intercropping with native perennial plants. Intercropping may save amounts of water sufficient to produce at least 26 kg per hectare and may be as much as 900 kg per hectare. Therefore, the amount of water loss is of high economic value. In addition, the percentage of runoff reduction (34% - 89%) by intercropping means that the infiltration rate in the intercropped field increased from 11% to 66%.

The results confirm the importance of the permanent vegetation cover in controlling water loss by runoff. This is especially important during the first rain event when the annual fields are usually free of any type of vegetation. The presence of the perennial intercrops was effective in controlling runoff even when the aboveground parts provide the minimum cover of the seasons. However, the root systems and the aboveground plants may provide some roughness in the soil surface which is responsible for reducing runoff and increasing infiltration. This importance was documented also by other authors (e.g., Seeger 2007, Neave & Rayburg 2007). The quantitative data about the effect of intercropping on runoff in semiarid regions is rare in the literatures. Therefore, we can not compare the data obtained from native plant intercropping with other intercropping data. However, the most closed design to our design was the complex system of Kinama et al. (2007) in which crop rotation, perennial hedgerow and grass strips were used in a semiarid region. That system achieved almost 55% to 80% reduction in runoff which is very close to the performance of our simple system. Our system reduced runoff by 34% - 89% at a comparable slope and mean annual rainfall. However, the simplicity and productivity of the system as our design is very important to encourage adaptation of the system by the local farmers.

The influence of intercropping on soil erosion

The soil loss in the bare plots was 5.6 ton ha^{-1} at the site A and 3.2 ton ha^{-1} at site H in the season of normal amount of rain fall, which is a considerable amount if compared to the estimations of soil loss in the whole world and the selected regions listed by Yang et al. (2003) which range from 3 ton.ha^{-1} to 17 ton ha^{-1}. Although our results appear to be at the lower limits of the world's estimation, it does not mean a healthy condition. Our measurements are obtained at a moderate slope and short plots in comparison to other steeper longer slopes of the study area which may suffer from higher rates of erosion. The rainfall of the study seasons was equal or less than long-term average, with few intensive rain events. Given that almost 50% of soil loss was occurred in one month with highest rain events, the soil loss may probably be higher during seasons of more rain. In addition, the expected climate changes for the area predict an increase in the frequency of high intensive rainfall events during which higher erosion is expected. Furthermore, the area of our study is semi-arid and suffers from poor soil resources and nutrients. The continuous loses of soil resources even in small quantities is leading the agricultural lands to catastrophic state. Therefore, conservation techniques are of great important.

However, like runoff the soil erosion was effectively controlled by intercropping with useful native perennial plants. The control effect of intercropping was highly pronounced during the high intensive rain events of Nov. During this period the area frequently faces high intense rain events while the annual production fields are free of any type of vegetation. Therefore, the ability of the intercropping system to reduce runoff and erosion during this period has critical advantages. The soil loss was reduced by intercropping even in autumn rain when only the root systems and residues of aboveground parts of the native plants were present in some cases like *Majorana syriaca* and *Salvia hierosolymitana*. This observation may be attributed to some activities of the root system of the native plants. The roots of the vegetation may increase the roughness of the ground and reduce the runoff velocity (Neave & Rayburg 2007, Seeger 2007, Barton et al. 2004). The roots also aggregate the soil, which increases porosity and reduces runoff. The effectivity of native plants in reducing soil losses increases as the aboveground vegetative parts grow and well developed in mid and late winter. At late winter when the native plants provide 100% cover the soil loss was almost neglected in the intercropping plots. Surface runoff between native plant rows was impeded, thereby reducing runoff velocities and erosion potential. The sediment was more likely to be redeposited behind the next native plant strip downslope, because of reduced runoff velocity. Additionally, the presence of permanent plants may develop a canopy that intercepts raindrops and deprive the raindrops their energy to erode the soil (Dunj'o et al. (2004). Therefore, the greatest erosion-control benefit from winter partially covers of the native plants resulted from their ability to reduce the soil concentration in the runoff. This is particularly important for surfaces of annual crop fields that are completely devoid of any other form of protective covering during winter. In addition, perennial plants may also increase organic material in the soil, which may bind the particles of soil together and reduce soil erodability during longer periods than the period of this study (Wischmeier & Mannering 1969, Duiker et al. 2001, Rhoton et al. 2002).

The erosion control effect of intercropping with native perennial plant in our study was 45% - 94%. This is very close to the effectivity of the soil protective system used by Kinama et al. (2007) in comparable conditions in semiarid area. This effectivity of intercropping with native perennial plants in controlling soil loss appears to be higher than other practices of the same aim such as mulch cover and crop rotation. The intercropping practice protected soil by applying a perennial ground cover of only 10%. Mulch cover of at least 25% was needed to reduce erosion, and 85% was estimated to prevent erosion (Adekalu et al., 2006). More than 50% of perennial grass species in crop rotation were needed to reduced erosion by 77–81% (Jankauskas and Jankauskiene 2003). These two later practices were applied in more humid conditions than the conditions of our study sites, therefore the differences may be attributed to the differences in the climate conditions. Therefore, the intercropping practice is a promising mechanism in soil protection as compared to other management practices under semiarid conditions.

The influence of intercropping on the retention of water in soils

The results of soil moisture content in the intercropped and bare plots indicate an increase in retention of water in soils after rainstorms by 12.5% under the average rain fall. The increase of water retention in dry years was not significantly observed. The increase of water retention results from increased water infiltration in intercropped plots. The strips of native plants intercept rain water ways and slow down water flow, which is running down slope and therefore, increase the infiltration rate. The percentages of water in the soil show that a ton of the top soils in the intercropped plots retains almost 27 l water more than the bare plots when rainfall is around the long-term average. This means that a hectare of the intercropped field may conserve more than 80 m^3 in the top 25 cm of the soil if the soil density is 1.2 g cm^{-3}. The estimated amounts of conserved water here are less than the estimated increase in the infiltration from the runoff results. The differences between the two estimates mean that most of these amounts may be infiltrated and take its way to the ground reserves to increase ground water. Therefore, the intercropping may provide more water for plants and may contribute to some extent in maintaining the ground water recourses if applied as large scale conservation management.

The effect of the surface plant cover on the intake of water by soil was reported by Ischemia (1966). The results show how the soil surface condition may influence the intake of water by soil. An increase in the water intake occurs in the case of native plants intercrops cover. In addition, surface runoff of the slope will be reabsorbed by the higher infiltration rate areas of intercropping which may act as sinks for overland flow and transported sediments (Fu et al., 2003).

Our results indicate that the effect of intercropping in increasing soil moisture was more pronounced in seasons of relatively heavy rain fall. While in the drier seasons the increase in soil moisture was less pronounced. It was noted that low differences in soil moisture between control and intercropping were associated with dry season and that high differences were associated with wet season. A possible explanation is that the heavy rain was sufficient to reserve moisture storage in subsoil of the intercropping treatments then a reciprocal action occurs in intercropping system for improving top soil moisture after rain periods. While in the drier season the sparse rainfall event were not sufficient to reserve moisture in soil. This possible explanation is supported by the results of Fu et al. (2003) about the variations of soil moisture according to different land uses in semiarid areas. Fu et al. (2003) found that the profile of soil moisture content in the intercropping land is different than fallow land. There was a gradual increase in soil moisture with depth. This revealed a reciprocal advantage of intercropping system for improving soil moisture. Fu et al. (2003) reports also a general increase of soil moisture under intercropping in the semiarid areas which agree with our results.

The influence of rainfall amount on the effects of intercropping

Runoff and soil erosion were more at site A than site H. The reason for such differences between sites is probably due to the different abilities of soils at both sites to support wild plants growth in the agricultural fields. It was noticed from the field observations that no type of wild plants or even dry residues was present in the agricultural fields during late summer at site A. While at site H there were several species of wild plants growing in the fields after harvesting the annual products and until the rainy season starts. In addition to the higher rainfall amounts during the rainy season, it is frequently occur that the ground and the vegetation cover are moistened at site A during the nights of summer by dew. This phenomenon may support the growth of some summer herbs in the agricultural fields which stay until the rain season. These plants may contribute to the reduced level of runoff and erosion at this site in general.

The effect of native plants intercrops in controlling runoff and soil erosion was also more pronounced in the drier season than in the season with normal rate of rainfall, and higher at the arid site (site A) than the semiarid site (site H). These differences are probably due to absent of any type of wild vegetation in the annual production fields at site A. So when native plants were planted purposely as permanent intercrops they contributed to a high percentage of runoff and erosion reduction. Therefore, the results may indicate that intercropping has a good soil protective effect in the semiarid-arid area. In addition, the intercropping system may be suitable with more aridity. Comparing these results with previous data taken in mild areas support this conclusion. Barton et al. (2004) reported a reduction of erosion rates in mild areas by 4% to 35% under annual crops intercropping (maize/soy bean intercropping) compared with conventional tillage without intercropping. The reduction of soil loss in our experiments was much higher (45% - 94%). The differences are probably because our data is obtained at semiarid-arid sites, where the reduction of erosion was more pronounced at the dried sites and seasons. It is also possible that the higher control activity in our study is related to the different vegetation cover presented by native perennial plants.

These results may allow concluding that intercropping with native perennial plants is suitable strategy to cope with the expected climate change especially the reduction in mean annual rainfall. So, if mild zones in the study area and similar areas became drier as climate change scenarios predict, the developed intercropping practice may stile effective in controlling water and soil loses. In addition, it is not expected that the decrease in rainfall will result in reduced amounts of runoff and soil erosion. Greater increases in soil loss and runoff may occur as well as a result of greater variability in monthly precipitation and increased frequency of large storms as predicted for other areas (Zhang and Nearing, 2005). Furthermore, the vegetative cover may be reduced due to the increasing temperature (O'Neal et al., 2005) which may facilitate soil and water losses. Under these scenarios, the partially permanent ground cover as proposed in the intercropping system using native perennial plants may be the promising option because its activity increased with increased aridity.

Species-specific effects of intercropping

The different species of native perennial plants used as intercrops contribute to almost the same level of controlling water and soil loss. There was no difference between the three species in reducing runoff and erosion despite that the intercropping species have different morphologies. For example *M. syriaca* is herbaceous plant, *S. fruticosa* is a shrub. Differences between species were also in the leaves area where *S. hierosolymitana* has the widest leaf. However, these species share some common features that may contribute to the closed effectiveness of these species in reducing runoff and erosion. These features are, the perennial life history, all species have well developed root system and at least part of the above ground vegetative shoots appears at any period of the year. Minimal variations were observed under the various species in reducing runoff and erosion. Therefore, plant species of the perennial intercropped strips seemed to have low effect on the efficiency of controlling runoff and trapping the sediment. Therefore, other local native perennial plants that share their characteristics are possibly suitable as well for intercropping practice. There are several useful native plants species in the study area, which may be suitable for intercropping (personal observation). These plants are usually collected from the wild and used as food, spices, and/or medicinal purposes, and many of them are considered as endangered species. In other regions other suitable useful species are probably present. The choice of the native perennial plant can depend mainly on local needs in terms of socio-economic and biodiversity conservation.

In this study, we focused on soil loss by runoff and water erosion. However, from field observations the intercropping of native perennial plants was also effective in reducing wind erosion, which is regarded as a major contributor to land degradation and the desertification process. We observed quantities of sediments accumulated on the vegetative parts of the native plants during late summer, the dry period. The native perennial plant strips work as windbreaks. This is probably another advantage of the partial perennial ground cover. In previous studies it was estimated that strips of the perennial and annual grass can reduce the total annual soil loss by wind by 6% - 55% (Michel's et al., 1998), or by 57% (Bielders et al., 2000). Other studies show that 10% soil covers were enough to break winds at natural speeds to become insufficient to cause enhanced sediment transport while less soil cover was less protective (Sterk, 2000). We used 10% ground cover in our intercropping system to conserve soil resources. It is likely to be enough according to Sterk's estimations to reduce wind speed to become insufficient to enhance wind erosion.

The intercropping of traditionally used agricultural crops with useful perennial native plants is a simple and economic mechanism. The perennial native plants are planted once with relatively very low cost. However, their advantages in soil protection and water efficiency enhancement are permanent. Therefore, the sustainability of this practice is obvious especially in semiarid regions. The question which remains, which we hope to address in a later paper is the economic value of this practice or the yield productivity of system especially because 10% of the productive area of annual crops is used for the native plants intercrops.

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Chapter Two

Managing soil organic matter by intercropping arable fields in Palestine with native perennial plants

Abstract

Loss of soil fertility by erosion is a common soil problem in semi-arid regions. That loss of soil fertility is often related to the loss of soil organic matter (SOM). Therefore, many studies tested the effect of various management practices on SOM. However, only few of these studies dealt with the possibility to intercrop fields of annual crops with additional perennial crops. Consequently, quantitative information on the influence of intercropping with perennial plants in annual crop production is very scanty. In order to fill that gap we conducted from 2004 to 2006 a field experiment to assess the influence of intercropping arable fields with native perennial plants on the conservation or improvement of SOM. We conducted the research at two sites in Palestine differing in mean annual precipitation in order to acquire additional information on the influence of climate on the effects of such management strategy. As intercrops we choose the native perennial plants *Majorana syriaca, Salvia fruticosa* and *Salvia hierosolymitana*. These species are widely collected from the wild stands and sold on local markets. Therefore, we expected the farmers to gain additional income from the perennial plants introduced to manage the SOM content.

The results of the study show a rapid decline of SOM in the not intercropped arable fields during the two years of study, while the level of SOM in intercropped fields was maintained. The conservation effect of intercropping with native perennial plants was not species-specific. The results of our study indicate that intercropping with native perennial plants is a management strategy that reduces

loss of soil fertility under different climatic conditions. Therefore, we assume that the observed positive influence of intercropping with perennial plants on SOM will be a useful management strategy even under the predicted climate changes and for other semi-arid regions.

Introduction

Soil Organic matter (SOM) is a major determinant of soil quality and influence almost all important soil physical, chemical and microbiological properties although it is generally present in relatively small amounts (Magdoff and van Es 2000, Chen et al. 2003, Fontaine et al. 2003, Arias et al. 2005). Depletion of SOM is a major process of soil degradation (Wischmeier & Mannering 1969, Roose & Barth'es 2001). Therefore, SOM content is often used as a sensitive indicator of soil quality under different land uses (Wander and Bollero 1999, Brejda et al., 2000).

Soil Organic Matter (SOM) is a critical component of production in cropping systems as it is the main nutrient source for plant growth after microbial decomposition. Reduction in crop productivity occurs when SOM declines in soils of arable fields (Lal et al. 2000, Kanchikerimath & Singh 2001, Regmi et al. 2002, Yadvinder-Singh et al. 2004a, Shibu et al. 2006). In addition, high SOM along with optimal physical and biological properties of soils may help to reduce the susceptibility of crop plants to pests (Altieri, 2002). Soils with high organic matter content exhibit good fertility as well as complex food webs and host beneficial organisms that prevent infections by disease-causing organisms such as *Pythium* and *Rhizoctonia*. Furthermore, SOM influences other soil quality factors that affect productivity mainly soil aggregate stability and soil biological communities (Magdoff and van Es 2000, Pendall et al. 2004). Therefore, the improvement of SOM by crop residues is an important aspect of environmentally sound sustainable and productive agriculture (Magdoff and van Es, 2000).

However, the amount of SOM in a given arable soil is determined by the input of crop residues and the decomposition rate (Vandermeer et al. 1998, Sa' et al. 2001, Fontaine et al. 2003, Yadvinder-Singh et al. 2004a). In addition, large quantities of SOM are added from root deposition and senescence of root segments and root hairs (Haynes and Beare 1997, Bolinder et al. 1999). However, the belowground carbon inputs from roots and root exudates are sufficient to maintain soil carbon in cool humid climates but not in temperate and semiarid environments (Rasmussen et al., 1998). Therefore, agricultural systems in semiarid regions must involve the management of organic matter by frequent inputs of fresh organic matter. Cropping practices with no return of crop residues and other organic inputs are assumed to be nonsustainable (Yadvinder-Singh et al., 2004b). Generally SOM content declines under continuous production of annual crops and in intensive agriculture unless organic matter is added from external sources (Haynes & Beare 1997, Degryze et al. 2004, Makinde et al. 2006, Bationo et al. 2007). Makinde et al. (2006) found that organic matter was reduced by about 76% with cropping for two years in Nigeria. The estimates of SOM lost from cultivated soils in the long term range from 20% to 30% and most of the loss occurs in the first few years after initial cultivation (Gregorich et al. 1998). Lobe et al. (2001) found reduction in SOM in long-term cultivation by 65% in the semiarid South African. The annual SOM loss ranges from 2% to 4.7% by mineralization, and 2% – 6.3% by erosion (Bationo et al., 2007). Therefore, maintaining optimal soil conditions under continuous production of annual crops is often difficult.

However, Makinde et al. (2006) found that the loss of SOM can be reduced if annual crops' intercropping (Soybean with cassava) is practiced. Restoration of SOM was documented for soils that were used for the cultivation of annual crops already two years after shifting to a soil management system that maintained plant root activity for most the year (Miller and Dick 1995). In addition, SOM can be increased by organic and biodynamic farming managements (Haynes & Beare 1997, Shepherd et al. 2002, Edmeades 2003). E.g., SOM concentrations in surface soils were found to be increased by 14% in organic farming practices compared to intensive management systems (Marriott and Wander, 2006). SOM usually increased also under permanent ground covers that keep the soil covered by plants for large parts of the year (Magdoff and van Es, 2000). SOM accumulation increased under partially permanent cover of fruit trees intercropped with vegetable annual crops (Manna and Singh, 2001). Some researches have demonstrated that SOM could be improved by promotion of biodiversity as mixed farming systems and crop rotation due to tighter nutrient cycling (Shepherd et al., 2002). Thus, intercropping with perennial crops as a form of mixing farming and permanent vegetation seems to be a possible management practice which may improve SOM.

In addition to the farming practice climate factors and some natural processes may affect SOM content. E.g., temperature impacts SOM indirectly by affecting microbial activity and decomposition rates (O'Neal et al., 2005). Sarah (2006) found that SOM decrease with the increase of aridity in soil of natural vegetation. In addition, the reports that predict global climate changes mainly rise in temperature and decrease in precipitation also alarm from the possibility of SOM loss in the future due to increase in decomposition and loss of vegetation (Lal 2004, Jones et al. 2005, Knorr et al. 2005, Zhang and Nearing, 2005). Therefore, climate changes need to be taken into account while developing strategies for sustainable resource management focusing on the conservation of SOM. It is known that in arid regions SOM content is low due to weak growth of vegetation (Magdoff and van Es, 2000). The fields of annual crops in semiarid regions stay devoid of a vegetation cover for along period of the year. Furthermore, considerable losses of SOM in semiarid regions occur through soil erosion (Lal et al., 2000). Therefore, the problems of SOM in semiarid regions still urging researchers to develop land-use strategies that will mitigate SOM loss and allow a sustainable land-use in current conditions and under changing climatic conditions. However, rotation systems and the cultivation of perennial species were suggested to maintain SOM in semiarid regions (Paustian et al. 2000, Ogle et al. 2005).

Several native perennial plant species are adapted to grow in semiarid-arid regions. Some of human requested species are endangered due to the collection pressure from locals, and need conservation precautions. Planting these perennial plants in arable fields as intercrops may help to improve SOM and conserve these species. However these species vary considerably in their morphology and vegetation growth period, which may contribute to some effects on SOM. Thus to derive conclusions about species specific effects in the intercropping practice it is important to test several species. Therefore, we introduce the intercropping with useful native perennial plants as a mitigation strategy to control declining SOM in arid regions. We were able to show that intercropping with useful native perennial plants as a partially permanent cover can reduce soil erosion and runoff (Chapter 1) and assume that it may also help to increase the quantity of SOM by continuous addition of plant residues to the soil. Consequently, positive effects on other soil properties such as soil microbial activity are expected as well. In the present study, we examined the effect of intercropping with native perennial plants on the organic mater content in soils of arable fields in Palestine. We tested the following hypothesis:

(1) the application of a permanent ground cover, as it is partially present in intercropping with native perennial plants, maintains and/or improves the soil organic matter,

(2) the efficiency of a permanent ground cover in improving SOM is not species specific, and

(3) the efficiency of a permanent ground cover in improving SOM is consistent under different climate conditions.

Materials and Methods

Study sites

The hilly slopes of the West Bank, Palestine have been selected as a suitable area to study our hypotheses.The area suffers from land degradation problems due to low vegetation cover (ARIJ 1995, Isaac and Maurice 1999). The area has a Mediterranean climate characterized by long, hot, dry summers and short, cool, rainy winters. Climate changes scenarios predict for 2071 to 2100 for the area a rise in temperature of about 3 °C - 5 °C, and a decrease annual precipitation of about 10% - 30% (Alpert et al., 2006). The study was conducted in annual cropping fields at Al-Khalil district in the southern part of the West Bank. The district is mostly semi-arid to arid (250 mm to 600 mm) with increasing aridity towards the south (Negev desert) and east (Jordan Valley). The monthly temperature ranges from 7.5 °C in winter to 22 °C in summer.

In order to test the influence of changes in climatic conditions on our proposed mitigation strategy we conducted our experiments at two sites differing in the mean annual precipitation (Figure 1 in Chapter 1):

- Al-Dhahriya (further referred to as Site A) located 15 km to the south of Al-Khalil city, (31º 26' 46.2" N, 34º 58' 18.3" E), receives a mean annual precipitation of 425 mm and is situated at 610 m above sea level.
- Halhul (further referred to as Site H) consisted of three fields H1 (situated at 31º 35' 41.3" N, 35º 06' 06.2" E), H2 (situated at 31º 35' 18.1" N, 35º 05' 08.9" E), and H3 (situated at 31º 34' 07.2" N, 35º 06' 12.0" E), receives a mean annual precipitation of 590 mm and is located between 910 m a.s.l. and 960 m a.s.l. Because of the local conditions at site H the distances between the experimental fields were larger than at site A. However, the distances between fields at each site were always shorter than the distance between sites.

The selected fields for our experiments share comparable features. They were located on moderated slopes with inclination between 8% and 10%. The soil of the investigation sites is classified as brown Terra Rossae (Land research Centre, 2002). All sites were used for rain-fed annual vegetables and field crops farming since decades (traditional agriculture). The field owner at site A used to apply organic manure regularly in the past years. The last application was in the summer of 2003. While at H manure amendments were not regular. The basic soil physical and chemical characteristics of the experimental fields were determined using standard methods (Table 1 in Chapter 1). In addition, the SOM was measured at the beginning of the intercropping experiment in the different treatment plots and the replicate fields in each site to examine the homogeneity of SOM distribution in the experimental fields. It was found that SOM is almost equal in all treatments in each field and site without significant variations. This homogeneity simplifies the later comparisons between the different treatments.

To test the above mentioned hypotheses, we conducted an intercropping experiment using native perennial plants as intercrops. The influence of climatic conditions on the observed effects was considered by conducting the research in two geographical regions differing in mean annual precipitation. For species-specific effects investigation, three different native perennial plants were used. The native perennial plants used as intercrops were: *Majorana syriaca, Salvia fruticosa,* and *Salvia hierosolymitana* (further referred to as *M. syriaca*, *S. fruticosa* and *S. hierosolymitana*). These native plants were chosen because they are commonly collected from the wild as food, spice and/or for medicinal purposes and because they have perennial life history. These plant species show good growth during and after the rain season. The consumable parts (stems and/or leaves) were harvested during the two seasons of the experiment and were measured as kg/ha (Table 1). After harvesting the consumable parts of the plants some parts of each plant persist in the fields. The parts include the following: the bases of the stems with the leaves for the species *M syriaca* (10-20 cm high) which represent almost 30% of the above ground vegetation, *S. fruticosa* (20-30 cm high) and represent 30%, and the whole stems with the tough leaves of *S hierosolymitana* which represent 70% of the above ground vegetation. In summer these plant bloom then the most of the above ground wilt and fall down in late summer.

The decision for the cash-crop used was left to the local farmers involved in the project. Therefore, the crop rotation followed the local tradition: Snake cucumber (*Cucumus melo, var. flexuosus*) in the first year (2004/5), and bean (*Phaseolus vulgaris*) was the main crop in the next year (2005/6) of study.

Table 1: The yield of the native plants during the two seasons and the estimated proportion of the yield out of the total above-ground biomass (aprox. % of biomass)

Native plant	**Site A**		**Site H**	
	Yield kg/m^2	aprox % of biomass	Yield kg/m^2	aprox % of biomass
Majorana syriaca	1.17	70	0.91	70
Salvia fruticosa	1.23	70	2.80	70
Salvia hierosolymitana	1.05	30	1.03	30

Experimental Design

A block design was used with 3 blocks in each site. Each block contained three intercropping treatments and a control (Figure 1). In the intercropping treatment plots, parallel strips of the native perennial plants were planted across the path of overland flow to reduce soil erosion. The width of each strip was 0.5 meter. The strips were planted with a distance of six meters in order to allow the machinery and other treatment necessary for agriculture in the field. This space was estimated to be suitable for the necessary treatments of the fields. Each treatment plot was 110 m^2 (5 m wide x 22 m long). The area covered by the native plant in each treatment plot was 10% of the total area. Spaces of 1-2 m were left between the adjacent treatments to reduce interaction effects. The arrangements of the different treatment plots were randomised in the different blocks.

The seedlings of the three native plants were planted in the third week of Feb. 2004 in the fields of site A and in the fourth week of the same month in the fields of site H. These dates were the earliest suitable times for planting in each site after heavy rainfall periods. Three rows of the seedlings were planted with a distance of 25 cm between rows and 50 cm between adjacent seedlings. The seeds of snake cucumber/bean were planted in the middle of April at site A and in the middle of May at site H in the two years, following the procedures of the farming in each site. The farming times of the annual vegetables starts usually at different times in the two sites because of the different climates. SOM was measured and compared in all treatment plots at the beginning of the intercropping experiment and after two year of intercropping.

Soil sampling

In May 2004 three bulk composite samples were taken from three locations of each experimental plot (upper slope, centre of slope and lower part of slope). For each sample four soil cores (diameter 2.5 cm, depth 0-20cm) were taken and composited immediately in plastic bags. This sampling happen prior to the application of the intercropping to test for the homogeneity of SOM distribution in the experimental fields, and was used as a reference to detect any change of SOM amount that may occur through time due to intercropping or due to natural processes.

After two years of intercropping (in April 2006), soils were sampled again. In the intercropped plots soil samples were taken from two positions, under the native perennial plant strips and between strips (Figure 1). Three bulk samples were taken from each position. Three bulk samples were also taken in the same way from different locations in the control plots. For each bulk sample four soil cores (diameter 2.5 cm) were taken from top soil (0 - 20 cm depth) and mixed together directly in a plastic bag. We used top soil sampling because the traditional ploughing - as used in our experimental fields - promotes a uniform distribution of organic matter through the soil profile of the plough layer without affecting the total quantity (Etana et al. 1999, Needelman et al. 1999).

Soil Analysis

Soil samples were air-dried and visible plant residues were picked out by hand. The soils were ground finely and sieved to a particle size of 0.5 mm. Organic matter was measured by wet oxidation using H_2SO_4 – $K_2Cr_2O_7$ (Weber 1977). Each sample was analyzed as follows:

A 1.5 g soil sample was weighed and placed in a 200 ml Erlenmeyer flask. 20 ml of 4N $K_2Cr_2O_7$ solution were poured in the flask, followed by 20 ml of 18M H_2SO_4. The flask was swirled vigorously for 1 minute, and left to stand for 1hr to allow a complete oxidation of organic matter. One hundred milliliter of deionised water was then added, mixed and allowed to stand overnight to permit soil particles to sediment. A blank reference (reagents only) was prepared by adding 20 ml of 18 M H_2SO_4 to 20 ml of 4N $K_2Cr_2O_7$ solution, followed by the addition of 100 ml deionised water.

About 10 ml of the supernatant liquid was drown out and aliquots were transferred to an absorption cell of a photoelectric colorimeter. The percentage transmittance was measured at 625 nm. The percent organic matter content of the soil was determined using the following equation based on a standard calibration curve (Weber, 1977):

$$\% \text{ Organic matter} = 14.97 - 0.3448(\%T) + 0.00201(\%T)^2$$

Where: %T = transmittance at 625 nm.

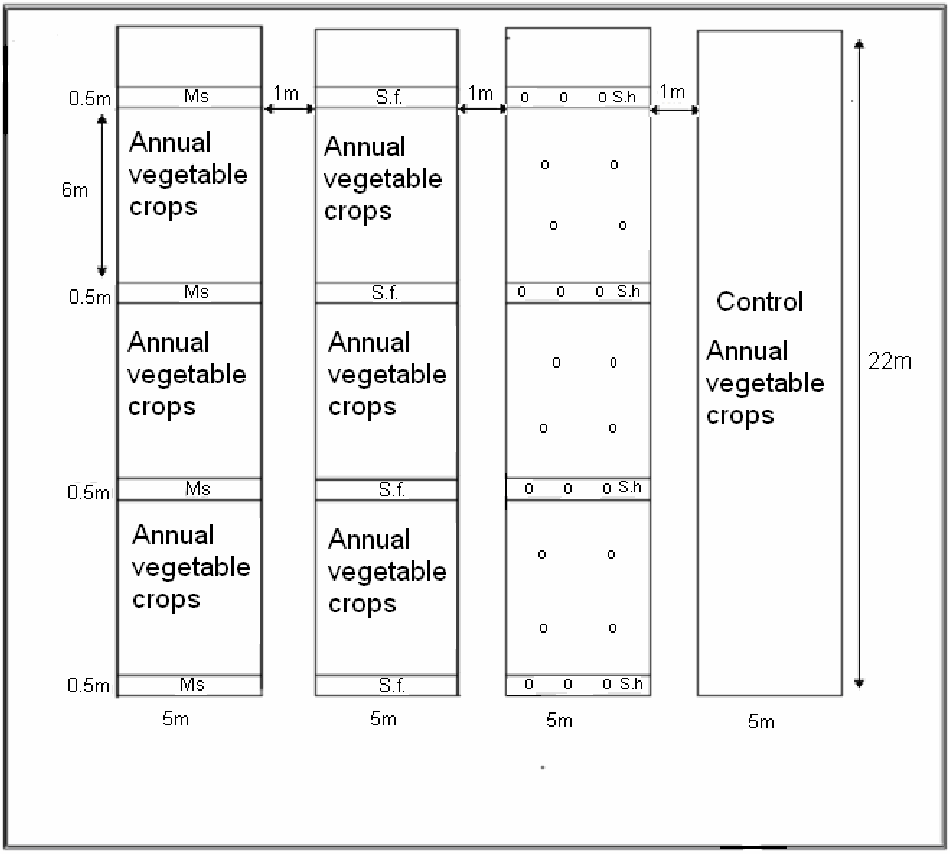

Figure 1: The experimental design and the spatial distribution of the annual crops and the native perennial plants intercrops in each block of the experimental fields. The arrangement of the different treatment plots was randomized for each block (therefore, the graph gives only an example). The small circles in one plot represent examples of the soil sampling positions from the intercropped plots.

M.s.: *Majorana syriaca, S.f.: Salvia fruticosa, S.h.*: *Salvia hierosolymitana.* The annual vegetable crop was snake cucumber in the 1st season and bean in the 2nd season.

Data Analysis

To test for the influence of intercropping with native perennial plants on SOM content (hypothesis 1) two sets of statistical analysis were calculated. In the 1st set, the data obtained after intercropping were analyzed by 3-way ANOVA. In this ANOVA SOM content was the dependent variable and the three intercropping treatments (*M. syriaca*, *S. fruticosa* and *S. hierosolymitana*), the three sampling positions (under native plant strip, between strips and control), the two sites (A: Al-Dhahriya and H: Halhul) were the independent variables (Table 3). Post Hoc Scheffe test ($p < 0.05$) was used to indicate the position/s differing from the control in each treatment.

In the 2nd analysis the SOM data obtained after two years of intercropping were compared to the data of SOM prior to intercropping by 3-way ANOVA (Table 4). In this ANOVA SOM content was the dependent variable and the four treatments (intercropping with *M. syriaca*, *S. fruticosa* and *S. hierosolymitana* and a control), the two sampling times (before intercropping and after two years of intercropping) and the two sites (Al-Dhahriya and Halhul) were the independent variables. Post Hoc Scheffe test ($p < 0.05$) was used to indicate the treatment/s that differs from the control.

To test for species-specific effects on SOM content (hypothesis 2) the relative change of SOM through the two years in the intercropping treatments were compared by 3-way ANOVA. In this ANOVA the %SOM change during the study period was the dependent variable and three intercropping treatments (*M. syriaca*, *S. fruticosa* and *S. hierosolymitana*), the two sampling positions (under and between strips) and the two sites (Al-Dhahriya and Halhul) were the dependent variables (Table 5).

To test whether or not the effect of intercropping is consistent under different climate conditions (hypothesis 3) the results from the 3-way ANOVAs mentioned above (Table 3, 5). In these ANOVAs the interactions effects between the independent factors; the intercropping treatments in the two climatic sites (the fixed variables) on the dependent variable SOM content was tested.

Data from all experiments satisfied the assumptions of ANOVA without transformation. All statistical analyses and graphical presentation of the results were done by SPSS.

Results

The influence of intercropping with native perennial plants on SOM

After two years of intercropping, significant differences in the SOM content were found between control and the different sampling positions in all intercropping treatments. SOM became higher in the three intercropping treatments if compared to the controls (Figure 2). The highest amount of SOM accumulation was observed under the strips of native plants in the three intercropping treatments. The final level of SOM at the end of the experiment in the intercropping plots was higher than the control by 76% - 97% under the intercropping strips, and by 47% - 69% between strips.

Significant differences among treatments were found for SOM accumulation after two years of intercropping compared with the original SOM content at the beginning of the experiment in each treatment. The SOM content changed after two years to different directions in the different treatments. There was a significant decline in the SOM content in the control plots in the two sites of study after the two years (Figure 3). The decline of SOM in control plot soils was 26.8% in site A (from 25.6 $g.kg^{-1}$ to 18.8 $g.kg^{-1}$), and 21.1% in site H (from 25.5 $g.kg^{-1}$ to 19.9 $g.kg^{-1}$). In the intercropped plots no decline in SOM content was observed. On the contrary in some intercropping treatments significant increases in SOM were found (Figure 4). The average change of SOM over the study period was 22% - 40% under the native plant strips, and 3% - 27% between strips.

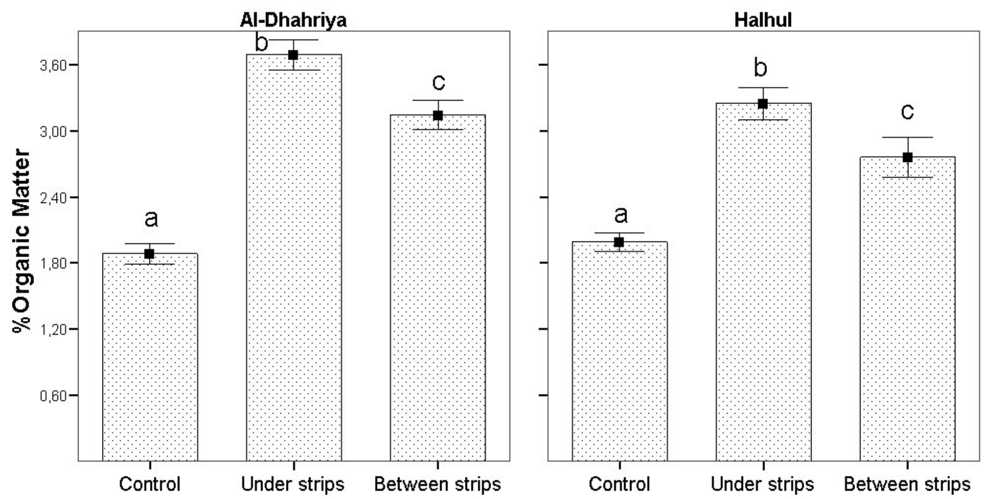

Figure 2: Soil organic matter (Avg. ± 1SE) in intercropped fields after two years of intercropping at two sites (Al-Dhahriya and Halhul). Error bars with similar letters at the same site have statistically equal means (Scheffe test, $p < 0.05$).

Control

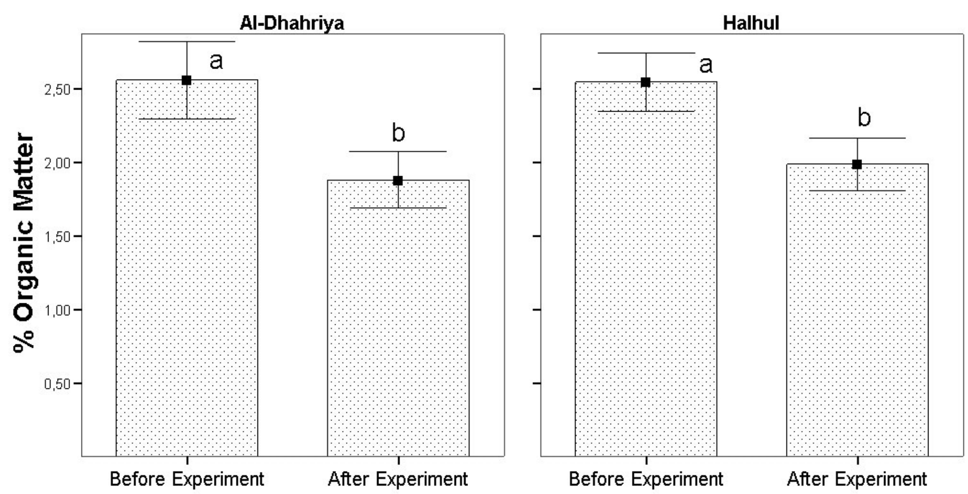

Figure 3: Organic matter (Avg. ± 1SE) in the control fields (without intercropping) in 2004 (before experiment) and 2006 after experiment). Error bars with similar letters are statistically not different (ANOVA, p = <0.001).

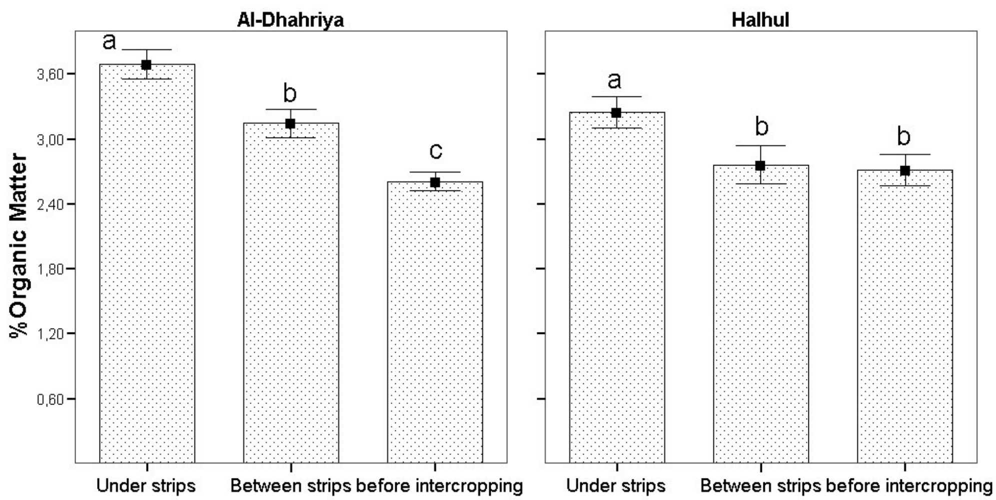

Figure 4: Soil organic matter (Avg. ± 1SE) in fields intercropped with useful native perennial plants for two years compared with SOM before intercropping at two sites (Al-Dhahriya and Halhul). Error bars with similar letters at the same site have statistically equal means (Scheffe test, $p < 0.05$).

The influence of native plant species on the effect of intercropping on SOM

The SOM varied between the different intercropping treatments (the three species) after two years. SOM was 3.03% (w/w of dry soil) in the plots of *M. syriaca*, 3.14% in the plots of *S. fruticosa* and 3.44% in the plots of *S. hierosolymitana*. However, the differences between species were statistically not significant. There were also no significant species-specific differences on the observed change in SOM over the experimental period. The change of SOM in the intercropping treatments was estimated as increase by 12% in the plots *M. syriaca*, 25% in the plots of *S. fruticosa* and 33% in the plots of *S. hierosolymitana* (Figure 5).

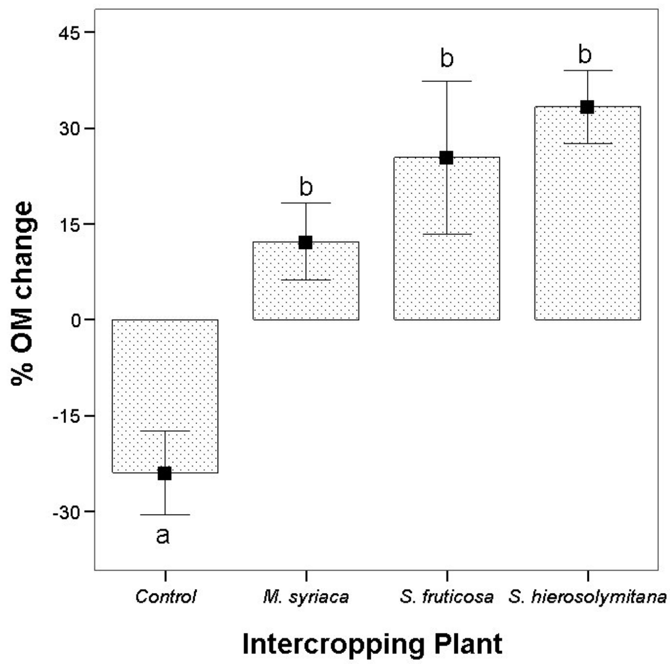

Figure 5: The species-specific effects on the percentage change of SOM level in the three intercropping treatments (data of under and between strips together) and a control without intercropping after two years of application. Error bars with similar letters are statistical not different (ANOVA, p = 0.194).

The influence of differences in mean annual precipitation on the effect of intercropping on SOM

Soil organic matter (SOM) increased by intercropping at both sites compared to the control. The percentages of differences of SOM between intercropping treatments and the control were significantly higher at site A (the drier site) in all intercropping treatments. In site A SOM increased in the intercropping plots compared to the control plots between 74% and 98%. In site H the increase of SOM ranged from 39% to 68% in the intercropping plots if compared to the control.

However, the differences in SOM reduction between sites in the controls were not significantly different.

Discussion

The influence of intercropping with native perennial plants on SOM

The results of the study point to a rapid decline of SOM over time in arable fields. This is consistent with results from previous studies (Gregorich et al. 1998, Lobe et al. 2001, Makinde et al. 2006, Bationo et al. 2007). SOM depletion over two years in our experiment ranged from 22% to 27%. This means that more than 15 ton ha^{-1} of organic matter may be lost on annual production fields. These are high rates in semiarid areas despite that they fall within the ranges reported by Gregorich et al. (1998), and lower than SOM loss of humid areas reported by Makinde et al. (2006). In addition, the results pointed to an increase of the SOM in the intercropped plots mainly under the strips of the native plants. Theses changes in the SOM content in the various treatments resulted in a relatively high differences between intercropped and not intercropped treatments. These differences may equal almost 0.46 kg m^3 in the top soil under the native plants and 0.3 kg m^3 between strips. This means that for the whole intercropped plots there was almost 35 kg organic matter more than the whole control plots. This is a very large amount which is difficult to explain. We will try to discuss some of the possible reasons that may contribute to some extent in these differences. However, any single reason for SOM loss or gain may not be sufficient to explain the results. First, it must be noted that the manure amendment was stopped by the beginning of the intercropping practice. The latest application was in summer of 2003 and the fields were ploughed in February of 2004. The first soil sampling was in May 2004 before the incorporated manure has been mineralized. These amounts of manure were a subject of decomposition and erosion after that. The manure used in these fields may be easily decomposed because it is composed of animal wastes. Therefore, mineralization may result in high rate of organic matter loss. In addition, the manure that was added in the previous year was subjected to runoff and erosion at high rate since it present in relatively high concentrations in the top few centimeters of the soil. Erosion may cause more losses of SOM where there is poor soil cover, steep slopes and erosive rain conditions (Tengberg et al.

1997, Gregorich et al. 1998, Lal 1998, Chappell et al. 1999, Roose & Barth'es 2001). SOM losses by erosion from cropped lands can be 4–20 times higher than on natural sites (Roose and Barth'es, 2001). However, the direct effect of erosion on organic matter loss of our sites may contribute to up to 3kg organic matter per plot according to the measured erosion rates (Chapter one). Erosion may also exacerbate the depletion of SOM because of reduction in biomass production and low amounts of residues returned to the soil in the long term (Lal, 2002), but in the study period of this experiment there was no significant reduction in crop yields (Chapter 4). The use of intercropping as an erosion controlling technique reduced the organic matter loss to high rates that may extend the differences between intercropped and not intercropped plots in their SOM content. In addition to water erosion there is the wind erosion which may contribute to a considerable amount of surface organic matter loss. Wind leaches manure and plant residues from the surface of soil. The wind erosion was clearly observed on control plots and the surrounding fields of the study fields (not measured). Wind erosion occurs during the long period between agricultural seasons when the fields stay free of vegetation. This process may result in accelerated loss of SOM in not-intercropped fields and further increase of SOM under the strips of the native plants. It was possible to observe that the litter under the native plants is composed of plant residues from different plant resources, not just from the native plants themselves. The partial permanent plant cover on the intercropped fields traps plant residues which may contribute to increase organic rich liter under native plant strips. In addition, the intercropping system may reduce wind leaching in the intercropping plots even in the area between strips. Native perennial plants strips may work as windbreaks and reduce wind speed to become unable to erode soil (Michels et al. 1998, Bielders et al. 2000, Sterk 2000). The reduction of soil erosion by runoff and wind may explain the conservative level of SOM between the native plant strips. The level of SOM between native plant strips was not significantly declined.

The increase of SOM in the intercropping treatments may be explained partially as a result of organic matter additions from the native perennial plants themselves. The native perennial plants exist in the field all over the year with

100% vegetation cover of the strips for most the year. The data about the harvested parts of the native plants indicates that high input of biomass may occur by the native plants. The amounts of above-ground biomass that may remain in the fields after harvesting may be estimated from 0.6 kg m^3 to 2.1 kg m^3 under strips (Table 2). In addition to the above-ground organic rich biomass enrichment, an enrichment of SOM may occur through the release of organic matter from the roots. In fact carbon may retain as SOM from roots more than from shoots under agricultural crops (Bolinder et al., 1999). The contribution of root derived C to SOM pool was 1.5 times that of the shoots (Bolinder et al., 1999). Further possible addition of organic matter occur in the long-term intercropping practice is from decomposing fine roots that die during the dry season as reported by Makumba et al. (2006). In addition, the native perennial plants can also place some organic matter into the subsoil through their deep root systems (Amado et al. 2006, Pendall et al. 2004). Consequently, losses due to mineralization will be slow due to less aeration. If we suppose that the biomass added by the roots is equal to the biomass produced above ground, then the total estimation of the biomass amendments may range from 1.8 kg m^3 to 5.6 kg m^3 under the native plant strips (Table 2). This means that 18 kg - 56 kg biomass may be added to the whole intercropped plots. We may use the evaluation of some literatures about water and organic matter content of perennial grasses to calculate the possible amounts of organic matter amendments by the native plants. The dry weight of perennial grass's shoots is estimated as 30% of the fresh weight (Garnier and Laurent 1994) and the average organic content is 40% of dry weight (Majumder et al. 2007). This means that the biomass of the native plants (leaves, stems, roots) may contribute to 2 kg – 6.7 kg organic matter amendments in each intercropping plot. In addition to these estimated values some organic matter are usually released from root to the soil to contribute to increase soil organic matter.

It is possible also that the new plant covers (intercrops) modify the habitat of soil biota especially under the native plant strips to a more efficient system in degrading plant residues. The habitat modifications under the native plant strips may include the moisture content, light intensity and temperature (Manna and

Singh, 2001). Soil animals may incorporate and mix more plant residues in the soil under the new condition. Therefore, soil biota may bring more organic compounds to the soil at early stages of decomposition.

Table 2: The estimated biomass added from the above-ground and roots (under ground) of the native plants as kg m^2 under strips:

Native plant	Site A			Site H		
	Above ground	Under ground	Total	Above ground	Under ground	Total
M. syriaca	0.6	1.77	2.37	0.45	1.36	1.81
S. fruticosa	0.6	1.83	2.43	1.4	4.20	5.60
S. hierosolymitana	2.1	2.1	5.36	2.1	3.13	5.23

Since the loss of organic matter by erosion is much higher than the loss by mineralization (Gregorich et al. 1998, Bationo et al. 2007), therefore, controlling SOM loss using erosion control techniques is more effective than controlling SOM alone by external inputs as organic manure amendments as farmers used to do. However, organic amendments are less frequently available with economic cost in arable systems. Furthermore, this is a temporary solution since SOM including the amended amounts will still be lost In addition, preventing or reducing erosion will be more helpful in conserving soil fertility because the most fertile soil is the top few centimeters which is usually eroded. Our proposed mitigation technique however, improves SOM by simultaneously increasing residue inputs and reducing its loss by erosion. In addition, when surface runoff leach some organic matter from the area between strips it is likely to be redeposited in the next native plant strip to contribute for further addition of SOM under native plant strips. Therefore, the native plants strips work as sinks for organic matter in the intercropping system.

Here, we tried to explain some of the possible sources for the differences of SOM content between control and intercropped plots. However, none of the mentioned possibilities alone may explain these differences between treatments. Possibly the combined effects of these sources contribute to the documented differences in the SOM content between treatments. However, the results and observations pointed to a critical role for permanent native ground cover in SOM protection. In addition, the benefits of the intercropping system using native perennial plants as intercrops were much higher than the benefits of other managements that focus on organic amendments alone such as organic farming managements. For example, the differences in organic matter content under organic farming managements compared with intensive agriculture was 14% (Marriott & Wander 2006). As the intercropping system with native perennial plants involves the return of crop residues to the soil and involve conservative mechanisms that maintain the existing organic matter it may be concluded that this system may play a dominant role in conserving SOM.

The influence of native plant species on the effect of intercropping on SOM

The results revealed that the increase of soil organic matter in the intercropping treatments was not species specific. The different species of the native perennial plants used as intercrops contribute to approximately the same level of maintaining and/or improving soil organic matter. Little variations were between the different species despite they have different morphology structure and vegetation growth period. The native plants used were even herbaceous with small leaves as *M. syriaca* or shrub as *S. fruticosa*. Differences were also in the leaf area where *S. hierosolymitana* has the widest leaf. On the other hand, these species share some common features that may contribute to the close effectiveness of these species in SOM conservation or improvements. All the species used were perennials and have well developed root and shoot systems which contribute to plant residue incorporation. In addition at least part of the above ground vegetation remains available at any time of the year which may contribute to reduce SOM loss by runoff and soil erosion. However, the observed SOM content in the intercropping treatments was ordered as *S. hierosolymitana* > *S. fruticosa* > *M. syriaca*. This order was generally proportional with the observed size of the inconsumable vegetative parts of the plants that remain in the fields after cutting the consumable parts. Therefore, any native perennial species that frequently add plant residues to the soil may be suitable for this intercropping practice. In the study area and other semiarid regions some other useful native perennial plant species are probably found. Some of these species are endangered species and need conservation. Planting such species as intercrops in annual crop fields may simultaneously conserve soil nutrients and participate in biodiversity conservation. The choice of the native perennial plant species for the intercropping practices may therefore, depends mainly on local needs in terms of economic and biodiversity conservation.

The influence of differences in mean annual precipitation on the effect of intercropping on SOM

Soil organic matter accumulated under intercropping with native perennial plants in the two climatic sites, semiarid and arid sites. This finding suggests a higher resistant and resilience capacity in the intercropping system to soil degradation under these climate conditions. The results farther show that the accumulation of SOM was significantly higher at site A, the drier site. This finding demonstrates that agricultural management impacts on SOM content vary depending on climatic conditions. Similar conclusion was found by Stephen et al (2005) who found that losses of SOM under long-term cultivation varied depending on the climate with highest loss in tropical moist condition and least loss in temperate dry condition. This finding may also explain the difference between our results about SOM depletion rate and the depletion rate found by Makinde et al. (2006) through a comparable period. The depletion in semiarid-arid sites of our study (from 22% to 27%) was less than the 75% depletion in SOM in warm moist sites in Nigeria (Makinde et al., 2006). This difference is most likely due to the differences in climate conditions.

The percentage of soil erosion reduction by intercropping was also higher in the drier site. This may explain the differences in the magnitude of SOM protection by intercropping between the two sites. These results support introducing the intercropping with native perennial plants as a mitigation technique for the expected climate changes of the study area which predicts warming and decrease in precipitation (Alpert et al., 2006). The east Mediterranean areas are threatened in these scenarios to become drier and to lose some of the natural vegetation. However, the intercropping with native perennial plants will remain effective in improving SOM and consequently other parameters of soil quality.

In this study we evaluated the influence of intercropping with native perennial plants in improving SOM content. Accordingly other related soil parameters are supposed to be improved especially soil microbial activity and aggregate stability. The financial income from the fields is likely to be influenced also. We hope therefore, to present the effect of intercropping with native perennial plants on soil microbial activity and to evaluate the economic value of this practice or the yield productivity of the system in later papers.

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Chapter three

Soil microbial activity response to intercropping with native perennial plants

Abstract

This study was conducted as part of a larger experiment designed to determine whether or not intercropping with native perennial plants may help to control land degradation in semiarid-arid areas. The objective of the presented study was to test the response of soil microbial activity to differences in crop management under two climate conditions. The crop managements tested were intercropping with three native perennial plants and the regionally traditional agriculture without intercropping (control). The native perennial plants intercrops were *Majorana syriaca, Salvia fruticosa* and *Salvia hierosolymitana*. The experiment (intercropping) started in 2004 and the response of microbial activity was examined in 2006. Microbial activity was measured as dehydrogenase enzyme activity in top soils (0-20 cm depth).

Our results indicate that intercropping with native perennial plants may help in enhancing soil microbial activity. Intercropping increased dehydrogenase enzyme activity by 61% to 113% if compared to fields of annual monocrops. Moreover, the change in microbial activity was generally accompanied with positive changes in soil organic matter. All the native perennial plants species intercrops may enhance soil microbial activity. However, the results indicate some trends of species-specific effects on the magnitude of enhancing microbial activity. Differences in mean annual precipitation did not influence the results. Since the enhancing microbial activity by intercropping with native plants was consistent under two different means of annual precipitation, we suggest the described

intercropping scheme as a suitable measure to cope with the effects of the expected global climatic change.

Introduction

Soil quality refers to the biological, chemical, and physical features of soil that are essential for long-term, sustainable agricultural productivity with minimal environmental impact (Arias et al. 2005, Bandick & Dick 1999, Schutter et al. 2001, Chen et al. 2003). Soil microorganisms in their particular environments are indicators of soil health, as microbial diversity and activity are intimately related to soil structure and function (Arias et al. 2005, Bastida et al. 2006b, Nielson and Winding 2002). Therefore, microbial biomass and activity can be used as early indicators of changes in soil management compared to other parameters like organic matter, which are unresponsive over short periods (Balota et al. 2003, Bandick & Dick 1999). In addition, microbial activity may serve as a valuable tool for understanding changes in soil properties and in the degree of soil degradation (Nielson and Winding 2002, Fisk et al. 2003, Balota et al. 2004), and as an estimation of the success of restoration of soil function in degraded systems (Harris, 2003).

The extent of the diversity of microorganisms in soil is critical to the maintenance of soil health and quality, as a wide range of microorganisms is involved in important soil functions (Vandermeer et al. 1998, Kirk et al. 2004, Arias et al. 2005). In soil ecosystems, the amounts of nutrients especially carbon and nitrogen are in balance. That balance is lost as a result of continuous cropping (Haynes & Beare 1997, Cambardella & Elliott 1993). Therefore, to maintain soil productivity on arable fields soluble nutrients removed from soil due to plant growth or leaching must be replaced. Microbes release nutrients from organic sources by mineralization to be utilized by plants (Chen et al. 2003, Balota et al. 2004, Arias et al. 2005). Additionally, microbes play a role in stabilizing the soil by physically binding soil particles together by releasing a polysaccharide byproduct called gloxmalin (Roldan et al. 1994, Bird et al. 2002, Chen et al. 2003). In addition, microbial communities affect plant productivity by playing a role in controlling plant diseases (Arias et al. 2005, Magdoff and van Es 2000). Soil microorganisms in fertile soils prevent plant infection by soil-borne pathogens such as *Pythium* and *Rhizoctonia* and enhance natural biocontrol of pathogens (Altieri 1999 & 2002, Garbeva et al. 2004). In healthy soils, pathogens cause little or no disease, despite an apparently favorable environment (Altieri 1999). The disease-suppressive capacity of soils is positively correlated with the microbial diversity (Garbeva et al., 2004). In addition, rhizosphere bacteria can influence plant growth via chemical signals such as auxins, gibberellins, glycolipids, and cytokinins (Garbeva et al., 2004). Thus, it is important to preserve and/or create healthy productive soils through improving soil microbial diversity and activity.

The main drivers of soil microbial community structure and activity are the plant cover, soil properties, the agricultural management (Dick 1992, Garbeva et al. 2004), and the climate conditions (Henry et al., 2005). Regarding plant cover, several studies found positive correlations between microbial biomass and activity with the degree of vegetal cover (Bastida et al., 2006b) as well as with plant diversity (Manna and Sigh 2001, Pascual et al. 2001, Zak et al. 2003, Carney and Matson 2005, Loranger-Merciris et al. 2006). The greater plant species richness influence microbial communities through resource provision at a consistent temporally and spatially level, or by alteration of plant litter quality (Insam et al. 1989, Chung et al. 2007). In addition, the perennial plant cover may enhance microbial biomass and activity more than annual cover (Magdoff and van Es, 2000). The change of microbial activity under different agricultural practices and plant covers occurs due to direct and/or indirect effects of the plant covers (Bünemann et al., 2006). The direct effects of plants occur via changes in nutrient availability or toxicity and appear in the first season after the application of new plant cover. Indirect effects take more than one season to establish, especially when changes in soil organic matter levels are involved (Hassett and Zak 2005, Bünemann et al. 2006). Therefore, management practices that increase inputs of organic residues from plant or animal manurees generally increase soil microbial activity (Dick 1992, Magdoff and van Es 2000). On the other hand, modern intensive agriculture has adverse consequences on microbial diversity and activity by decreasing biodiversity and soil organic matter amendments (Matson et al. 1997, Arias et al. 2005, Hole et al. 2005, Bünemann et al. 2006). The specific practices of intensive agriculture that have negative effects on soil microbial activity are the high input of chemicals as pesticides and fertilizers, and the use of deep tillage without adequate organic matter management (Vandermeer et al. 1998, Magdoff and van Es 2000). Salinity and/or sodicity which are common problems under long term irrigated agriculture especially in areas of low rainfall (Wang et al., 2003) have extremely adverse affects on the size of the soil microbial biomass and their activity (Rietz and Haynes 2003). Therefore, the most promising approach to improve soil microbial activity and to secure sustainable soil health is to maximize the plant diversity in arable fields with minimal external resource inputs and minimal soil disturbance. In addition, the agricultural management must control other features of land degradation - especially erosion - by which soil, nutrient and plant residues are lost.

Climate conditions indirectly affect soil microbial activity by modifying the quantity and quality of plant material entering the soil (Henry et al., 2005). In temperate regions drought events may strongly reduce soil microbial activity (Jensen et al., 2003). However, in semiarid climate the microbial biomass and activity are usually low (Garcia et al., 1994), especially under mono-species cropping (Pascual et al., 2001) because of low amounts of organic matter entering the soil. Devegetation of fields in semiarid areas was found to cause negative long-term irreversible effects on the biochemical state and microbial activity of soils (Bastida et al., 2006 a&b). Despite that climate conditions have a critical effect on microbial activity the plant diversity and cover persist as the most significant determinant of microbial activity even under changes of climate conditions (Chung et al., 2007). The negative effects of devegetation on soil microbial activity are found to occur regardless the climatic differences (Hassett and Zak 2005). Therefore, the maintenance of suitable diversified plant cover is vital for preserving soil microbial activity and soil health in marginal and transitional ecosystems under the current climate and for the future expected climate conditions.

In a relative study we introduced a multi-species agricultural system namely intercropping arable fields with useful native perennial plants as a mitigation strategy for soil degradation in semiarid-arid areas. This practice was effective in reducing soil erosion and unproductive surface runoff (chapter 1) and proved to be able to improve soil organic matter (chapter 2). The increased supplies of organic matter to the soil increase the available substrate for decomposition and accordingly a response of increased microbial activity is assumed. Therefore, this part of the study aimed to investigate the soil microbial activity response to the intercropping management. The study further investigates if the response of microbial activity is consistent under different climate conditions.

In addition, the different plant species in the intercropping system may supply the soil microbial communities with different types of substrates which may result in different microbial responses. The species specific effect of plant on the microbial activity is controversially discussed in the literatures. Some studies found species specific effects (Johnson et al. 2003, Garcia et al. 2005), while other studies disprove such effect (Loranger-Merciris et al. 2006, Potthoff et al. 2006). Therefore, more investigations are needed to affirm the relation between plant species and microbial activity by testing several native perennial plant species as intercrops. Specifically we tested the following hypothesis:

(1) a partially permanent ground cover, as it is present in intercropping with native perennial plants, will improve the soil microbial activity,

(2) the efficiency of intercropping with native perennial plants in improving microbial activity is consistent under different climate conditions,

(3) the effect of intercropping with native perennial plants on microbial activity is not species specific.

Microbial activity was monitored in the different treatments by measuring the dehydrogenase enzymes activity. Dehydrogenase enzyme was used as an indicator of soil microbial activity because it provides a valid indicator of the respiration and hence the activity of soil microbes. This enzyme responds rapidly to changes in soil managements and may easily be measured (Nielson and Winding 2002, Harris 2003, Izquierdo et al. 2004). In addition, dehydrogenase activity was proposed as a measure of microbial activity in soil particularly in a semiarid climate (Garcia et al. 1994 & 2002, Bastida et al. 2006b). Dehydrogenase activity was found to be identical to the microbial respiration rate and positively correlated with the microbial biomass. In fact, dehydrogenase has been widely used to measure soil microbial activity to compare soils under different crops as well as natural and cultivated soils (Garcia et al. 2002&2005, Biederbeck et al. 2005, Pascual et al. 2001).

Materials and Methods

Study sites

The hilly slopes of the West Bank, Palestine were selected to study our hypotheses. The area suffers from soil degradation problems due to a naturally scarce vegetation cover (Isaac and Maurice 1999, ARIJ 1995). The selected area has semi-arid to arid climate characterized by long, hot, dry summers and short, cool, rainy winters. Furthermore, climate changes scenarios predict for the area a rise in temperature by 3℃ - 5 ℃ from 2071 to 2100, and a decreasing winter precipitation by about 10% - 30% (Alpert et al. 2006).

In order to test for the influence of mean annual precipitation on our proposed mitigation strategy we conducted our experiments at two sites differing in the mean annual precipitation (See Figure 1 in chapter 1). These sites were:

- Al-Dhahriya (further referred to as Site A) located 15 km to the south of Al-Khalil city, 31º 26’ 46.2” N, 34º 58’ 18.3” E), at 610 m a.s.l. and receives a mean annual precipitation of 425 mm.
- Halhul (further referred to as Site H) consisted of three spatially separated fields (H1: 31º 35’ 41.3” N, 35º 06’ 06.2” E, H2: 31º 35’ 18.1” N, 35º 05’ 08.9” E and H3: 31º 34’ 07.2” N, 35º 06’ 12.0” E) located between 910 m a.s.l. and 960 m a.s.l. receives a mean annual precipitation of 590 mm. However, the distance between fields was always lower than the distance between sites.

The selected fields for our experiments share comparable features. They were located on moderated slopes with inclination between 8% and 10%. The soil of the investigation sites is classified as brown Terra Rossae (Land research Centre, 2002). All sites were used for rain-fed annual vegetables and field crops farming since decades (traditional agriculture).

General experimental design

This study was conducted as part of a larger experiment designed to determine the effects of intercropping with native perennial plant on land degradation. A block design was used with 3 blocks at each site. Each block contained three intercropping treatments and a control (Figure 1). In the intercropping treatment plots parallel strips of the native perennial plants were planted across the path of overland flow to reduce soil erosion. The width of each strip was 0.5 meter. The strips were planted with a distance of six meters in order to allow the machinery and other treatment necessary for agriculture in the field. This space was estimated to be suitable for the necessary treatments of the fields. The area covered by the native plant in each treatment plot was 10% of the total area. Uncultivated spaces of 1-2 m were left between the adjacent treatments to reduce edge effects. The arrangements of the different treatment plots were randomised in the different blocks.

For species-specific effects we tested three different native perennial plant species as intercrops. These species were: *Majorana syriaca, Salvia fruticosa,* and *Salvia hierosolymitana* (further referred to as *M. syriaca*, *S. fruticosa* and *S. hierosolymitana*). These native plants were chosen because they are commonly collected from the wild as food, spice and/or for medicinal purposes and because they have perennial life history.

The main annual crops in the fields under study were snake cucumber (*Cucumus melo, var. flexuosus*) in the first year (2004/5), and bean (*Phaseolus* *vulgaris*) in the next year (2005/6). These annual crops represent the traditional crop rotation in this area.

The intercropping experiment started in 2004 and continued until 2006. Microbial activity was measured in April 2006 for all experimental plots.

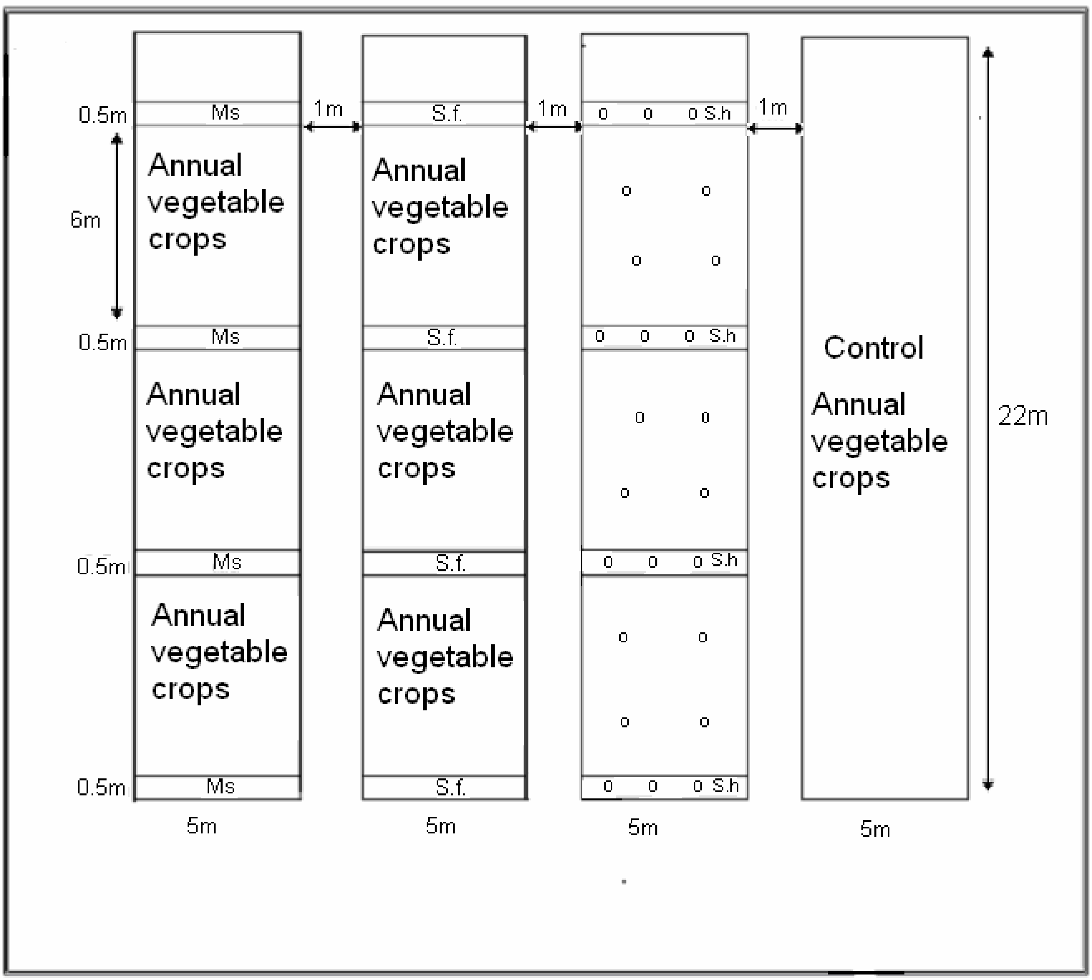

Figure 1: The experimental design and the spatial distribution of the annual crops and the native perennial plants intercrops in each block of the experimental fields. The arrangement of the different treatment plots was randomized for each block (therefore, the graph gives only an example). The small circles in one plot represent examples of the soil sampling positions from the intercropped plots.

Ms.: *Majorana syriaca, Sf.: Salvia fruticosa, Sh.*: *Salvia hierosolymitana.* The annual vegetable crop was snake cucumber in the 1st season and bean in the 2nd season.

Soil Sampling

Soil samples were collected from the top soil (0 - 20 cm depth). This depth was sampled because the traditional ploughing - as used in our experimental fields - promotes a uniform distribution of soil components through the soil profile of the plough layer (Etana et al. 1999, Needelman et al. 1999). In the intercropped plots soil samples were taken from two positions, under the native perennial plant strips and between strips as presented in Figure 1. Three bulk samples were taken from each position. For each bulk sample four soil cores (diameter 2.5 cm) were taken and mixed together directly in a plastic bag. Three bulk samples were also taken in the same way from different positions in the control plots.

Subsequently, the soils were air-dried, sieved through 2 mm mesh screen, then stored in a plastic cups at room temperature until analysis. Organic matter content in the soil samples was measured by wet oxidation using H_2SO_4 – $K_2Cr_2O_7$ (Weber 1977).

Measuring dehydrogenase enzyme activity

Dehydrogenase activity was determined by measuring the rate of reduction of 2,3,5-triphenyltetrazolium chloride (TTC) to 2,3,5-triphenyltetrazolium formazan (TTF).

For the dehydrogenase enzyme measurement, 1 g air-dried soil samples were transferred into sterile test tubes and saturated with 400 µl of a 1% solution of 2,3,5-triphenyltetrazolium chloride (TTC, Sigma T-8877). The TTC solution was freshly prepared by dissolving 1g of TTC in 100ml of sterilized distilled water. The tubes of soil with TTC solution were mixed thoroughly by a vortex shaker. The tubes were sealed then incubated in dark incubator shaker at 30 °C for 24 h. After incubation, red color was produced by the reduction of TTC to 2,3,5-triphenyltetrazolium formazan (TTF). The TTF was extracted using methanol (Sigma, M-364). A 2.4 ml of methanol was added to each tube and the contents were vortexed, and allowed in the dark at room temperature for 10 min. The tube contents were centrifuged at 5000 rpm for 15 min. Aliquots were removed and the intensity of red color was determined spectrophotometrically at 485 nm. Standard solutions of TTF were prepared freshly in methanol. The concentrations used were 50, 37.5, 25, 12.5, 6.25, 3.12, 1.56 µg ml^{-1}. The dehydrogenase activity was expressed as µg TTF formed per gram of dry soil per 24 hour incubation (µg TTF g^{-1} soil $24h^{-1}$).

Data analysis

To test for whether or not the partially permanent ground cover namely intercropping with native perennial plants, will improve the soil microbial activity (hypothesis 1) a three-way ANOVA was used to compare microbial activity in the positions of intercropping treatments with the not intercropped control. In this ANOVA microbial activity (µg TTF g^{-1} soil 24 h^{-1}) was the dependent variable. The independent variables were three treatments (intercropping with *M. syriaca*, *S. fruticosa*, *S. hierosolymitana*) three sampling positions (under native plant strip, between strips and control) and two sites (Al-Dhahriya and Halhul). Post Hoc Dunnett-t test ($p < 0.05$) was used to indicate the position/s of each treatment that differs from the control.

To test for whether or not the efficiency of intercropping with native perennial plants in improving microbial activity is consistent under different mean annual precipitations (hypothesis 2) the relative efficiency (Treatment : Control Ratio) was calculated for each intercropping treatment. The ‘Treatment : Control Ratio’ for a treatment equals the microbial activity in the treatment soil divided on the microbial activity in the control soil. Then this dependent variable ‘Treatment: Control Ratio’ was compared between the two sites by two-way ANOVA in which the independent variables were the three intercropping treatments and the two sites.

To test for whether or not the effect of intercropping with native perennial plants on microbial activity is species specific (hypothesis 3) the data obtained from the intercropping treatments was used in two steps. In the first step we compared the dependent variable microbial activity of the samples from ‘under the plant strips’ between three species (the independent variable) by one-way ANOVA. The second was another one-way ANOVA compared the dependent variable microbial activity in the samples from 'between strips' between three species (the independent variable). The Post Hoc Scheffe test ($p < 0.05$) was used to indicate the inter-treatment differences (differences between species) in the microbial activity.

In addition, an analysis for the correlation and regression between microbial activity and soil organic matter content for each treatment were performed to acquire some information about the way of the microbial activity response to the vegetation of the different treatments.

Data from all experiments satisfied assumptions of ANOVA. All statistical analyses and graphical presentation of the results were done by SPSS.

Results

The influence of intercropping with native perennial plants on soil microbial activity

The dehydrogenase activities in all intercropping treatments were significantly higher than in control. Significant differences were found also between the different tested positions compared with the control. The averages of TTF produced were 14.35±0.86 µg g^{-1} soil $24hr^{-1}$ in the control soils, 28.59±1.37 µg g^{-1} soil $24hr^{-1}$ in the soil under native plant strips, and 17.44±1.22 µg g^{-1} soil $24hr^{-1}$ in the soil between strips. The differences in dehydrogenase activity between the different positions of each intercropping treatment compared with the control are illustrated in figure 2 for *M. syriaca*, Figure 3 for *S. fruticosa* and Figure 4 for *S. hierosolymitana*. Microbial activity was highest under the strips of the intercrops, intermediate between the strips in intercropped plots and lowest in the control plots. However the differences between control and the areas between strips in intercropped plots were not always significant. The dehydrogenase activity in the intercropping plots under the strips of native plants was in average 105% higher than the control, and between the strips 27% higher than the control. The microbial activity was proportional with the soil organic matter content in the overall plots (R^2 = 0.39, p = 0.01).

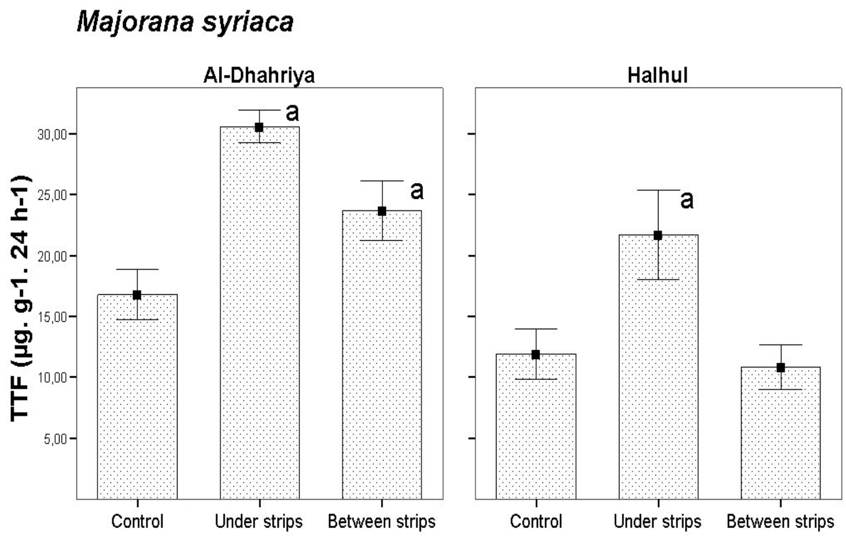

Figure 2: Soil microbial activity (µg TTF g^{-1} soil 24 h^{-1} Avg ± 1SE) in fields intercropped with *Majorana syriaca* at two sampling positions and in a not intercropped control at two sites (Al-Dhahriya and Halhul). Error bars with letter (a) represent means significantly different from the control (Dunnett-t test, $p < 0.05$).

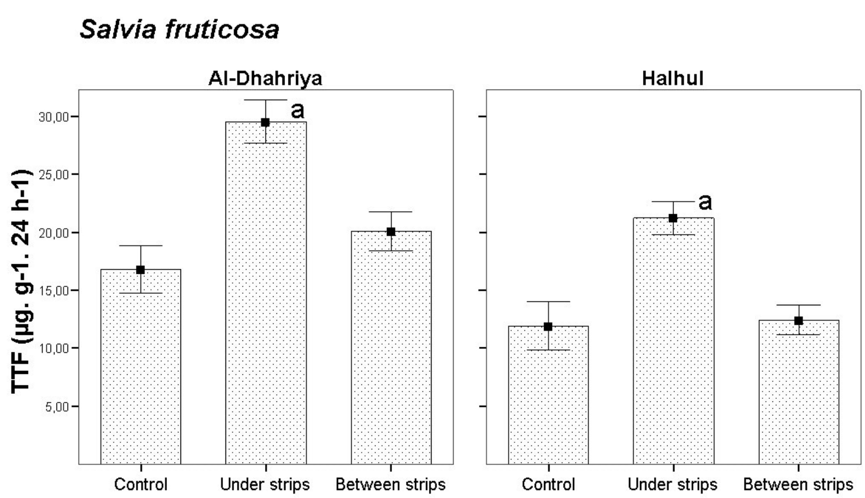

Figure 3: Soil microbial activity (µg TTF g^{-1} soil 24 h^{-1} Avg ± 1SE) in fields intercropped with *Salvia fruticosa* at two sampling positions and in a not

intercropped control at two sites (Al-Dhahriya and Halhul). Error bars with letter (a) represent means significantly different from the control (Dunnett-t test, $p < 0.05$).

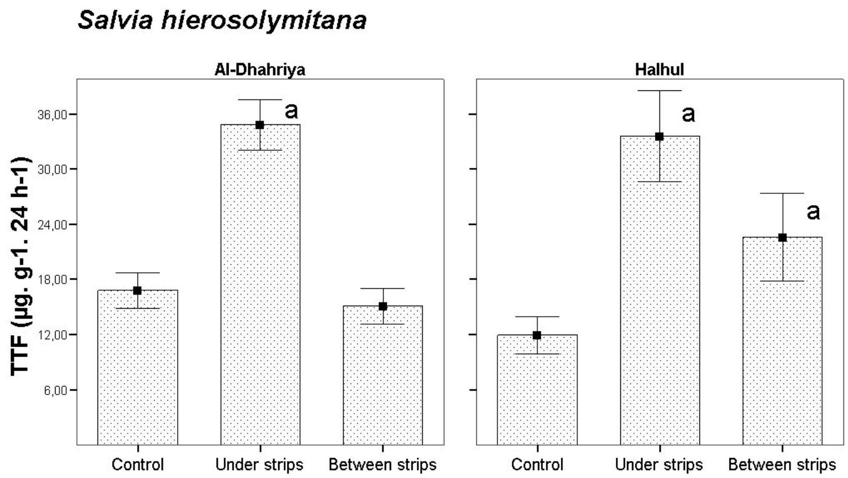

Figure 4: Soil microbial activity (µg TTF g^{-1} soil 24 h^{-1} Avg ± 1SE) in fields intercropped with *Salvia hierosolymitana* at two sampling positions and in a not intercropped control at two sites (Al-Dhahriya and Halhul). Error bars with letter (a) represent means significantly different from the control (Dunnett-t test, $p < 0.05$).

The influence of the mean annual precipitation on the effects of intercropping

Intercropping with native perennial plants enhanced microbial activity in the both sites. The relative efficiency of intercropping in improvement microbial activity given by the 'Treatment: Control Ratio' was slightly higher in site H than in site A in the plots of *S. fruticosa* and *S. hierosolymitana* (Figure 5). While for *M. syriaca* the 'Treatment: Control Ratio' was slightly higher in site A. The average 'Treatment: Control Ratio' for all intercropping treatments was 1.61 at site A and 1.99 at site H. However the high variation in data leads to insignificant differences in the 'Treatment: Control Ratio' between the two sites.

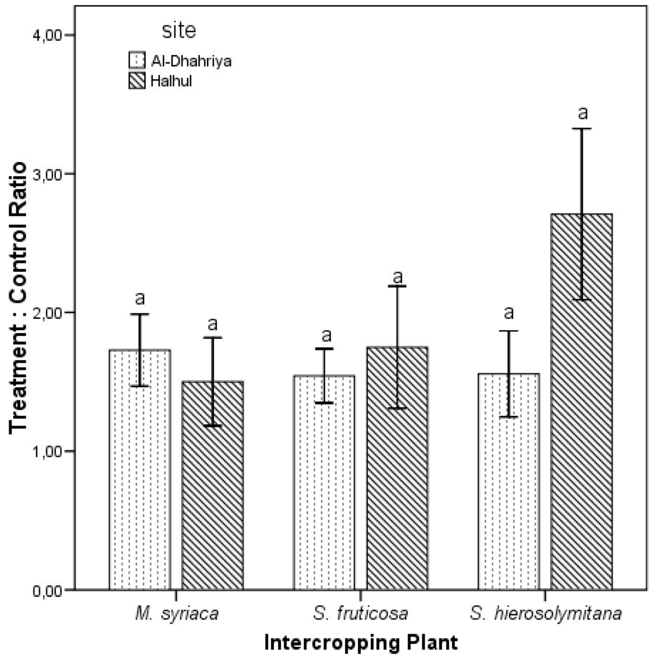

Figure 5: The relative differences of microbial activity in intercropped treatments compared to not intercropped control (treatment: control ratio) in two climatic sites. Error bars with similar letters for each species represent insignificant difference between sites.

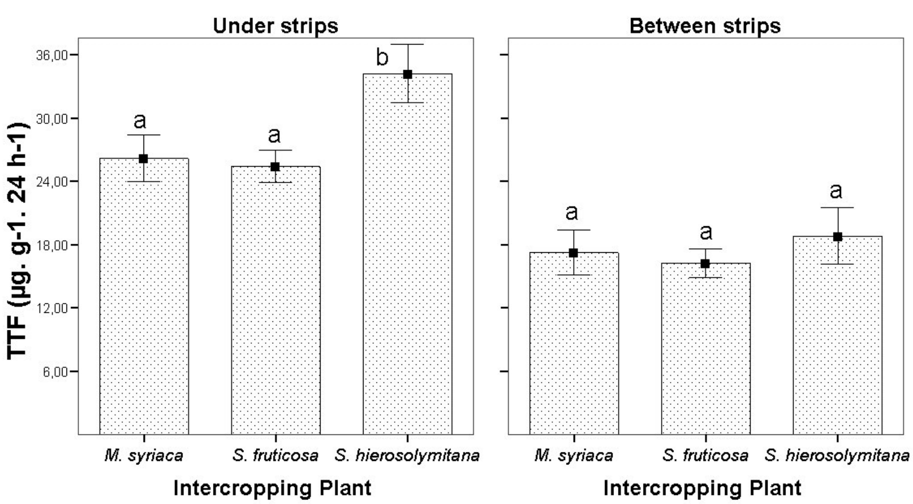

Figure 6: The species-specific effect of intercropping on soil microbial activity (µg TTF g^{-1} soil 24 h^{-1}, Avg ± 1SE) in two positions of intercropping plots (under native plant strips and between native plant strips). Error bars with similar letters in the same position are statistically not different (Scheffe test, $p < 0.05$).

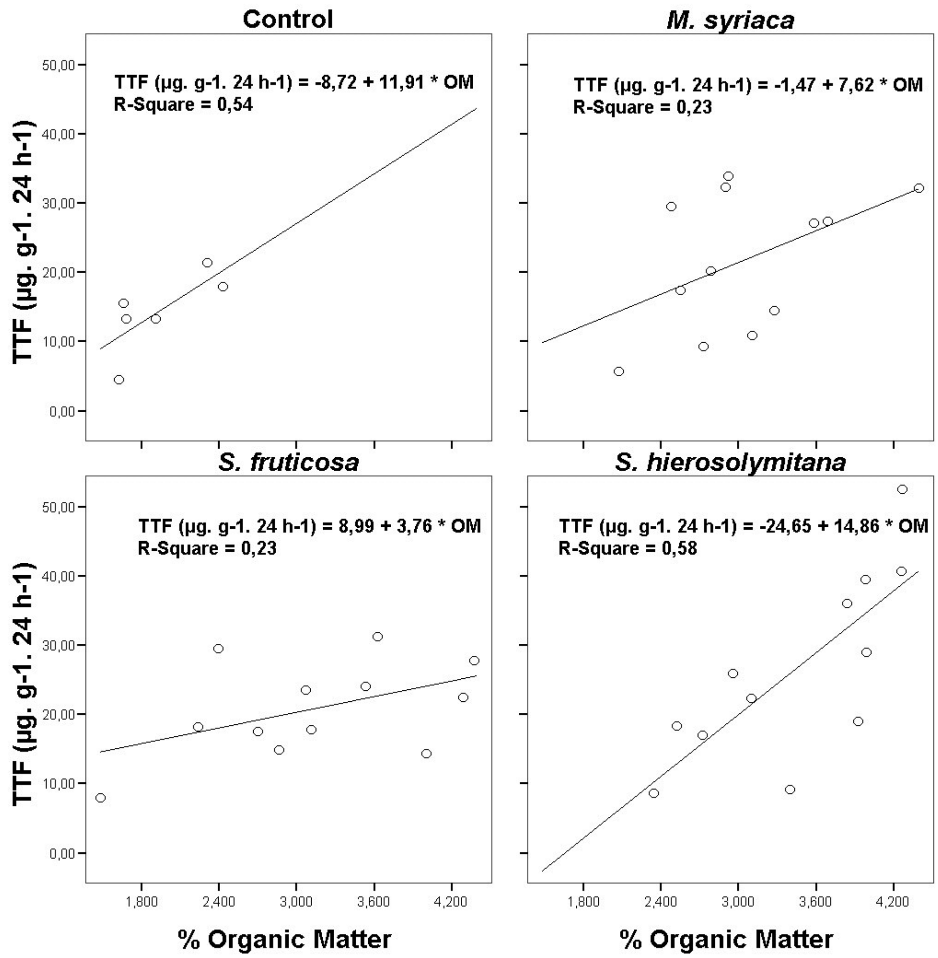

Figure 7: The relation between soil organic matter content with the soil microbial activity intercropping with three native plant species and control (no intercropping) for the data of the two sites.

The species-specific effects of intercropping on microbial activity

There was significant differences in microbial activity under the strips of the three native perennial plants intercrops (one-way ANOVA, F = 4.866, P = 0.012). The microbial activity under the strips of *S. hierosolymitana* was 34.22 µg TTF g^{-1} soil $24hr^{-1}$, which was higher than the other two species (Figure 6). Under the other two species there were statistically equal levels of microbial activity of 26.16 µg TTF g^{-1} soil $24hr^{-1}$and 25.39 µg TTF g^{-1} soil $24hr^{-1}$ for *M. syriaca* and *S. fruticosa,* respectively. There was no significant difference in microbial activity between the three species in the samples from between strips (one-way ANOVA, F = 0.372, P =

0.691). The microbial activity between strips ranged from 16.24 µg TTF g^{-1} soil $24hr^{-1}$ to 18.83 µg TTF g^{-1} soil $24hr^{-1}$ (Figure 6).

The analyses of the correlation and regression between microbial activity and organic matter content of each treatment detected some species-specific differences also. There was significant linear correlation only in the plots intercropped with *S. hierosolymitana* (R^2 = 0.58, P = 0.01) (Figure 7). The correlation (R^2) in the plots intercropped with *M. syriaca* and *S. fruticosa* was not significant with an R^2 = 0.23.

Discussion

The influence of intercropping with native perennial plants on soil microbial activity

This study provides experimental evidence for positive effects of the partially permanent ground cover in the form of intercropping with perennial plants on soil microbial activity. The microbial activity was relatively low in the monoculture plots. This means that agriculture of mono-species in semiarid soils have a negative effect on microbial activity. Dehydrogenase activity was elevated in all intercropped fields if compared to annual monocrop fields. After two years of intercropping the microbial activity in the intercropping treatment plots was almost two times higher than at monocrop plots. These results confirm the important role of a perennial plant cover in microbial activity improvements. The decrease in microbial activity in mono-species cropping may result in a decrease in the mineralization of residues and consequently in a decrease of the concentration of plant available nutrients. These observations are in agreement with previous reports about higher microbial activity under greater plant diversity and higher plant cover (Manna and Sigh 2001, Pascual et al. 2001, Zak et al. 2003, Carney and Matson 2005, Loranger-Merciris et al. 2006).

The enhanced level of microbial activity under native plants intercrops is probably due some modifications of the soil biota habitat by the plants cover.

Habitat modifications may include soil moisture, high intensity and the available substrates. In a parallel study (Chapter one) we found high soil moisture after rainfall in the intercropped plots. In addition, an improved level of organic matter (SOM) in soils was found in the intercropped plots (chapter 2) and high correlation was between SOM and microbial activity The lower plant cover of the mono-species plots means a lower soil organic matter content and so the microorganisms have less organic matter to decompose, resulting in lower enzyme activity values. Therefore, we may assume that the higher levels of microbial activity in the intercropping plots even under the native plant strips or between strips are partially a response to the improved amounts of organic matter in the soil. This assumption is in agreement with results obtained by (Balota et al. 2003 & 2004, Hassett and Zak 2005). In addition, the greater variety of organic matter residues derived from the multi-species of intercropped plots may allow more efficient organic matter utilization as compared to the more uniform input from monoculture plots (Insam et al., 1989).

The higher levels of microbial activity under the intercropping strips suggest that intercropping with native perennial plants may help to enhance microbial activity in arable fields. Additionally, we may suggest that intercropping is a suitable strategy to improve soil quality by the critical role of microbes in soil. Therefor, the study demonstrates the potential for human alteration of aboveground plant cover and land-uses as mean to enhance soil microorganisms and possibly the processes they mediate.

The influence of the mean annual precipitation on the effects of intercropping

The soils studied showed low microbiological activity in general. We found dehydrogenase activity values from 5 to 53 µg TTF g^{-1} soil $24hr^{-1}$. These values are inconsistent with dehydrogenase activity values reported in other semi-arid areas of the Mediterranean region (Garcia et al., 1994). These results reflect the normal microbial activity shortcomings of soils in semiarid and arid areas and in soils suffering degradation and desertification as documented in previous reports such as Bastida et al., (2006b). However, the intercropping with native perennial plants was effective in improving microbial activity under all climate conditions studied. This shows that the plant cover plays the dominant role in the determining the soil microbial community regardless the climatic differences and the climate conditions may have the indirect effect on soil microbial community. Therefore, the enhancement of microbial activity by intercropping was independent of the climatic characteristics of the sites in semiarid-arid areas. Subsequently, we suggest that intercropping with native perennial plant may help in improving soil quality and controlling land degradation in semiarid-arid areas.

In addition, the magnitude of microbial activity enhancement by intercropping was not also affected by the differences in the mean annual precipitation. That suggests the possibility of applying intercropping in other semiarid regions with different mean annual precipitation as a mitigation strategy for reduced soil microbial activity. We suggest that the possibility to enhance microbial activity by intercropping to be persistent under the current climate and may remain so under the future suspected climate condition. Therefore, intercropping practice using native perennial plants as soil fertility management may help to cope with the effects of the predicted climate changes.

The species-specific effects of intercropping on microbial activity

The results of microbial activity in the fields intercropped with the three native plant species reveal some trends toward different effects of various species on microbial activity. Different levels of dehydrogenase activity were detected in treatment plots intercropped with different native plant species. *S. hierosolymitana* enhanced microbial activity more than the other two species. This suggests a species-specific effect on soil microbial activity. This finding strengthens the assumption about species specific effect as reported in some previous studies (Johnson et al. 2003, Garcia et al. 2005).

In addition, the results of the correlation between microbial activity and soil organic matter content in the different species plots support the possibility of species-specific effects on microbial activity. Basically, it is known that a positive linear correlation links the microbial activity level with soil organic matter content (Dick 1992, Magdoff and van Es 2000, Hassett and Zak 2005). However, in our study this positive correlation was found in the plots intercropped with *S. hierosolymitana.* This observation suggests that the response of microbial activity in the plots of this species was attributed to the change in soil organic matter content. By contrast, in the plots of other species (*M. syriaca* and *S. fruticosa*) no such correlation was between the two soil parameters. The microbial activity level under these species was lower than under *S. hierosolymitana,* despite that the organic matter content was not different between the different species. These results suggest different effects of plant species on microbial activity. The first effect is through increasing soil organic matter content. This effect was detected under all species as both soil organic matter and microbial activity were improved. The second possible effect is suggested to occur in the plots of *M. syriaca* and *S. fruticosa* where the magnitude of enhancing microbial activity was not proportional with the level of improving soil organic matter. This effect may be explained by the presence of non-easily decomposable organic matter added from these species. Such suggestion was mentioned by Garcia et al. (2005) as an explanation for species-specific effects on microbial activity under semiarid-arid climates. Another possible effect on the microbial activity response under *M. syriaca* and *S. fruticosa* is that an allelopathic release of some substances occurs from these species. It is known that *M. syriaca* and *S. fruticosa* produce some antimicrobial substances and used for medicinal purposes which may support the hypothesis of the allelopathic effect of these species. However, when toxic releases contribute to control the level of microbial activity after new permanent vegetal cover application, this effect may be balanced after a long-term of application by the continuous enrichment of soil with organic matter (Bünemann et al., 2006). Therefore, the results clearly demonstrate that all native perennial plants species studied may enhance soil microbial activity to different magnitudes. These results may allow us to suggest that other perennial plants may help to enhance microbial activity and improve soil quality. The preferable species are those that produce dense vegetation of easily decomposable materials with minimal allelopathic effects.

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Chapter four

Intercropping annual fields with native perennial plants as management strategy that reduces socioeconomic risks

Abstract

The rain fed mono-species cropping in semi-arid regions is susceptible to economic risks due to frequent dry seasons and accelerated soil degradation. A possible management to reduce soil degradation and the socioeconomic risks in such regions is to apply multi-species intercropping systems using marketable native perennial plants. This system combines the advantages a permanent ground cover with the production needs for the farmers. In a field experiment from 2004 to 2006, we developed an intercropping system in which useful perennial native plants were used as intercrops. The native plants intercrops used are usually collected by the local population as food, spice and/or medicine, and cultivating them may provide some payment income for the farmers. This system was effective in controlling water loss in runoff and soil erosion (Chapter 1) and may improve soil quality (Chapter 2, 3). In this part of the study we want to test experimentally for the ability of this agricultural system to maintain farmers yield and income under rain fed agriculture. In order to acquire additional information about the possibility to use this system as a mitigation strategy to cope with the effects of the expected global climatic change we conducted the experiment at two sites differing in the mean annual precipitation in Palestine.

The results of the study show that intercropping with native perennial plants had minimal negative effect on the yield of the annual crops, while the overall financial income were higher on intercropped plots if compared to the income from

the fields with annual monocrops. There was a tendency toward lower annual crop yield in the intercropped fields if compared to the non intercropped plots. However, that reduction was compensated by the income gained from the native plants. The income gained from the annual crops in the dry season (2005/6) was less than in the wet season (2004/5), while a stable consistent income was gained from the native plants in both seasons. This indicates that, in semiarid regions the income from intercropping system may be more sustainable and reliable compared with the monoculture system. In addition, the risk of low yields or crop failure which frequently occurs in the traditional rain fed production system due to frequent dry seasons may be minimized by intercropping with marketable native perennial plants. These results were consistent in semi-arid and arid sites therefore we recommend this management as a mitigation strategy to cope with the effects of the expected global climatic changes.

Introduction

The rain fed mono-species cropping in semi-arid regions is susceptible to economic risks due to frequent dry seasons and accelerated soil degradation. However, human activities, mainly land-use change and intensification of agriculture, may further accelerate soil degradation and result in less sustainable agriculture (Vandermeer et al., 1998). The modern high intensive agriculture depends on monocultures and the use of crop varieties that have narrow genetic base. These crop varieties are not adapted to tolerate drought and consequently, needs lots of water through artificial irrigation which is often not available in semiarid regions. In addition, these varieties are high susceptible to plant pests and need different types of pesticide application to succeed. The high external inputs of modern agriculture represented by water, pesticides and new varieties results in non-sustainable agroecosystems especially for in transitional areas (Vandermeer et al. 1998, Altieri 1999b, Darkoh 2003). Therefore, the modern high intensive agriculture may not be considered a sustainable production system in semiarid regions. New managements are needed for semi arid regions that increase farm productivity by environmentally sound activity.

In addition, the application of modern agriculture in transitional regions such as semiarid regions has also adverse consequences on agro-biodiversity and accelerates soil degradation processes (Darkoh 2003, McNeely 2003, Hole et al. 2005, Jackson et al. 2007). Declining diversity of the weed flora under intensive agriculture is reported in many studies (See reviews of Altieri 1999 & 2002, Hole et al. 2005, Jackson et al. 2007). Further stress on biodiversity resources is predicted through the global climate changes (Hampe and Petit 2005, Bochet & Garcia-Fayos 2007). Vegetal cover and species richness may decrease with changing climatic toward higher temperatures and lower precipitation (Bochet & Garcia-Fayos, 2007). Additionally, the harmful effects of climate change on biodiversity resources are more serious in the transitional regions such as semi-arid regions (Hampe and Petit, 2005). Marginal plant populations are more prone to extinction because they tend to occur in less favorable habitats and at lower and more variable densities (Hampe and Petit, 2005). The reduction of plant biodiversity in turn enhances catastrophic events, such as accelerated runoff and soil erosion as well as other forms of land degradation (Altieri*,* 2002). Therefore, biodiversity conservation is among the most urgent of the issues that need addressing when developing new agriculture managements especially in dry lands. In addition, these agriculture managements must be able to conserve and regenerate the soil resources.

As management strategies for the annual crop fields, several authors suggested diversifying the agricultural systems and the application of permanent ground covers (Lal 1995, Vandermeer et al. 1998, Altieri 1999 & 2002, Jackson et al. 2007, Pascual and Perrings 2007). One of the recommended diversified agricultural systems for semiarid areas is intercropping (Altieri 1999). Several environmentally and economically advantages may result from intercropping agriculture. Intercropping systems are expected to be less susceptible to erosion (Nelson et al. 1998, Barton et al. 2004) and may contribute to improve soil fertility (Altieri 1999b, Ghosh 2004). The multi-species systems may enrich the soil with greater variety of organic matter residues and improve soil microbial activity (Altieri 1999b). In addition, diverse agricultural systems as intercropping may be more productive than simple systems (Vandermeer 1998, Hallam et al. 2001, Ghosh 2004, Yildirim & Guvenc 2005, Alene et al. 2006, Ghosh et al. 2006). Additionally, intercropping is regarded also as an environmentally sound method to manage pests (Risch et al. 1983, Khan et al. 1997, Altieri 2002 & 2004, Butts et al. 2003), and weeds (Oswald et al. 2002, Poggio 2005, Fenández-Aparicio et al. 2007, Hollander et al. 2007, Singh et al. 2007). Therefore, intercropping systems may mitigate many of the environmental problems associated with agriculture. However, the application of permanent vegetation cover is usually not an option for farmers of annual crops, since they will lose some of the productive area for the perennial cover. Therefore, new ways of production are needed that combine the advantages of permanent ground cover with the production needs of the farmers.

We suggested that the domestication of useful native perennial plants and planting them as strips in annual crop fields may contribute to financial reward for the farmer while serving as a partially permanent cover that help in soil protection. By marketing the useful native perennial plants a new source of field income will probably be available. In addition, the domesticated native plants may help the agroecosystem to mimic the natural ecosystem and acquire some of its benefits (Vandermeer et al. 1998, Jackson et al., 2007). The perennial life history of many native species may contribute to reduce overland flow in rills and gullies sinks (Dunj'o et al., 2004). This will provide sediment traps and enhance water efficiency by minimizing un-productive water losses (surface runoff). In addition, it may also help to increase the quantity of soil organic matter by frequent addition of plant residues to the soil. Consequently, positive affects are expected on other soil properties such as soil microbial activity and aggregate stability. The use of native perennial plants as intercrops may benefit biodiversity also by reducing the pressure on the natural habitats of these plants especially the threatened species.

During the years 2004 - 2006 we studied the effect of the developed intercropping system with useful native perennial plants on reducing runoff and soil loss (Chapter 1), and on improving soil quality (Chapter 2, 3). This intercropping system was effective in reducing unproductive water loss and soil erosion. In addition, some soil quality parameters namely soil organic matter and microbial activities were improved by this system. In this part of the study we want to test experimentally for the ability of this agricultural system to maintain farmers yield and income under rain fed agriculture. In order to evaluate the ability of this mitigation strategy to cope with the effects of the expected global climatic change we conducted the study at two sites differing in mean annual precipitation in Palestine. We assume that the loss of some areas for the native plants will not negatively affect the annual crop's yield; on the contrary the native plants may provide additional reliable income to the farmers. In particular we tested the following hypotheses:

1) The annual crop's yield will not be affected by the intercropping system.
2) The farmer's financial income will increase due to the additional income from the production of marketable native perennial plants.
3) The farmer will gain a more sustainable and reliable income from intercropping system if compared to the income from not intercropped fields.
4) The observed effects of intercropping are independent of the mean annual rainfall.

Methods

The study sites

The hilly slopes of the West Bank, Palestine, have been selected as study sites. Water availability in the area is low and the area suffers from land degradation problems (Isaac and Maurice 1999, ARIJ 1995). The climate of the area is characterized by long, hot, dry summers and short, cool, rainy winters with frequent reduced rain fall seasons (ARIJ, 1995). Climate change scenarios predict for the area for 2071-2100 an increase in temperature of about 3 C° - 5 °C, and a decrease in mean annual precipitation of about 10 % - 30% (Alpert et al, 2006).

A gradual shift from traditional rain-fed agriculture to intensive agriculture began in Palestine in the early 1970s which increased the demand of water for agricultural purposes. Furthermore, the agrobiodiversity resources have been reduced due to the replacement of indigenous species and local varieties with hybrid and/or imported species (Isaac and Stephen 1995). Many native plant species were formerly common in the agricultural fields but are now rare (e.g. *Eminium spiculatum*, *Tetragonolobus palestinus*, wild *Pisum* spp) or extinct like *Citrullus colocynthis* (Isaac and Maurice 1999, Al-Sheikh et al. 2000). In addition, indicators of desertification appear clearly in the Eastern Slopes and in the south region of the area (ARIJ, 1995).

We conducted the intercropping experiments in Al-Khalil district, the southern part of the West Bank on fields traditionally used for annual crops farming. There is a strong gradient in precipitation in this area, which allowed us to test for the influence of mean annual precipitation on our proposed mitigation strategy by conducting our experiments at two sites differing in the mean annual precipitation. The study sites were the following (See Figure 1 in Chapter 1):

- Al-Dhahriya (further referred to as Site A) located 15 km to the south of Al-Khalil city, (31º 26' 46.2" N, 34º 58' 18.3" E), with a mean annual precipitation of 425 mm.
- Halhul (further referred to as Site H) consisted of three spatially separated fields (31º 35' 41.3" N, 35º 06' 06.2" E, 31º 35' 18.1" N, 35º 05' 08.9" E, and 31º 34' 07.2" N, 35º 06' 12.0" E), with a mean annual precipitation of 590 mm. However, the distance between fields was always lower than the distance between sites.

To test the above hypothesis we experimentally tested the effect of intercropping with native perennial plants on the annual crop's yield and the total income of the farmers. Four treatments were tested: control (no intercropping) and intercropping with three native perennial plant species. Four replicates of each treatment were established at site A and three replicates at site H. The experiment was conducted during two consecutive seasons from 2004 to 2006 to detect the effect of inter-annual rainfall variations on the measured variables.

The native perennial plants used as intercrops were: *Majorana syriaca, Salvia fruticosa,* and *Salvia hierosolymitana* (in the following referred to as *M. syriaca*, *S. fruticosa* and *S. hierosolymitana*)*. M. syriaca* is used in the area as food, spice and for medicinal purposes*, S. fruticosa* is used as spice and for medicinal purposes and *S. hierosolymitana* is a food plant*.* These species were chosen for their perennial life history to provide a permanent vegetation cover that may contribute to reduce soil erosion. In addition, the wild stands of these species are threatened due to collecting pressure by the local populations and needs protection procedures.

The annual crops were selected according to the traditional crop rotation in the area: snake cucumber (*Cucumus melo, var. flexuosus*) in the first year (2004/5), and bean (*Phaseolus vulgaris*) in the next year (2005/6). The farmers follow this rotation system routinely and expect sustainable income from different crops at different seasons unless an extreme climate conditions occurred at a specific season.

Experimental Design

A block design was used with four blocks at site A and three blocks at site H. Each block consisted of three intercropping plots and one control plot (Figure 1). The area of each treatment plot was 110 m^2 (5 m wide x 22 m long). In the intercropping treatments parallel strips of the native perennial plants were planted across the path of overland flow. The width of each strip was 0.5 meter. The strips were planted with a distance of six meters in order to allow the machinery and other treatment necessary for planting the annual crops in the field. The arrangements of the treatments in each block were randomised. The area of each experimental block was about 1000 m^2 or 0.1 ha.

The seedlings of the native plants intercrops were planted in the 3rd week of Feb. 2004 at Site A and in the 4th week of the same month at site H. These were the earliest possible dates for planting due to the heavy rainfall in that season. Three rows of the seedlings were planted with a distance of 25 cm between rows and 50 cm between adjacent seedlings. The seeds of snake cucumber/bean were planted in the middle of April at site A and in the middle of May at site H in the two years. These planting times follow the beginning of the warm season (after the cold rainy period). Since the beginning of the planting season varies according to the geographic location, planting started at site H one month later than at site A. Four seeds x13 rows were sowed in the intercropped treatment plots and 4 x 17 rows in the control plots. The annual crops rows in the intercropped plots were less than in the control because 10% of the intercropped plot area was used for the native perennial plant strips.

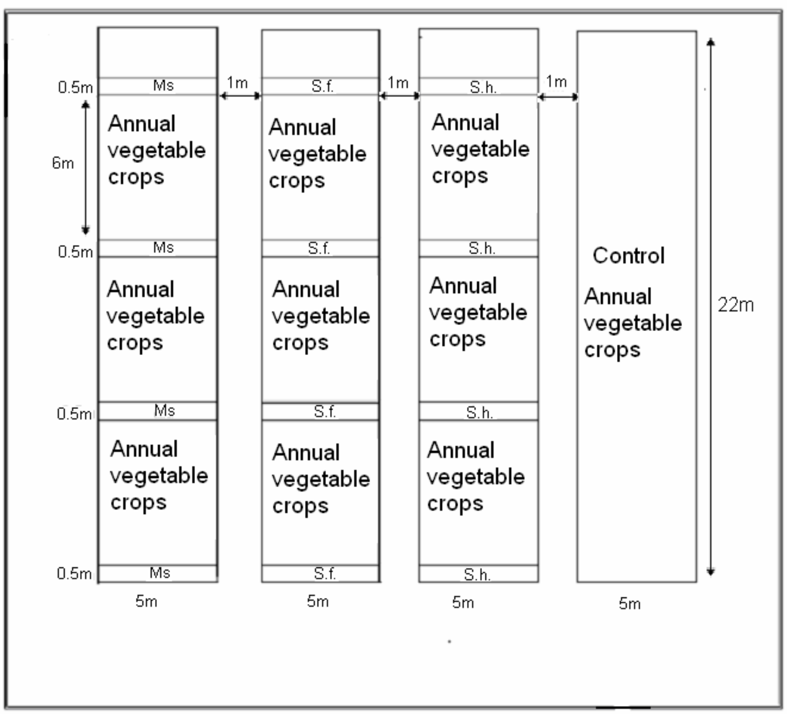

Figure 1: The experimental design and the spatial distribution of the annual vegetable crops and the perennial intercropped native plants in a block of the experiment. The arrangement of different treatment plots is randomised (therefore, the graph gives only an example). *M.s.*: *Majorana syriaca, S.f.: Salvia fruticosa, S.h.*: *Salvia hierosolymitana*. The annual vegetable crop was snake cucumber in the 1st season and bean in the 2nd season.

Measurements

The annual crop's yield in the intercropping system

The yield of the annual vegetable crops was measured for each treatment as the weight (kg) of the fruits. In both seasons the fruits of the annual crops were manually collected daily during the fruiting period (June – July) and weighed immediately. The summation of the daily harvested crops along the whole fruiting period represents the crop yield for each treatment and was expressed as kg per hectare ($kg.ha^{-1}$).

The influence of intercropping on the financial income

That information was gained by comparing the income gained from the intercropping system with the income gained from plots without intercropping (control). The income gained from the control has one component, the income from the annual crops only. The income from the intercropping system was estimated by the summation of income from two components of the fields, the income from the annual crops and the income from marketing the native perennial plants. The income from the annual crops was estimated as (€.ha^{-1}) by multiplying the crop yield ($kg.ha^{-1}$) measured in the previous section by the average price of the crop as obtained from the Central Vegetable Market in the production period. The invoices for the whole farmer's production of snake cucumber in the first year and for bean in the second year were taken from the farmers and the average price for each product all over the season was calculated and used to estimate the income from each crop. The average price for snake cucumber in the season 2004/5 was 0.55 €/kg, and for bean in the season 2005/6 the average price 0.82 €/kg

For measuring the income gained from the native plants the marketable parts of each species (stems and/or leaves) were cut and weighed when they were suitable for human traditional consumption. *M. syriaca* stems with the leaves were cut two times in each season (in late February and early April), *S. fruticosa* stems with the leaves were cut two times in March and September, and the flesh leaves of *S. hierosolymitana* were picked every 10-15 days in the period from January to

March of the seasons 2004/05 and 2005/06. The annual yield of each native plant species was measured as kg of the marketable vegetative parts per hectare of intercropped area ($kg.ha^{-1}$). Most of the native plant production was consumed by farmer's family and relatives, and the author's family. So to estimate the income of each native plant the price of each species was taken by the author from the Central Vegetable Market weakly during the production period for each species. Then the average price was calculated for the whole season as $€.kg^{-1}$. The average price for each native plant species in each season is listed in table 1 Then the income from each species was calculated as $€.ha^{-1}$ in the same way mentioned for the annual crops.

The sustainability of the income from intercropping system

Rainfall amounts were measured in the two seasons of investigation to detect some of the inter-annual variation in precipitation, and to test whether or not the income gained from different treatments is influenced by inter-annual variations. The amount of rainfall was measured after each rain event of each rainy season (from October to April) at both sites from one simple rainfall gauge. The total accumulative amount was given by mm rainfall per season.

Data analyses

The annual crop's yield under the intercropping system

To test for the effects of intercropping on the annual crop's yield (hypothesis 1) a 3-way ANOVA was conducted with the yield of the annual crop ($Kg.ha^{-1}$ of snake cucumber in the 1st season and bean in the 2nd season) as dependent variable, and treatment (intercropping with *M. syriaca*, *S. fruticosa*, *S. hierosolymitana* and control), sites (A: Al-Dhahriya and H: Halhul) and seasons of investigation (2004/5 and 2005/6) as independent variables. Then post Hoc Dunnett t-tests ($P < 0.05$) were used to test for differences between each treatment and the control within each site and season.

The influence of intercropping on the financial income

To test for the influence of intercropping on the total income (hypothesis 2) a 3-way ANOVA was conducted with the total income of the fields (€.ha^{-1}) as dependent variable, and the four treatments, two sites and two seasons of investigation as independent variables. The post Hoc Dunnett t-tests ($P < 0.05$) were used to test for differences between each treatment and the control within each site and season.

The sustainability of the income from intercropping system

To test for whether or not the farmers gain more sustainable and reliable income from the intercropping system compared to the income from not intercropped fields (hypotheses 3) two steps of analyses were conducted. The first was to test for inter-seasonal difference of the total income of the fields. This information was obtained from the results of the ANOVA mentioned in the previous section. The second was to test for inter-seasonal difference of the income gained from the native plants alone. This was obtained by conducting a 2-way ANOVA with the dependent variable the income of the native plants (€.ha^{-1}). The independent variables were three intercropping treatments (*M. syriaca*, *S. fruticosa*, *S. hierosolymitana*) and two seasons (2004/5 and 2005/6).

The effects of intercropping are independent of the mean annual rainfall

To test whether or not the observed effects of intercropping are independent of the mean annual rainfall (hypothesis 4) a 2-way ANOVA was conducted with the dependent variable the '% income from the native plants'. The independent variables were three intercropping treatments (*M. syriaca*, *S. fruticosa* and *S. hierosolymitana*) and two sites.

Data from all experiments satisfied assumptions of ANOVA without transformation. All statistical analyses and graphical presentation of the results were done by SPSS.

Results

The annual crop's yield under the intercropping system

The snake cucumber yield of the first season was lower in the intercropping treatments if compared to the control (Table 1). However these differences were never significant (Figure 2). The average snake cucumber yield was 6261 $kg.ha^{-1}$ in the control plots, 5967 $kg.ha^{-1}$ in the plots of *M. syriaca*, 5669 $kg.ha^{-1}$ in the plots of *S. fruticosa* and 5016 $kg.ha^{-1}$ in the plots of S. *hierosolymitana*.

In the 2nd season the average of bean yield was 1361 kg ha^{-1} in the control plots, 1091 kg ha^{-1} in the plots of *M. syriaca*, 878 kg ha^{-1} in the plots of *S. fruticosa* and 947 kg ha^{-1} in the plots of S. *hierosolymitana*. These differences were significant only at site H but not at site A (Figure 2).

The influence of intercropping on the financial income

The total financial income of the fields varied significantly between the different treatments. Higher incomes were obtained from the intercropped plots if compared to the control (Table 1). The income from the control and each component of the intercropped fields are illustrated in table 5. The average total income was 2280.2 $€.ha^{-1}$ from the control, 3327.4 $€.ha^{-1}$ from the plots of *M. syriaca*, 3643.1 $€.ha^{-1}$ from the plots of *S. fruticosa* and 3086.8 $€.ha^{-1}$ from the plots of S. *hierosolymitana*. However, the differences between treatments were significant only in the second season (Figure 3). The average total income from the intercropped fields was 103% - 160% of that from the control in the 1st season and 174% - 564% in the 2nd season. The proportion of the income added from the native plants was 12% - 43% of the total income in the 1st season and 51% - 86% in the 2nd season.

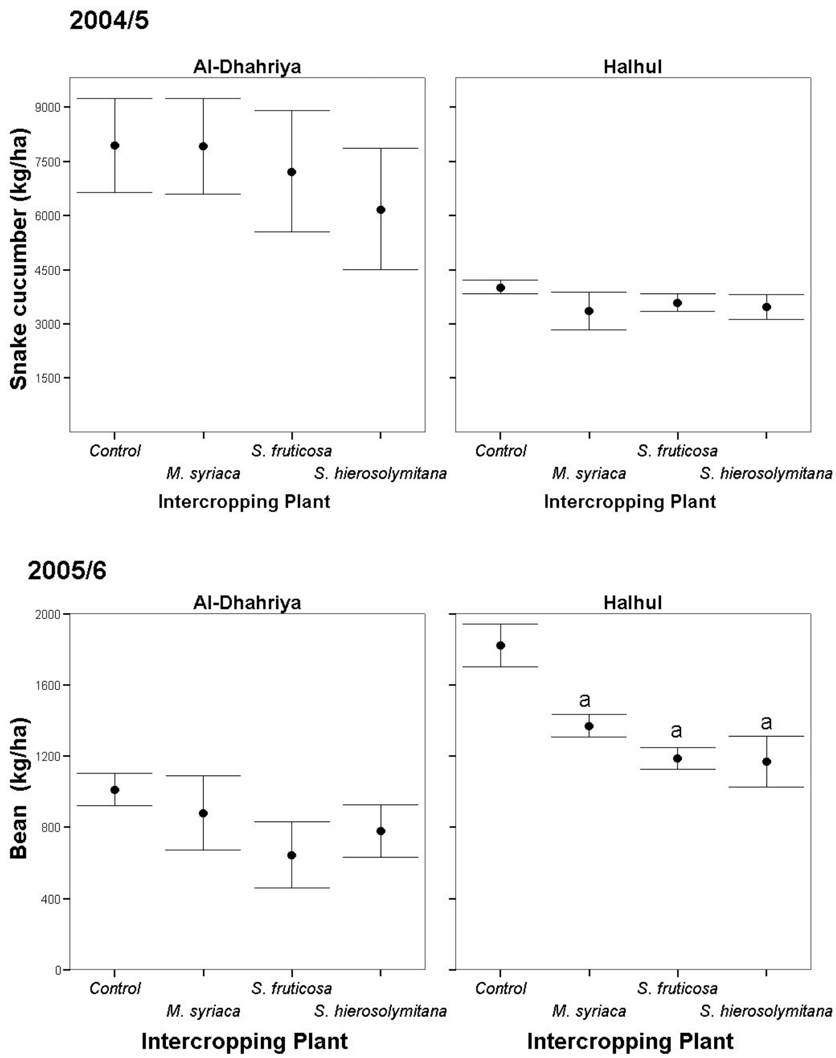

Figure 2: The yields of the annual crops (Kg.ha^{-1} Avg. ± 1SE) in two sites in Al-Khalil district in four different treatments in two seasons of investigation. Error bars with the letter (a) are significantly different from control (Dannett t test, P < 0.05).

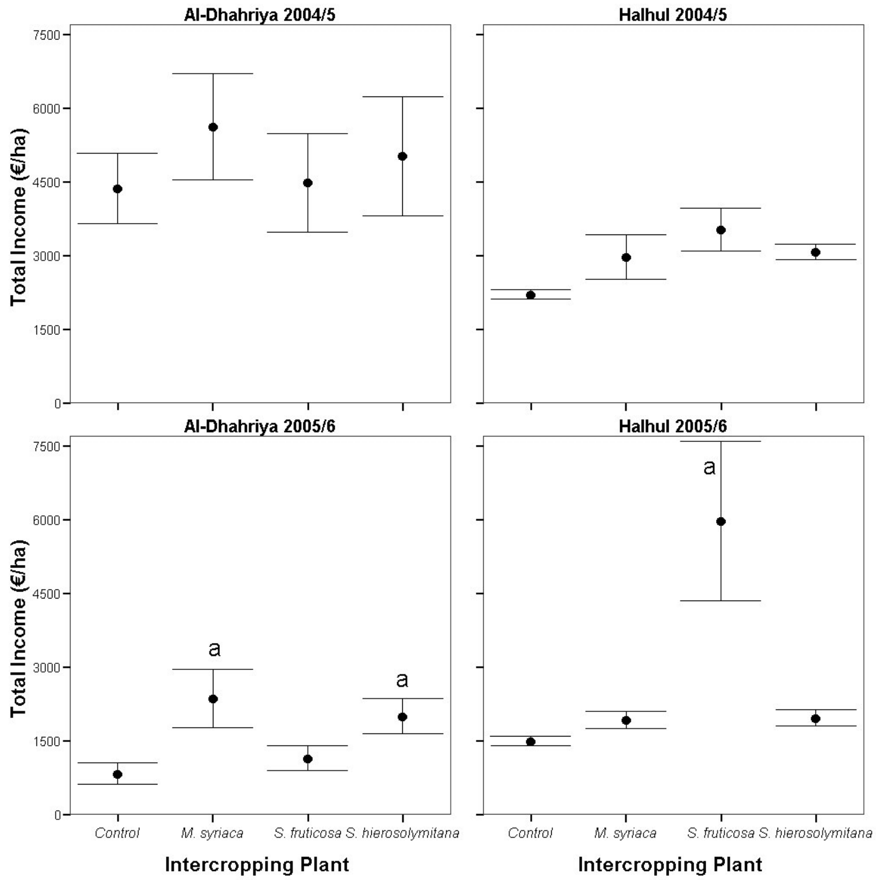

Figure 3: The total income (€.ha^{-1} Avg. ± 1SE) in two sites in Al-Khalil district from four different treatments, intercropping with three native plant species and a control treatment, in two seasons of investigation. Error bars with the letter (a) are significantly different from the control (Dannett t test, $P < 0.05$).

Table 1: The field crop yields (the annual crops and the native plants crops) and the financial income from the fields.

Site	Season	Intercropping Plant	Annual crop yield (kg/plot)[1]	Annual crop Yield (kg/ha)[1]	Annual crop Income (€/ha)[1,2]	Native plant yield (kg/plot)[1]	Native plants yields (Kg/ha)[1]	Prices (€/kg)	Native Plants Income (€/ha)[1]	Total Income (€/ha)[1]
Site A (Al-Dhahriya)	2004/5	**Control**	87.35±14.23	7941.5±1295.1	4367.8±712.3	-	-		-	4367.8±712.3
		M. syriaca	87.17±14.54	7925.0±1322.4	4358.8±727.3	12.36±3.71	1124.0±336.9	1.12	1258.9±377.3	5617.6±1085.8
		S. fruticosa	79.50±18.39	7226.5±1674.1	3974.6±920.8	6.05±1.19	550.0±108.0	0.92	506.0±99.4	4480.6±1006.8
		S. hierosolymitana	67.93±18.51	6175.0±1681.1	3396.3±924.6	12.14±2.45	1104.0±222.3	1.47	1622.9±326.8	5019.1±1216.8
	2005/6	**Control**	11.15±0.99	1013.6±90.0	833.0±222.7	-	-	-	-	833.0±222.7
		M. syriaca	9.70±2.32	881.7±210.5	723.0±172.6	12.25±3.50	1113.5±318.1	1.47	1636.9±467.7	2359.9±590.8
		S. fruticosa	7.10±2.07	645.4±187.9	529.2±154.1	6.17±1.17	561.3±106.1	1.1	615.0±114.4	1144.2±255.3
		S. hierosolymitana	8.58±1.61	779.5±146.7	639.2±120.3	11.80±2.25	1072.6±204.5	1.27	1359.1±160.1	2001.4±351.2
Site H (Halhul)	2004/5	**Control**	44.23±2.05	4020.0±184.8	2211.0±101.6	-	-	-	-	2211.0±101.6
		M. syriaca	36.92±5.66	3356.7±516.7	1846.2±284.2	11.00±2.17	1000.0±197.3	1.12	1120.0±221.0	2966.2±450.3
		S. fruticosa	39.53±2.68	3593.3±245.4	1976.3±135.0	18.59±3.75	1690.0±341.2	0.92	1554.8±313.9	3531.1±432.0
		S. hierosolymitana	38.17±3.78	3470.0±346.4	1908.5±190.5	8.75±0.78	795.0±71.1	1.47	1168.7±104.6	3077.2±154.2
	2005/6	**Control**	20.07±1.33	1823.9±120.8	1495.6±99.1	-	-	-	-	1495.6±99.1
		M. syriaca	15.07±0.70	1369.6±63.3	1123.0±51.9	6.00±1.00	545.4±91.1	1.47	801.7±133.8	1924.8±181.4
		S. fruticosa	13.07±0.70	1187.8±63.3	974.0±51.9	49.99±15.72	4545.0±1428.6	1.1	4996.4±1571.1	5970.4±1623.0
		S. hierosolymitana	12.87±1.56	1169.6±141.7	959.1±116.2	8.73±0.69	793.9±63.1	1.27	1007.9±80.3	1967.0±172.5

[1] : The values represent the mean ±SE.
[2] : The annual crop of the season 2004/5 was snake cucumber and its average price was 0.55 €/kg, and in the season 2005/6 the annual crop was Bean with an average price of 0.82 €/kg.

The sustainability of the income from intercropping system

The total amount of rain received in the first season (Oct. 2004 to April 2005) was 422 mm at site A and 572 mm at site H. In the second season of investigation (2005/6) the total amount of rainfall was 248 mm at site A and 367 mm at site H. These differences reflect the typical inter-annual variations known for the region.

The total income from all treatments was significantly lower in the second season (the drier season) if compared to the first season. The income from the annual crops alone in the second season was less than the first season in the intercropped plots as well as the control (Table 1, Figure 4). The reduction of the annual crop's income in the second season was 78% to 85% compared to the first season. However, despite lower income was gained in the second season in all treatments the loss of income in the intercropped plots was less than in the control plots. The differences between the two seasons were -78% in the control plots, -58% in the plots of *M. syriaca*, -27% in the plots of *S. fruticosa,* and -59% in the plots of *S. hierosolymitana*. The lower level of income loss in the intercropped plots was related to the stable income gained from the native plants. The income from the native plants was consistent in the two seasons (Figure 5). No significant difference in the income gained from the native plants was related to inter-seasonal variation in the received rainfall. The average income from the native plants in the intercropped plots ranged from 1239 €.ha^{-1} to 1724 €.ha^{-1}.

The effects of intercropping are independent of the mean annual rainfall

The intercropping system provided higher income compared with the not intercropping control in the two sites of different mean annual precipitation. The contribution of the native plants to increase the total income was statistically equal in the two investigated sites. The average proportion of income gained from the native plants was 47.4% of the total income in site A (the drier site), and 52.9% in site H (the semiarid) (Figure 6).

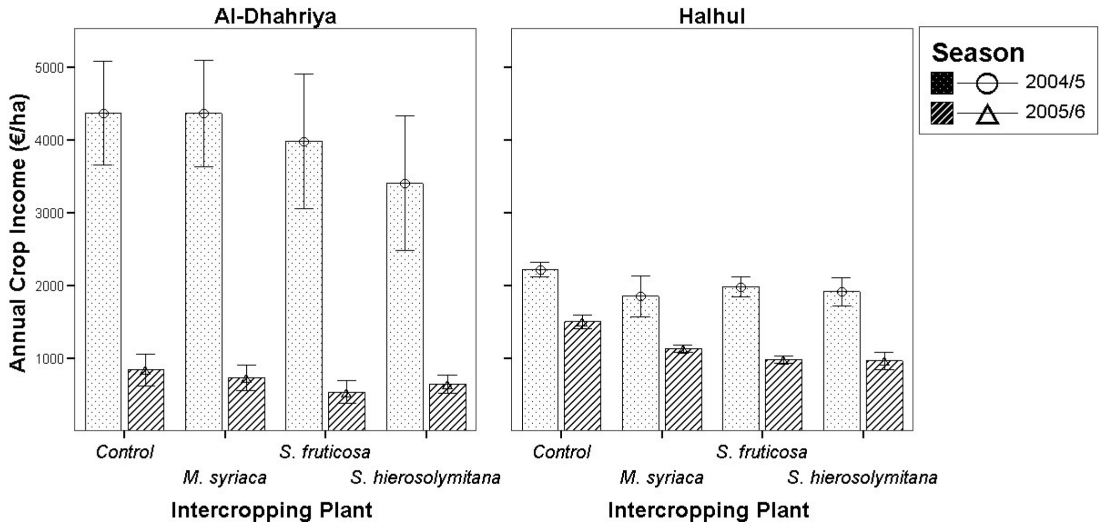

Figure 4: The Change of income from annual crop's of different treatments, intercropping with three native plants (*M. syriaca*, *S. fruticosa* and *S. hierosolymitana*) and a control in two consecutive seasons. Snake cucumber was the annual crop in the 1st season 2004/5 and bean in the 2nd season 2005/6.

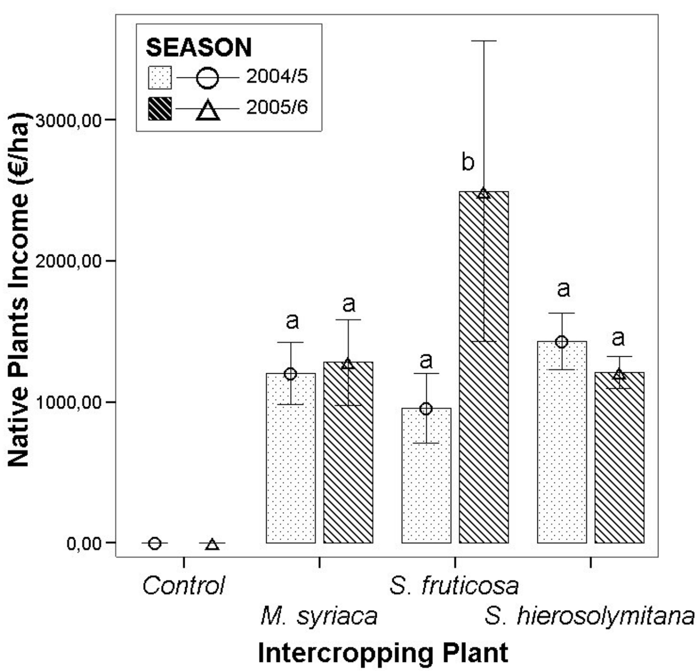

Figure 5: The sustainable income (€/ha, Avg. ± 1SE) from three native plant species intercrops, *M. syriaca*, *S. fruticosa* and *S. hierosolymitana* in two consecutive seasons varying in the amount of rainfall received. Error bars with the same letter for each species are not significantly different.

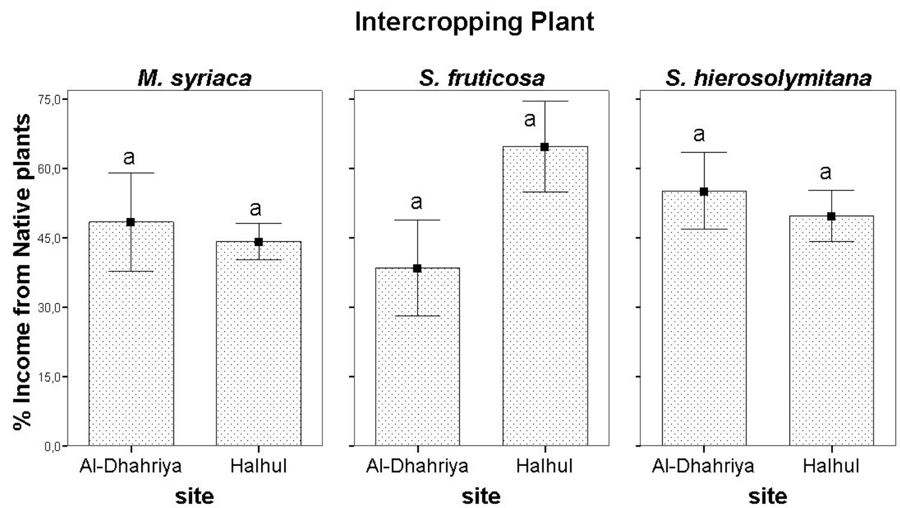

Figure 6: The percentage of income gained from three native perennial plant intercrops (Avg. ± 1SE) under two sites of different mean annual precipitation. Error bars with similar letters in the same species are statistically not different.

Discussion

The annual crop's yield under the intercropping system

This study was conducted as part of a larger experiment designed to develop an environmentally sound management for soil degradation in semiarid-arid areas. This part of the study focuses on the productivity of the system. The aim was not to enhance the productivity of an existing agricultural system, which is the duty of agriculturists. It is difficult to develop environmentally sound agriculture management without some economic loss especially in semiarid regions, especially if some productive area is lost for conservation purposes. However, we aim to proof in this paper that intercropping with native perennial plants as soil conservation strategy is environmentally economic sound management. In addition to the direct economic benefits of the crops, the environmental benefits provided by an agricultural system are also of economic values despite it is difficult to translate these benefits into tangible benefits for the society.

Our results prove that intercropping with useful native perennial plants had minimal effect on the annual vegetable yields. The intercropping with the native perennial plants did not affect negatively the yields of the annual vegetables in the first season in all research sites and treatments. There were insignificant variations in the annual crop's yield in intercropped fields ranged from –6% to 20% compared with control yields. In the second season when only 60% of annual rainfall was received, there was a tendency toward lower amounts of the annual crop's yield in the intercropped fields. The reduction was significant only in site H with reduction of 25% - 35%. This was partly the result of the lower plant population of the annual crops in the intercropping plots. The annual crop plants in the intercropping treatments were 24% less than in the monocrops plots. However, the farmers were compensated for this reduction in the annual crop's yield by the crops of the native perennial plants (see next section). Therefore, the intercropping system with native perennial plants has minimal effects on the annual crops.

The influence of intercropping on the financial income

The intercropping with useful native perennial plants did not result in any reduction in the total income of the intercropped fields. On the contrary, the income gained from marketing the native perennial plants increased the total income. Moreover, the native perennial plants provided income at different seasons during the year, and were the main source for farmer's income in some periods of the year. Some native perennial plant gives the products in winter such as *S. hierosolymitana*, or spring such as *M. syriaca* and *S fruticosa* and some species can be harvested in the late summer such as *S. fruticosa*. While the period of harvesting annual crops in the area of study is usually two months in summer Therefore, the intercropping system with native perennial plants may provide an additional source of income.

These results are in agreement with other studies on other intercropping systems in which increased production was recorded in terms of harvestable products per unit area and the financial income (Ghosh 2004, Yildirim & Guvenc 2005, Alene et al. 2006, Ghosh et al. 2006). Yield advantages from multi-annual species in semi-arid areas may range from 20% to 60% (Ghosh et al., 2006). However, the use of mixture of perennial intercrops and annual crops in our intercropping system increased the total income by 74% - 464% compared to annual monocrop fields. In fact the income gained from some native plants was more the income from the annual crop in the second season such as the income from *S. fruticosa* in at site H, and S hierosolymitana at site A.

Most previous intercropping studies focused only on the productivity, but not on the conservative benefits and sustainability of intercropping systems (Connolly et al., 2001). Therefore, the information in the literatures about the productivity of soil conservation practices in semi-arid area is rare. One of the studies that evaluated a soil management strategy under semi-arid conditions is the proposed system of Kinama et al., (2007). In that study a combined system of crop rotation, perennial hedgerow and grass strips was effective in reducing land degradation in semi-arid area. However that conservation system failed to maintain the crop yields (Kinama et al., 2007). Our proposed intercropping system is simple and proved to be able to reward direct compensation payments that increase the total income. Therefore, the adaptation of this strategy by the local farmers is mostly possible.

The sustainability of the income from intercropping system

The results show that the intercropping system using useful native perennial plants may provide sustainable and reliable income more than the not intercropped fields. A stable income was gained from the native plants in the two repetitive seasons despite the reduced amount of the received rain. By contrast, the annual crops productivity and their financial income were proportional with the amount of rainfall. The rainfall received in the second season was almost 60% of the mean annual rainfall, and the annual crops yields were less in this season than the first season of normal rainfall. The loss of the income from the annual crops was mostly pronounced in the drier site where 248 mm rain was received. The minimum amount of rainfall essential for rain fed annual crops is 300 mm as estimated by Tengberg et al. (1998). Therefore, the amount of rain received was not enough to produce sufficient annual crops and the crop failure is not surprising. The loss of income gained from the annual crops at site H was less than at site A. The difference may be explained as the received rainfall at this site (60% of the long-term average) was enough to allow crop growth. In addition, it is frequently occur at this site that the ground and the planted crops are moistened at the nights of summer by dew. This phenomenon may provide minimum moisture enough for the growth of summer crops. These results reflect the normal situation of rain fed annual crop agriculture in the study area and other semi-arid regions. The productivity of rain fed agriculture in such regions is known to be dependent on the amount of rainfall which varies from year to year. Drought of unpredictable intensity and duration may frequently occur and result in low and unstable crop productivity in semiarid-arid regions. Therefore, farmers of annual monocrops in these areas may suffer from economic losses due to yield failure.

However, these economic losses could be reduced and/or compensated by practicing the intercropping with native perennial plants. The loss of income in the intercropped fields in the drier season was apparently less than the loss in the monocrop treatment. The native perennial plants provide an essential source of income in dry seasons. The native perennial plants added 12% - 43% of the total income in the intercropped fields in the wet season and increased to 57% - 86% of the total income in the drier season. The native perennial plants are adapted to grow in the wild in shallow soils and between rocks in the semiarid areas. Therefore, they can succeed to produce sufficient vegetation in all seasons regardless the amount of rain received. The more stable income of the intercropping system was achieved by using only 10% of the field area for native plants intercrops. We supposed that the economic loss will be reduced more if the area of the native perennial plants increased. Therefore, sustainable and reliable income could be gained from the native perennial plants intercrops in the semiarid-arid regions and the native perennial plants may provide the substitute income for farmers in dry seasons when most of the annual vegetable crops fail.

The effects of intercropping are independent of the mean annual rainfall

The advantages of intercropping with native perennial plants were consistent in the two investigated sites. The attribution of marketable native perennial plants to increase the field income was not affected by the mean annual precipitation of the different sites. The incomes from the native perennial plants were almost the same in the two sites for all the intercropped species. These results show that intercropping with native perennial plants may be an environmentally sound management under the current climate conditions of semi-arid and arid of Palestine. We suggest also that this management may be suitable for other semi-arid regions. Further, the stability of the economic income from the intercropping system under different annual rain fall suggests this management to be persistent also under the predicted climate changes. This leads us to recommend this management as a mitigation strategy to cope with the effects of the expected global climatic change.

In addition to the sustainable income from the domesticated native plants these plants were observed to retain the quality of the original wild populations. This was observed by the farmers in the surrounding area of our experiment and from the locals who consume some of the produced native plants. Some of the locals spontaneously expressed their appreciation of the taste of the domesticated native plants after consuming some of them. This observation may support the willingness of locals (farmers and their family counterparts) to establish planting native plants and to buy them instead of collecting them from the wild. We already observed some farmers in the surrounding area of our experimental fields began to cultivate these native plants in their fields after they noticed the success of the native plants in our experimental fields despite that they did not follow our design. Therefore, we expect that it will be easy to extend the intercropping system with marketable native perennial plants as sustainable practice from the socio-economic view. If the intercropping with native perennial plants is adapted at high scale, it is expected to reduce the collecting pressure on native plant populations and consequently support biodiversity conservation of threatened species.

It is apparent from the results that intercropping annual crops with useful native perennial plants is simple and economic mechanism. The native perennial plants are planted once with relatively very low cost. However, the advantages of this system are permanent in terms of sustainable economic and conservation. The intercropping system using useful native perennial plants can minimize the risk of crop loss in dry season, stabilize the yields over the long term, and promotes biodiversity by decreasing the pressure on the wild populations of the intercropping species. Furthermore, intercropping with native perennial plants is effective in soil protection and water efficiency enhancement. Therefore, the sustainability of this practice is obvious especially in semiarid regions.

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Overall Conclusions

1. The annual crop production fields which lack a permanent plant cover suffer from soil degradation represented by water, soil and nutrient loses.
2. Intercropping with useful native perennial plants is effective in reducing unproductive water loss by runoff and in reducing soil loss by erosion.
3. Intercropping enhances infiltration and retention of water in soils after rainstorms. This observation along with the reduction of surface runoff suggest the possibility of intercropping with native perennial plants to enhance water efficiency and may contribute to some extent in maintaining ground water resources in high scale applications.
4. Intercropping with native perennial plants maintains the soil organic matter content in the soils by reducing soil and nutrient loss and potentially increases soil organic matter by adding plant residues to the soil on the long-term. Therefore, the results generally support the suggestion that a feature of sustainable agriculture is the recycling of on-farm crop residues to maintain or even improve soil fertility.
5. Intercropping with native perennial plants enhanced soil microbial activity which demonstrates the potential for human alteration of aboveground plant cover and land-uses may affect soil microorganisms and possibly the processes they mediate.
6. The correlation coefficients between microbial activity and soil organic matter content points to the close relationship between the organic matter content of the soil and the development and activity of the microbial populations existing.
7. The advantages of intercropping with native perennial plants in reducing runoff and erosion and improving soil quality are consistent in semiarid and arid regions. This assumes that this agricultural scheme is a suitable mitigation strategy for land degradation in semiarid and arid regions, and suggests intercropping as a coping strategy for the future suspected climate condition mainly the reduction in mean annual precipitation.

8. The effectivity of intercropping in soil conservation is not species specific. However, differences in the magnitude of the efficiency may exist between different species. Therefore, different alternative species of native plants especially the endangered species may be used as intercrops to conserve soil resources. This allows biodiversity conservation to benefit from this agricultural technique.
9. Intercropping with native perennial plants had minimal negative effect on the yield of the annual crops and may increase the total financial income of the intercropped fields.
10. A more sustainable and reliable income may be gained from intercropping system that use native plants intercrops compared to that from not monospecies annual fields. Therefore, the risk of low yields or crop failure associated with the traditional rain fed production system due to frequent dry years may be minimized by intercropping with marketable native perennial plants.

Appendix A

Data Tables

Table 1: The Runoff and erosion results under intercropping system using native perennial plants intercrops in the site and two seasons.

Site	Season	Treatment/ Intercropping Species	Runoff Volume (L/ha)	Water loss (% of Reinfall)	% runoff reduction	Soil Erosion (kg/ha)	% Erosion reduction
Site A	2004/5	Control	287933.75±15051.55	6.82±0.36		5625.36±462.08	
		M. syriaca	189153.13±12294.27	4.4823±0.29	34.31±4.27	3094.64±133.51	44.99±2.37
		S. fruticosa	168387.50±13470.31	3.9902±0.32	41.52±4.68	1816.97±93.54	67.70±1.66
		S. hierosolymitana	169897.50±8581.70	4.0260±0.20	40.99±2.98	2092.60±483.12	62.80±8.59
	2005/6	Control	185375.00±18135.06	7.475±0.73		1919.88±315.45	
		M. syriaca	67181.63±26645.27	2.709±1.07	63.76±14.37	380.88±173.28	80.16±9.03
		S. fruticosa	24515.40±8994.69	0.989±0.36	86.78±4.85	124.30±39.74	93.53±2.07
		S. hierosolymitana	21045.13±9902.36	0.849±0.40	88.65±5.34	133.55±60.96	93.04±3.18
Site H	2004/5	Control	223100.00±11698.01	3.900±0.20		3158.67±409.13	
		M. syriaca	142833.33±8823.89	2.497±0.15	35.98±3.96	1327.54±200.99	57.97±6.36
		S. fruticosa	138466.67±15663.69	2.421±0.27	37.94±7.02	1728.10±301.66	45.29±9.55
		S. hierosolymitana	132900.00±15855.91	2.323±0.28	40.43±7.11	1543.92±369.11	51.12±11.69
	2005/6	Control	30172.83±2624.93	0.8221±0.07		319.83±92.71	
		M. syriaca	14605.70±2046.52	0.398±0.06	51.59±6.78	82.23±13.20	74.29±4.13
		S. fruticosa	12248.47±3291.55	0.334±0.09	59.41±10.91	62.17±13.41	80.56±4.19
		S. hierosolymitana	14614.97±2867.71	0.398±0.08	51.56±9.50	74.77±10.29	76.62±3.22

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Table 2: Soil organic matter (SOM) content in the experimental fields before the intercropping experiment and after two years of intercropping.

Site	Field	Sampling Time	Treatment / Intercropping Plant	Sampling position	SOM w/w%*	%OM change in 2 yr
Site A	Field 1	Before Intercropping	Control		2.506±0.250	
			M. syriaca		3.578±0.177	
			S. fruticosa		2.373±0.197	
			S. hierosolymitana		3.253±0.446	
		After Intercropping	Control		1.683±0.062	-32.9
			M. syriaca	Under strips	4.397±0.268	22.9
				Between strips	3.585±0.719	0.2
				Total	3.991±0.388	11.6±11.4
			S. fruticosa	Under strips	4.377±0.346	84.5
				Between strips	3.537±0.224	91.0
				Total	3.957±0.263	87.8±3.3
			S. hierosolymitana	Under strips	3.989±0.104	22.6
				Between strips	3.926±0.251	20.7
				Total	3.957±0.122	21.7±1.0
	Field 2	Before Intercropping	Control		2.632±0.131	
			M. syriaca		2.465±0.108	
			S. fruticosa		2.137±0.069	
			S. hierosolymitana		2.727±0.344	
		After Intercropping	Control		2.307±0.184	-12.4
			M. syriaca	Under strips	3.691±0.085	49.8
				Between strips	3.282±0.292	33.2
				Total	3.486±0.164	41.5±8.3
			S. fruticosa	Under strips	3.627±0.103	69.7
				Between strips	3.114±0.118	45.7
				Total	3.370±0.134	57.7±12.0
			S. hierosolymitana	Under strips	3.840±0.154	40.8
				Between strips	3.398±0.047	24.6
				Total	3.619±0.122	32.7±8.1
	Field 3	Before Intercropping	Control		2.554±0.271	
			M. syriaca		2.469±0.231	
			S. fruticosa		2.358±0.118	
			S. hierosolymitana		2.218±0.202	
		After Intercropping	Control		1.661±0.119	-35.0
			M. syriaca	Under strips	2.903±0.334	17.6
				Between strips	2.477±0.228	0.4
				Total	2.690±0.204	9.0±8.6
			S. fruticosa	Under strips	2.394±0.129	1.5
				Between strips	2.235±0.201	5.2
				Total	2.315±0.112	-1.9±3.4
			S. hierosolymitana	Under strips	3.981±0.209	79.5
				Between strips	2.722±0.063	22.7
				Total	3.352±0.298	51.1±28.4
Site H	**Field 1**	Before Intercropping	Control		2.644±0.110	
			M. syriaca		2.662±0.277	

Cont.

Table 2: cont.

Site	Field	Sampling Time	Treatment / Intercropping Plant	Sampling position	SOM w/w%*	%OM change in 2 yr
			S. fruticosa		2.550±0.299	
			S. hierosolymitana		2.218±0.202	
		After Intercropping	Control		1.624±0.053	-38.6
			M. syriaca	Under strips	3.106±0.537	16.7
				Between strips	2.072±0.190	-22.2
				Total	2.589±0.344	-2.8±19.5
			S. fruticosa	Under strips	2.704±0.271	6.0
				Between strips	1.481±0.141	-41.9
				Total	2.093±0.306	-18.0±24.0
			S. hierosolymitana	Under strips	3.102±0.538	39.8
				Between strips	2.342±0.134	56.0
				Total	2.722±0.301	47.9±8.1
	Field 2	Before Intercropping	Control		2.363±0.221	
			M. syriaca		2.158±0.508	
			S. fruticosa		3.179±1.285	
			S. hierosolymitana		2.038±0.180	
		After Intercropping	Control		2.433±0.104	3.0
			M. syriaca	Under strips	2.787±0.201	29.1
				Between strips	2.548±0.142	18.1
				Total	2.668±0.122	23.6±5.5
			S. fruticosa	Under strips	3.069±0.069	-3.5
				Between strips	2.863±0.089	-9.9
				Total	2.966±0.068	-6.7±3.2
			S. hierosolymitana	Under strips	2.961±0.175	45.3
				Between strips	2.525±0.364	23.9
				Total	2.743±0.205	34.6±10.7
	Field 3	Before Intercropping	Control		2.642±0.061	
			M. syriaca		3.120±0.461	
			S. fruticosa		3.110±0.461	
			S. hierosolymitana		3.803±0.553	
		After Intercropping	Control		1.910±0.129	-27.7
			M. syriaca	Under strips	2.923±0.192	-6.3
				Between strips	2.728±0.193	-12.6
				Total	2.826±0.129	-9.5±3.2
			S. fruticosa	Under strips	4.293±0.270	38.0
				Between strips	4.009±0.349	28.9
				Total	4.151±0.207	33.5±4.6
			S. hierosolymitana	Under strips	4.270±0.417	12.3
				Between strips	4.261±0.500	12.0
				Total	4.265±0.291	12.2±0.2

*: Values represent means ±SE.

Appendix B
ANOVA table

1- Chapter one:

Table 1: Results of ANOVA for the dependent variable runoff (L/ha) with the independent variables intercropping (*M. syriaca*, *S. fruticosa*, *S. hierosolymitana* and a control), sites (Al-Dhahriya and Halhul) and seasons (2004/5 and 2005/6).

Independent variables	D.f	F	Sig.
Site	1	51.298	<0.001
Treatment	3	43.209	<0.001
Season	1	367.577	<0.001
Site * Treatment	3	8.873	<0.001
Site * Season	1	0.734	0.397
Treatment * Season	3	0.453	0.716
Site * Treatment * Season	3	3.788	0.018

Table 2: Results of ANOVA for the dependent variable soil erosion (kg/ha) with the independent variables intercropping (*M. syriaca*, *S. fruticosa*, *S. hierosolymitana* and a control), sites (Al-Dhahriya and Halhul) and seasons (2004/5 and 2005/6).

Independent variables	Df	F	Sig.
Site	1	37.701	<0.001
Treatment	3	39.048	<0.001
Season	1	237.356	<0.001
Site * Treatment	3	9.876	<0.001
Site * Season	1	6.457	0.015
Treatment * Season	3	7.321	0.001
Site * Treatment * Season	3	1.156	0.339

Table 3: Results of ANOVA for the dependent variable soil moisture content (w/w %) with the independent variables intercropping (*M. syriaca*, *S. fruticosa*, *S. hierosolymitana* and a control), sites (Al-Dhahriya and Halhul) and seasons (2004/5 and 2005/6).

Independent variables	Df	F	Sig.
Site	1	0.563	0.457
Treatment	3	4.587	0.007
Season	1	0.143	0.707
Site * Treatment	3	0.958	0.420
Site * Season	1	0.031	0.862
Treatment * Season	3	0.200	0.896
Site * Treatment * Season	3	0.089	0.966

Table 4: Results of ANOVA for the dependent variable %reduction of runoff and % reduction of erosion with the independent variables intercropping (*M. syriaca*, *S. fruticosa* and *S. hierosolymitana*), sites (Al-Dhahriya and Halhul) and seasons (2004/5 and 2005/6).

Dependent Variable	Independent variables	D.f	F	Sig.
% runoff reduction	Site	1	8.464	0.007
	Treatment	2	2.004	0.154
	Season	1	39.367	<0.001
	Site * Treatment	2	0.845	0.440
	Site * Season	1	7.437	0.011
	Treatment * Season	2	0.484	0.622
	Site * Treatment * Season	2	0.549	0.583
% Soil erosion reduction	Site	1	6.106	0.020
	Treatment	2	1.541	0.232
	Season	1	54.468	<0.001
	Site * Treatment	2	3.010	0.065
	Site * Season	1	0.385	0.540
	Treatment * Season	2	0.130	0.878
	Site * Treatment * Season	2	1.131	0.337

2- Chapter two:

Table 1: Results of ANOVA for the dependent variable soil organic matter (SOM) with the independent variables treatments (4) (intercropping *with M. syriaca*, *S. fruticosa*, *S. hierosolymitana* and a control), replicate fields (3), and sites (2) (Al-Dhahriya and Halhul) at the first days of the intercropping experiment.

Independent variables	Df	F	Sig.
Site	1	0.412	0.524
Field	2	1.556	0.221
Treatment	3	0.287	0.835
Site * Field	2	4.861	0.012
Site * Treatment	3	1.426	0.247
Field * Treatment	6	0.756	0.608

Site * Field * Treatment	6	1.586	0.172

Table 2: Results of ANOVAs for the dependent variable soil organic matter (SOM) with the independent variables three intercropping treatments (*M. syriaca*, *S. fruticosa*, *S. hierosolymitana*), three sampling positions (under native plant strip, between strips and control) and two sites (A: Al-Dhahriya and H: Halhul) after two years intercropping.

	Independent variables	Df	F	Sig.
All Data	Site	1	4.849	.029
	Treatment	2	2.174	.117
	Position	2	67.967	<.001
	Site * Treatment	2	.945	.391
	Site * Position	2	2.532	.083
	Treatment * Position	4	.547	.701
	Site * Treatment * Position	4	.274	.894
Site A	Treatment	2	1.346	.267
	Position	2	55.834	<.001
	Treatment * Position	4	.346	.846
Site H	Treatment	2	1.721	.186
	Position	2	19.733	<.001
	Treatment * Position	4	.459	.765

Table 3: Results of ANOVA for the dependent variable soil organic matter (SOM) with the independent variables four treatments (intercropping with *M. syriaca*, *S. fruticosa* and *S. hierosolymitana* and a control), two sampling times (before intercropping and after two years of intercropping) and two sites (Al-Dhahriya and Halhul).

Independent variables	Df	F	Sig.
Site	1	1.055	0.305
Treatment	3	13.229	<0.001
Time	1	5.232	0.023
Site * Treatment	3	2.535	0.057
Site * Time	1	4.245	0.040
Treatment * Time	3	8.914	<0.001
Site * Treatment * Time	3	0.966	0.409

Table 4: Results of ANOVAs for the dependent variable % SOM change over two years, with independent variables three treatments, two sampling positions (under and between strips) and two sites (Al-Dhahriya and Halhul)

Independent variables	Df	F	Sig.
Site	1	5.637	.026
Treatment	2	1.797	.187
Position	1	2.883	.102
Site * Treatment	2	1.760	.194
Site * Position	1	.034	.855
Treatment * Position	2	.032	.969
Site * Treatment * Position	2	.332	.721

3- Chapter three

Table 1: Results of ANOVA for the dependent variable microbial activity (µg TTF. g^{-1} soil. 24 h^{-1}) with the independent variables; three treatments (intercropping with *M. syriaca*, *S. fruticosa*, *and S. hierosolymitana*), three sampling positions (under native plant strip, between strips and control) and two sites (Al-Dhahriya and Halhul).

Independent Variables	Df	F	Sig
Site	1	17.862	<0.001
Treatment	2	3.809	0.024
Position	2	51.026	<0.001
Site * Treatment	2	5.534	0.005
Site * Position	2	0.198	0.820
Treatment * Position	4	1.977	0.101
Site * Treatment * Position	4	2.167	0.076

Table 2: Results of ANOVA for the dependent variable the relative efficiency (Treatment: Control Ratio) with the independent variables three treatments (*M. syriaca*, *S. fruticosa*, *S. hierosolymitana*) and two sites (Al-Dhahriya and Halhul).

Independent Variable	Df	F	Sig.
Site	1	1.460	0.236
Treatment	2	1.158	0.328
Site * Treatment	2	1.703	0.199

4- Chapter four:

Table 1: Results of ANOVA for annual crop yield (Kg.ha^{-1}) in four treatments (intercropping with *M. syriaca*, *S. fruticosa*, *S. hierosolymitana* and a control) in two sites (Al-Dhahriya and Halhul) and in two seasons (2004/5 and 2005/6).

Independent Variables	Df	F	Sig.
Site	1	12.025	0.001
Season	1	91.964	<0.001
Treatment	3	0.559	0.645
Site * Season	1	22.051	<0.001
Site * Treatment	3	0.158	0.924
Season * Treatment	3	0.139	0.936
Site * Season * Treatment	3	0.224	0.879

Table 2: Results of ANOVA for Total Income of the field (€.ha^{-1}) in four treatments (intercropping with *M. syriaca*, *S. fruticosa*, *S. hierosolymitana* and a control) in two sites (Al-Dhahriya and Halhul) and in two seasons (2004/5 and 2005/6).

Independent Variables	Df	F	Sig.
Site	1	1.258	0.269
Season	1	29.870	<0.001
Treatment	3	3.371	0.028
Site * Season	1	17.199	<0.001
Site * Treatment	3	4.500	0.008
Season * Treatment	3	1.419	0.251
Site * Season * Treatment	3	1.456	0.241

Table 3: Results of ANOVA for income from the native plants (€.ha^{-1}) in three intercropping treatments (*M. syriaca*, *S. fruticosa* and *S. hierosolymitana*) in two seasons (2004/5 and 2005/6).

Independent Variables	Df	F	Sig.
Season	1	1.397	0.245
Treatment	2	0.581	0.564
Season * Treatment	2	1.897	0.165

Table 4: Results of ANOVA for the % income from the native plants in three intercropping treatments (*M. syriaca*, *S. fruticosa* and *S. hierosolymitana*) in two sites (Al-Dhahriya and Halhul).

Independent Variables	Df	F	Sig.
Site	1	0.548	0.464
Treatment	2	0.264	0.769
Site * Treatment	2	1.932	0.160

Curriclum Vitae

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Publications

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