OPTIMIZING BIOLOGICAL NITROGEN FIXATION AND EVALUATING IRAQI EXTENSION EDUCATION

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OPTIMIZING BIOLOGICAL NITROGEN FIXATION AND EVALUATING IRAQI EXTENSION EDUCATION

Abstract

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An alternative to synthetic nitrogen (N) fertilizer is the use of legumes with rhizobia bacterial symbionts that fix soil atmospheric N into plant-available forms. In this study we evaluated biological nitrogen fixation by strains of *Rhizobium leguminosarum* associated with breeding lines of peas (*Pisum sativum* L.) and lentils (*Lens culinaris* Medik.). We also isolated *Mesorhizobium ciceri* from Middle Eastern soils and compared interactions of Middle Eastern and commercial strains of *M. ciceri* with U.S. and Middle Eastern varieties of chickpeas (*Cicer arietinum* L.). In all trials, plant varieties had a greater effect in determining the proportion of plant N provided by fixation (PNF) than did rhizobial strains. Within each legume species, the greatest PNF was provided by Eston and Meritt lentils (80%), Shawnee and Bohatyr peas (91%), and Sierra chickpeas (87%). Our results suggest that crop breeding should be a fruitful avenue for increasing biological N fixation.

Since science should utilize public outreach and serve society, extension education lectures were taught to Iraqis whose access to N fertilizers is limited. The recent war and instability have significantly impacted the country's agricultural production and knowledge support systems. To support revitalization of the Iraqi agricultural system, the USDA funded a consortium of five U.S. universities to provide training to agricultural extension personnel from

Iraq. Surveys of the trainees guided training agendas and enhanced our understanding of extension, cropping systems, and information needs in Iraq. Both basic and advanced agricultural resources are lacking in Iraq, especially in plant protection, food and vegetable production, machinery use and repair, row crop production, and soil fertility. There is great demand for training, technology, basic farm equipment, seed, and fertilizers. In addition further training is needed in utilizing on-farm resources to efficiently produce crops while reversing the physical and chemical damage to Iraq's soil and other natural resources.

Biological N fixation could provide significantly more N to cropping systems, both in developing countries where fertilizers are limited and developed countries where fertilizers are available but expensive. This work improves our understanding of both research and extension opportunities to increase use of biological N fixation.

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DEDICATION

I dedicate my dissertation work to my sister Admitta who contributed since my childhood to my education, provided financial and moral support, and encouraged in me the love to help other people.

CHAPTER ONE

GENERAL INTRODUCTION

The world population is projected to reach 8.3 billion by 2025. The global demand for food will rise and perhaps change alongside this population growth. The increase will mostly occur in developing countries, many of which suffer from limited access to fertilizers (Sylvia et al., 2005). Sustainable agriculture education and sustainable nitrogen (N) fertility sources are needed to fulfill crop requirements and increase food production in these countries. The work in this dissertation aims to address both of these needs through research on N fixation and international extension.

NITROGEN FIXATION RESEARCH

The recent world fertilizer N demand is 127, 820 thousand tonnes in 2008. The Haber Bosch process of industrial N fixation globally supplies 131, 106 thousand tonnes (FAO, 2008) and requires tremendous natural gas energy (IFA, 2006). Nitrogen fertilizer costs have more than tripled over the last three years, increasing crop production costs by billion of dollars (Fertecon, NYMEX, 2008). The forecast predict the rate of N to continue increasing by 1.4% until 2012 (FAO, 2008). There is a worsening limitation in natural gas for the Haber-Bosch process in some regions including the U.S. Also there is a huge demand for organic N sources for organic crops. Thus, even in industrialized nations there is need for cheaper, more sustainable alternative N sources.

Biological N fixation (BNF) is based on plant-microbe interactions. Rhizobia can be free living in the soil or in symbiosis with the crop. Symbiotic legume-rhizobial bacteria interactions have been estimated to contribute to 91-163 million tonnes N per year and 65% of this is used in agriculture (Burris and Roberts, 1993). Biological N fixation efficiency depends on the type of rhizobia strain, crop variety, and interactions between specific strains and crop varieties. In a study by Hafeez et al. (2000), N_2 fixation varied among rhizobial strains by 42% and among lentil varieties by 81%. The total proportion of plant N derived from N_2 fixation for different cultivar–strain combinations ranged from 3-52%. This indicates the importance of selecting cultivars for high N_2 fixation in addition to the most efficient rhizobial strains.

Grain legumes fix approximately 20-100 lb N/year and use almost that entire amount of fixed N in grain production (Evans, 1989). Western extension publications tend to allow only 10-25 lb N credit for previous grain legume crops. At least part of the cause for this low level of N fixation and N credit from grain legumes is the fact that these legumes have been bred for yield but have not been bred for N fixation (McPhee, 2006). In addition, inoculant companies have focused their strain formulations not on the ability to fix large amounts of N, but on the ability to associate with many different legume varieties (Novozyme, 2006).

The greatest benefit to producers will come in the future when this research is used by legume crop breeders to select varieties that better interact with rhizobia to increase the efficiency of N_2 fixation.

EXTENSION FOR BNF AND INTERNATIONAL SUSTAINABILITY

Whenever possible, research should be paired with extension efforts to improve the agricultural natural resources and increase the efficiency of their use and should set the stage for future research. Despite decades of research and extension, many producers lack knowledge of proper legume management. For instance some are applying N fertilizer to their legume crops which inhibits nodulation and BNF. It is clear that extension outreach is needed to clarify the basic principles of BNF management. Several classes in improving N fixation and in designing crop rotation were taught in extension field days in central Washington and for Iraqi extension agents.

Iraq before the sanctions in 1992 used to have a well-developed agricultural system with three companies averaging 80,000 tons of seed sales per year, sufficient supplies of nitrogen and phosphorus fertilizers, and modern machinery (Bishay, 2003). Nowadays, economic and social conditions in Iraq have been unstable. Iraq has suffered from limited food and drinking water, limited electricity, massive unemployment, inflation, a national debt that ballooned to nearly $400 billion, destruction of infrastructure, and an agricultural system in disarray (Looney, 2003). As a result of the multiple hardships, many Iraqis have left the country, taking their resources and talents, and further weakening the country.

The European Union and USA both have instituted programs to help Iraq rebuild its agricultural system. The Iraq Agricultural Extension Revitalizing Program (IAER) provides training to agricultural extension personnel from Iraq. Washington State University (WSU) was involved in five training sessions focusing in dryland cropping systems. If successful, the IAER program will change the Iraqi agricultural system by encouraging cooperation between the agricultural colleges of Iraq, the agricultural extension agencies, farming associations, and rural communities.

OBJECTIVES

My research objectives are the following: i) identify strains of *Rhizobium leguminosarum* and breeding lines of peas and lentils that exhibit high BNF (chapter 2), ii) increase the number of *Mesorhizobium ciceri* strains by isolating *M. ciceri* from Middle Eastern soils and determine strains of *M. ciceri* and varieties of chickpeas with high BNF (chapter 3), iii) describe and evaluate recent extension education for dryland cropping systems in Iraq that enable designing future training sessions (chapter 4), and iv) assess the agricultural status and the role of women in agriculture in Iraq to improve the current agricultural situation (chapter 5) . Both breeding legumes and commercial strain selection can be improved with the information yielded from this study. In addition, these findings will be of assistance in formulation of cropping systems that are more dependent on the use of on-farm resources such as areas that have limited access to fertility inputs as in Iraq.

LITERATURE CITED

Bishay, F. 2003. Towards Sustainable Agricultural Development in Iraq. Food and Agriculture Organization of The United Nations. Rome. http://www.fao.org/docrep/006/Y9870E/y9870e00.HTM. Rome.

Burris, R.H., and G.P. Roberts. 1993. Biological nitrogen fixation. Annual Review of Nutrition. 13: 317-335.

Evans, J., G.E. O'Connor, G.L. Turner, D.R. Coventry, N. Fettell, J. Mahoney, E.L. Armstrong, and D.N. Walsgott. 1989. N_2 fixation and its value to soil N increase in lupin, field pea and other legumes in south-eastern Australia. Aust. J. Ag. Res. 40 (4): 791 – 805.

FAO. 2008. Current world fertilizer and trends and outlook to 2011-2012. Available at: ftp://ftp.fao.org/agl/agll/docs/cwfto11.pdfFAO, Rome.

Fertecon NYMEX. 2008. Nitrogen. http://www.potashcorp.com.

Hafeez, F. Y., N.H. Shah, and K.A. Malik. 2000. Field evaluation of lentil cultivars inoculated with *Rhizobium leguminosarum bv. viciae* strains for nitrogen fixation using nitrogen-15 isotope dilution. Biology and Fertility of Soils. 31:65-69.

IFA (International Fertilizer Industry Association). 2006. Nitrogen fertilizer nutrient consumption. http://www.fertilizer.org/ifa/statistics/indicators/tablen.asp.

Looney, R. 2003. Bean counting in Baghdad: Debt, reparations, reconstruction, and resources. Middle East Review of International Affairs (MERIA) Journal. 7:60-72. http://meria.idc.ac.il/journal/2003/issue3/looney.pdf.

McPhee, K. 2006. Personal communication.

Novozyme Biologicals, Inc. 2006. Personal communication.

Sylvia, D.M., J.J. Fuhrmann, P.G. Hartel, and D.A. Zuberer. 2005. *Principles and Applications of Soil Microbiology*. Second Edition. New Jersey. USA.

CHAPTER TWO

NITROGEN FIXATION IN PEA AND LENTIL VARIETIES WITH DIFFERENT RHIZOBIAL STRAINS

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ABSTRACT

Nitrogen fixation in legumes requires the symbiotic interaction of plants with rhizobia bacteria. Increasing the quantity and efficiency of the N fixating process could both increase crop productivity and reduce fertilizer costs. Optimizing this symbiosis may require improving the selection of the host and rhizobia participating in this interaction. In this study five varieties of lentils and five varieties of peas were tested with 13 to 15 commercial strains of *Rhizobium leguminoserum* bv. *viciae* to identify more efficient bacterial strains for inoculation and more sustainable plant varieties with high potential to be used in new breeding lines. Peas and lentils were inoculated with individual strains and grown in growth chambers for 6 weeks. Plants received 2 mM $(^{15}NH_4)_2\ SO_4$ (5% A) to provide supplemental starter N and allow the measurement of N fixation by isotope dilution. Below and above ground biomass, numbers of nodules, and the proportion of plant N provided by fixation were determined. The number of nodules was highly correlated to the proportion of N fixed (PNF). This implies that one of the strategy for enhancing crop N fixation is developing varieties that have higher infection rates.

Total N fixation in lentils was significantly influenced by both crop variety and rhizobial strain. Eston and Meritt varieties fixed the highest percentage of total plant N at 80.8% and 80.5% respectively. In peas fixed N reached 91.3 % and 90.5% in Shawnee and Bohatyr respectively, and different strains all produced similar levels of PNF. Legume varieties had a significant influence on PNF suggesting that crop breeding to support higher rates of N fixation may be possible.

INTRODUCTION

Over 12 million tons of fertilizer N are applied annually in North America (IFA, 2006). The price of these fertilizers has more than tripled over the last three years due to an increase in natural gas price (Fertecon, NYMEX, 2008). Several billion dollars in producer profit has been lost to these price increases (IFA, 2006). In 1975, nearly half of the N needed in agriculture, 44 to 66 million tons annually, was provided through legume-rhizobial symbiosis (Burns and Hardy, 1975). In 2009, synthetic N provides four times as much N as BNF on a global basis (Nielsen, 2005). Biological N fixation (BNF) presents economic, environmental, and agronomic benefits and could be used to a larger degree as an alternative to synthetic fertilizers (Silva and Uchida, 2000).

Biological nitrogen fixation may be increased by repeated rhizobial inoculation (Vessey, 2004; Athar, 1998)**,** more effective strains (Hynes et al. 2005), or co-inoculation with “helper organisms” (Dileep Kumar et al., 2001). The efficiency of N_2 fixation is not only dependent on the selection of the most robust strains of rhizobia but is also related to crop varieties and the interactions of specific strains with specific varieties. Hafeez et al. (2000), found 42% variability in N_2 fixation among various rhizobial strains and 81% variability among different varieties of lentil (*Lens culinaris* Medik.). In addition they found that the total proportion of plant N derived from N_2 fixation for different cultivar –strain combinations was 3-52%. This demonstrates that it is important to select cultivars for N_2 fixation efficiency in addition to the most productive rhizobial strains. Additionally, a strong cultivar x strain interaction on BNF has been reported in soybeans (*Glycine max* Linn.Merr.) (Israel, 1981), beans (*Phaseolus vulgaris*) (Valverde and Otabbong, 1997), and peanuts (*Arachis hypoge*) (Wynne et al., 1980). An evaluation of BNF by rhizobial strains paired with several legume varieties would be beneficial for identifying both superior strains for BNF and legume breeding lines more likely to support greater BNF.

Legume grains or pulses are grown worldwide as a source of high-quality protein and BNF. Peas are grown on over 10 million ha around the world (Schatz, 2002) with an average N fixation of 86 kg/ha (Soon and Arshad, 2004). Lentils provide approximately 22 kg/ha N into the soil (Mcnew and Bixley, 2001). World lentil production was over 4 million tons harvested from 4.1 million hectares in 2005 (CGIAR, 2005). Improving N fixation in these major food crops may both increase plant-based protein for human consumption and reduce synthetic N fertilizer.

The objective of this research was to determine the efficiency of nodulation and biological N fixation of five varieties of lentils and peas (*Pisum sativum* L.) with different commercial inoculant strains of *Rhizobium leguminosarum* bv. *viciae*.

MATERIALS AND METHODS

Rhizobia strains

Strains of *Rhizobium leguminosarum* bv. *viciae* were obtained from three companies in the U.S. and Canada. Novozymes Biologicals provided 9 commercial strains for both lentils and peas designated as NB-R1 to NB-R9. Becker Underwood supplied five strains of which three interact with peas (BU-R1, BU-R2, BU-R3), one with lentil (BU-R5), and one with both lentils and peas (BU-R4). Four strains were supplied by EMD, two for peas (EMD-R1, EMD-R2) and two for lentils (EMD-R3, EMD-R4). Strains were stored in glycerol and yeast extract broth at -80°C (Novozyme Biologicals, 2006). Five days before seed inoculation, strains were grown in 1 x yeast extract broth at 22°C on an orbital shaker (Novozyme Biologicals, 2006). Cells were collected by centrifugation at 1000 g for 4 minutes. An optical density (A= 0.3) corresponding to a bacterial count of 10^6-10^7 depending on strain, was determined using a spectrophotometer at 640 nm wavelength. Inocula were diluted to 10^5-10^6 cfu per ml for efficient nodulation (Osorio Vega, 2007).

Legumes

Five varieties of peas (cvs. Lifter, Bohatyr, Delta, Shawnee, Medora) and lentils (cvs. Eston, Meritt, Pennel, Pardina, Riveland) were supplied by the USDA-ARS Grain Legume Genetics-Physiology Research Unit, Pullman, WA. Varieties were selected based on their yield, potential use as breeding lines, and the availability of genetic maps for some varieties. Wheat was used as a control in the experiment as described by Knowles and Blackburn (1995), and Smith et al. (1987).

Pot study

Seeds were surface disinfected with 0.5% sodium hypochlorite for three min and washed three times with sterile distilled water. Seeds were germinated for five days on sterile filter paper. At the day of planting, seeds were inoculated with 1 ml of inocula containing 10^5-10^6 cfu ml^{-1} and sown, one per pot, in cones (4 cm x 20 cm) (SC10 container, Steuwed & Sons, Inc.)

containing a mix of sterile sand and perlite (1:1 volume). Pots were irrigated with 10 ml of 2 mM $(^{15}NH_4)_2\ SO_4$ (Parra-Colmenares, 2005) containing five atom percent ^{15}N (5% A) three times per wk for the first two wks, and 10 ml distilled water thereafter. Once a week 10 ml sterile N-free Hoagland solution was added as a nutrient source. All solution volumes were limited to prevent any leaching during the growth period. Plants were placed in a growth chamber at 20°C and 16 hrs light for six wks.

Measurements

After 6 wks whole plants were removed from the pots. Root nodules were counted and plants were cut at root crown. Above-ground biomass (AGB) and below-ground biomass (BGB) portions were dried at 65°C for 48 hrs and weighed. Atom percent $^{15}N/^{14}N$ (A %) of combined AGB and BGB was measured by an isotope ratio mass spectrometer (Thermo-Finigan, Delta Plus Advantage). The atom % excess (A % - 0.366 A %) was used to calculate the proportion of N fixed (PNF) based on the method of Fried and Mellado (1977): PNF = 1-[% atom excess ^{15}N in fixing crop / % atom excess ^{15}N in non-fixing crop] x 100, and using wheat as the non-fixing crop.

Experimental design and statistics

Treatments were a factorial design of two main factors, rhizobial strain and crop variety. Lentils had 5 varieties and 13 bacterial strains. Peas had 5 varieties and 15 bacterial strains. Three replicates were distributed in a randomized complete block design blocked by time (1wk interval). Analysis of variance (ANOVA) was conducted and correlations between various parameters were determined using SAS system for Windows version 9.1. Means were calculated with LSM in Proc Mixed. Data were considered significantly different at $P \leq 0.05$ according to

Tukey's method within Proc Mixed.

RESULTS

Number of nodules

The number of nodules per plant was significantly affected by the various varieties of lentils (Table 1) and peas (Table 2). Strains did not have a significant effect on nodule number in lentils (Table 3) but did in peas (Table 4). Among lentils, Eston produced the most nodules and also the greatest PNF. Riveland had fewer nodules corresponding with lower PNF. There was no significant interaction between varieties and strains, but the percentage of strains with more than 20 nodules varied between varieties from 61% in Eston to 7% in Pennell (Table 1). In peas the number of nodules produced was greatest for Delta with an average of 21 nodules and lowest in Medora with an average of 14 nodules per plant (Table 2). Peas exhibited no substantial interaction between varieties and strains, but the percentage of strains producing more than 20 nodules varied between varieties from 53% in Delta to 13% in Medora (Table 2).

Above and below ground biomass

Above ground biomass in lentils was significantly influenced by variety as a main effect, though there were no significant differences between varieties (Table 1). Below ground biomass was not significantly affected by bacterial strain or lentil variety (Table 1). In peas varieties affected the AGB and BGB (Table 2). The highest AGB was produced in pea varieties Bohatyr and Medora, and the highest BGB was in Bohatyr and Lifter. Above ground biomass was positively correlated with BGB in lentils (r = 0.69) and peas (r = 0.57; Table 5). On average above ground biomass and BGB were positively correlated with the number of nodules in both lentils and peas (Table 5). In lentils, on average an increase in one nodule correlated to an increase in 1.49 mg of AGB (Fig. 1). While in peas, on average an increase in one nodule correlated to an increase in 4.81 mg of AGB (Fig. 2).

N Fixation

The PNF varied with varieties and ranged from 70-80% in lentils and 87-91% in peas (Tables 1 and 2). Eston and Meritt lentil varieties had greater PNF in comparison to Riveland. In lentil, rhizobia strains also significantly affected PNF (Table 3). All strains tested on Eston and Meritt provided more than 70% of plant N, whereas in Riveland only eight strains contributed more than 70 % of N by fixation (Table 1). Pea varieties significantly affected the PNF with fixation supplying a greater proportion of N to Shawnee than Medora and Lifter (Table 2). Twelve out of fifteen strains contributed to more than 90% PNF in Shawnee while only two strains in each Medora and Lifter provided more than 90% PNF. In lentils the number of nodules was significantly correlated to PNF ($r = 0.25$) while in peas the correlation was weaker (Table 5). In lentils, on average an increase in one nodule correlated to an increase in 0.203 % of PNF (Fig. 3). While in peas, on average an increase in one nodule correlated to an increase in 0.045 % of PNF (Fig. 4). In lentils, Eston and Meritt had higher PNF than Riveland, and the most nodules. In peas, Bohatyr and Shawnee contributed to higher PNF than Lifter, though nodule number was not significantly different.

DISCUSSION

In this study the number of nodules was significantly affected by various varieties of lentils and peas. Strains affected nodulation only in peas, and in neither crop was there a significant interaction between variety and strain. Hafeez et al. (2000) demonstrated the efficiency of inoculation by relying on number of nodules, and in his study there was a statistical interaction of legume variety and *Rhizobium* strain on nodule number. Also, Hafeez et al. (2000) demonstrated high correlations between number of nodules and nodule dry weight, and between nodule dry weight and plant biomass. In our study nodule number was highly correlated with both AGB and BGB. We find no previous study that correlates plant biomass in legumes to number of rhizobial nodules.

Many researchers have found a strong influence of plant variety on N fixation. Bello et al. (1980) found 70% and 25% variability in kg N fixed ha^{-1} among three soybean varieties at two sites. Hafeez et al. (2000) demonstrated that PNF varied from 9 to 48% among varieties of lentils in a field trial. Our research confirmed the affect of varieties on the PNF in lentils and peas using potential U.S. breeding lines. Among five varieties PNF varied 14.4% and 4.7% in lentils and peas respectively.

Hafeez et al. (2000) found a significant interaction between crop variety and rhizobial strain, while in our study the variety-strain interaction was never statistically significant. Still there were some varieties that enabled high PNF with more strains than others. In lentil, only 61% of strains contributed to more than 70% PNF in Riveland variety while all tested strains contributed > 70% PNF in Eston and Meritt (Table 1). Similarly in peas only 13% of strains contributed to more than 90% PNF in Lifter and Medora varieties which also had the lowest average PNF (Table 2). In Shawnee, with the highest PNF among peas, 80% of the tested strains provided over 90% PNF.

Plant breeders have developed varieties in legumes that are high yielding, and resistant to disease, but have not focused on improving N fixation (McPhee, 2006). Variability in PNF among pea and lentil varieties suggests it would be possible to breed for high N fixation. One of the mechanisms for enhanced crop N fixation implied from this research is the development of varieties with the capacity to yield elevated nodule numbers. In our study, the ability to form nodules (infectiveness) was correlated to the proportion of N fixed (effectiveness). Plant species and varieties differ in their amount or type of flavonoid signals that promote rhizobial nod factors for initiating the nodulation process (Spaink, 2000). In lentils, the type and/or amount of flavonoid may have contributed to higher number of nodules in Eston comparing to Pardina, Pennell, and Riveland; while in peas, Medora contributed to fewer nodules than Delta. Different varieties of legumes may also vary in their capacity to provide carbon to rhizobia which can be used as an energy source enabling the process of N fixation. The amount of available energy may directly affect the efficiency of the bacteroids in fixing N which may affect PNF.

The survival and number of inoculant rhizobia are very critical for successful nodulation, yet limited effort has been made to improve rhizobial inoculants (Brockwell, 1995). Effectiveness of strains in fixing N may be related to variation in substrate utilization profiles. For instance Baldwin and Fred (1927) documented variation in rhizobial mannitol fermentation. The nod factor may also affect infectiveness. This factor has 9 different radicals in the oligosaccharide backbone that vary among strains of rhizobia (Spaink, 2000). Future studies are needed to determine nod and nif genes in these strains that are capable of improving both nodulation and N fixation. This will result in application of better and faster tools in screening for robust strains.

In summary, legume varieties had a major influence on the number of nodules, AGB, BGB, as well as PNF. Selection of varieties and breeding for high N fixation is recommended.

The results from this research can be used to develop molecular markers and breed for high N fixation in order to increase the proportion of N fixed, potentially also improving yield and protein content. The further study of mechanisms involved in legume x rhizobial interaction will allow a better understanding of N fixation process which may speed the development of improved varieties. The greatest advantage to producers will come in the future when this research is used by legume crop breeders to select varieties that better interact with rhizobia to increase the efficiency of N fixation. Better N fixation for different regions may be achieved by testing more strains and varieties in diverse field soil conditions.

LITERATURE CITED

Athar M 1998. Drought tolerance by lentil rhizobia (Rhizobium leguminoserum) from arid and semiarid areas in Pakistan. Lett Appl Microbiol. 26:38-42.

Baldwin E L, Fred E B 1927. The fermentation characters of the root nodules bacteria of leguminosae. Soil Sci. 24: 217-230.

Bello A B, Ceron-Dias W A, Nickell C D, Elsheriff E O and Davis L C 1980. Influence of cultivar, between-row spacing and plant population of fixation of soybeans. Crop Sci. 20:751-75.

Brockwell J and Bottomley P J 1995. Recent Advances in Inoculant Technology and prospects for the Future. Soil Biol. Biochem. Vol. 27. No. 4/5: 683-697.

Burns R C and Hardy R W 1975. Nitrogen Fixation in Bacteria and Higher Plants. Springer, New York.

CGIAR (Consultative Group on International Agricultural Research) 2005. Research and Impact: Lentils. http://www.cgiar.org/impact/research/lentils.html.

Dileep Kumar B S, Berggren I and Martensson A M 2001. Potential for improving pea production by co-inoculation with fluorescent Pseudomonas and Rhizobium. Plant Soil. 229: 25-34.

Fertecon NYMEX 2008. Nitrogen. http://www.potashcorp.com.

Fried M and Mellado L 1977. In: Int. Symp. on Limitations and Potentials of Biological Nitrogen Fixation in the Tropics. Basic Life Sciences, Vol. 10. Plenum Press, New York

(1978).

Hafeez F Y, Shah N H and Malik K A 2000. Field evaluation of lentil cultivars inoculated with *Rhizobium leguminosarum bv. viciae* strains for nitrogen fixation using nitrogen-15 isotope dilution. Biol Fert Soils. 31:65-69.

Hynes R K, Craig K A, Covert D, Smith R S, and Rennie R J 1995. Liquid rhizobial inoculant for lentil and field pea. Prod Agric J. 8: 547-552.

IFA (International Fertilizer Industry Association) 2006. Nitrogen fertilizer nutrient consumption. http://www.fertilizer.org/ifa/statistics/indicators/tablen.asp.

Israel D W 1981. Cultivar and Rhizobium strain effects on nitrogen fixation and remobilization by soybeans. Agron J. 73:509-516.

Knowles R and Blackburn T H 1993. Nitrogen Isotope Techniques. Academic Press, Inc. California. USA.

McPhee K 2006. Personal communication.

Mcnew K and Bixley S 2001. Lentils: Production, Uses, and Exports. Agricultural Marketing Policy Center. Montana State University. Briefing No. 20. www.ampc.montana.edu.

Nielsen R 2005. Can We Feed the World? Is There a Nitrogen Limit of Food Production? Available at: http://home.iprimus.com.au/nielsens/nitrogen.html.

Novozyme Biologicals, Inc 2006. Personal communication.

Parra-Colmenares A and Kahn M 2005. Determination of Nitrogen fixation effectiveness in selected *Medicago truncatula* isolates by measuring nitrogen isotope incorporation into pheophytin. Plant Soil. 270: 159-168.

Osorio Vega, N.W. 2007. A review on beneficial effects of rhizosphere bacteria on soil nutrient availability and plant nutrient uptake. Rev.Fac.Nal.Agr.Medellín.Vol.60, No.1.p.3621-3643.

Schatz B 2002. Feeding Field Peas to Livestock. www.ag.ndsu.edu.

Silva J A and Uchida R 2000. Biological Nitrogen Fixation. Nature's Partnership for sustainable Agricultural Production. Niftal center for BNF Technologies. University of Hawai at Manoa. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm.

Smith S C, Bezdicek D F, Turco R F and Cheng H H 1987. Seasonal N_2 fixation by cool-season pulses based on several ^{15}N methods. Plant Soil. 97: 3-13.

Soon Y K and Arshad M A 2004. Contribution of di-nitrogen fixation by pea to the productivity and N budget of a wheat-based cropping system. J. Ag Sci. 142: 629-637.

Spaink H P 2000. Root Nodulation and Infection Factors Produced by Rhizobial Bacteria. Annu. Rev Microbiol. 54: 257-88.

Valverde G and Otabbong E 1997. Evaluation of N_2-fixation measured by the ^{15}N-dilution and N-difference methods in Nicaraguan and Ecuadorian *Phaseolus vulgaris* L. plants inoculated with *Rhizobium leguminoserum* biovar. Acta Agric Scand B. 47: 71-80.

Vessey J K 2004. Benefits of inoculating legume crops with rhizobia in the northern Great Plains. Online. Crop Management 10.1094/CM-2004-0301-04-RV.

Wynne J C, Elkan G H, Meisner C M, Scheewis T J and Ligon J M 1980. Greenhouse evaluation of strains of *Rhizobium* for peanuts. Agron J. 72:645-649.

Table 1. Mean % N fixation, number of nodules, above ground biomass (AGB), and below ground biomass (BGB) in lentils (n=39)

Variety	N fixed (%)	Strains providing > 70% N fixed (%)	Root nodules (#/plant)	Strains promoting >20 nodules (%)	AGB (dry mg $plant^{-1}$)	BGB (dry mg $plant^{-1}$)
Eston	80.9[a]	100	26[a]	61	76.7[a]	108.5
Meritt	80.5[a]	100	19[ab]	38	104.5[a]	114.5
Pardina	74.8[ab]	92	16[b]	23	68.7[a]	137.1
Pennell	76.9[ab]	69	13[b]	7	105.0[a]	141.6
Riveland	70.7[b]	61	16[b]	23	94.6[a]	120.05
P values	0.001	NA	0.004	NA	0.017	0.57

Letters that are the same within a column are not significantly different at $P \leq 0.05$.
[+]NA = Statistical P value is not applicable to this data.

Table 2. Mean % N fixation, number of nodules, above ground biomass (AGB), and below ground biomass (BGB) in peas (n=45)

Variety	N fixed (%)	Strains providing > 90% N fixed (%)	Root nodules (#/plant)	Strains promoting >20 nodules (%)	AGB (dry mg plant^{-1})	BGB (dry mg plant^{-1})
Bohatyr	90.5^{ab}	46	18^{ab}	40	294.8^{a}	344.0^{a}
Delta	88.7^{abc}	26	21^{a}	53	240.2^{ab}	287.6^{ab}
Lifter	87.2^{c}	13	15^{ab}	20	211.9^{b}	352.0^{a}
Medora	87.5^{bc}	13	14^{b}	13	297.1^{a}	224.1^{bc}
Shawnee	91.3^{a}	80	18^{ab}	38	209.6^{b}	205.4^{c}
P values	<0.0001	NA^{+}	0.028	NA	0.0004	<0.0001

Letters that are the same within a column are not significantly different at $P \leq 0.05$.
$^{+}$NA = Statistical P value is not applicable to this data.

Table 3. Strain effect on % of plant N supplied by fixation in lentils (n=15)

Strain	N fixed (%)	Number of nodules
EMD- R4	82.6[a]	15
NB-R2	80.2[a]	19
EMD-R3	80.2[a]	24
NB-R1	79.3[ab]	17
NB-R6	78.5[ab]	23
NB-R7	77.3[ab]	16
NB-R9	77.2[ab]	15
NB-R4	76.3[ab]	16
NB-R8	76.0[ab]	17
NB-R5	76.0[ab]	26
BU-R5	74.5[ab]	20
NB-R3	74.1[ab]	14
BU-R4	65.5[b]	12
P value	0.032	0.29

Letters that are the same within a column are not significantly different at $P \leq 0.05$.

Table 4. Strain effect on number of nodules per pea plant root system (n=3)

Strain	N fixed (%)	Number of nodules
NB-R7	89.2	24[a]
NB-R3	88.6	21[a]
NB-R2	89.0	21[a]
NB-R9	87.6	20[a]
NB-R6	89.4	20[a]
BU-R4	88.8	20[a]
BU-R2	90.9	19[a]
NB-R4	89.1	18[a]
NB-R1	88.6	18[a]
NB-R5	89.4	16[a]
BU-R1	88.6	15[a]
NB-R8	89.9	15[a]
BU-R3	88.0	12[a]
EMD-R2	87.4	11[a]
EMD-R1	89.7	10[a]
P value	0.855	0.038

Letters that are the same within a column are not significantly different at $P \leq 0.05$.

Table 5. Pearson correlation coefficient (r) between various measurements in peas and lentils (p value)

Crop	Nodule[+] /AGB[++]	Nodule/BGB[+++]	Nodule/PNF[++++]	PNF/AGB	PNF/BGB	AGB/BGB
Lentil	0.38 (<0.0001)	0.32 (<0.0001)	0.25 (0.0005)	0.02 (0.812)	- 0.1 (0.186)	0.69 (<0.0001)
Pea	0.48 (<0.0001)	0.50 (<0.0001)	0.13 (0.054)	- 0.05 (0.456)	- 0.08 (0.217)	0.57 (<0.0001)

[+]Nodule = Number of nodules per plant
[++] AGB = Above ground biomass
[+++] BGB = Below ground biomass
[++++] PNF = Proportion of N fixed

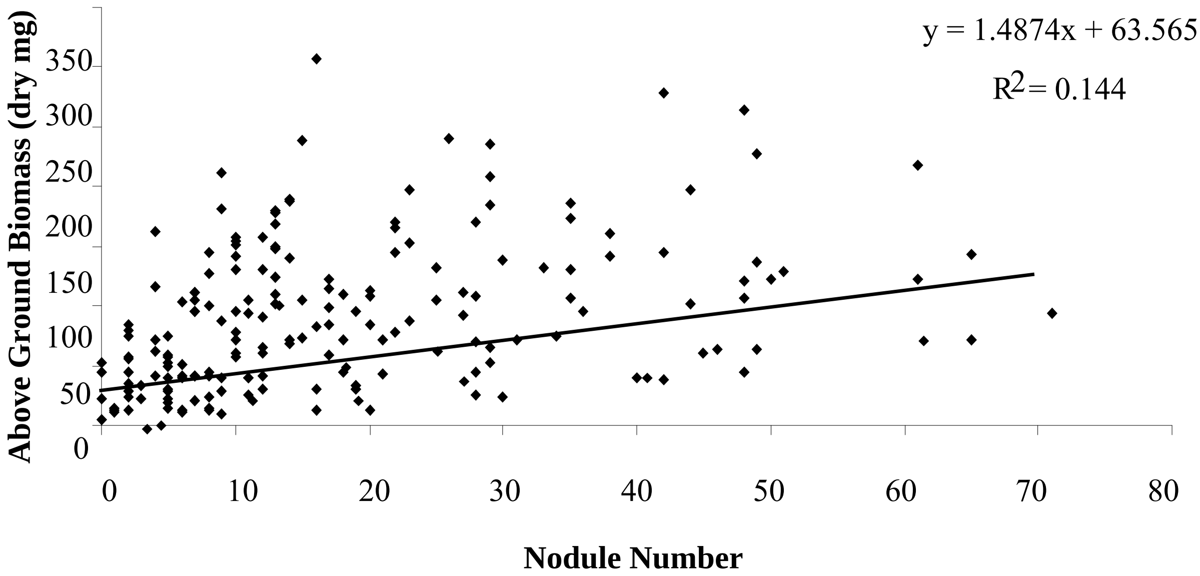

Fig 1. Correlation of nodule number with the above ground biomass in lentil.

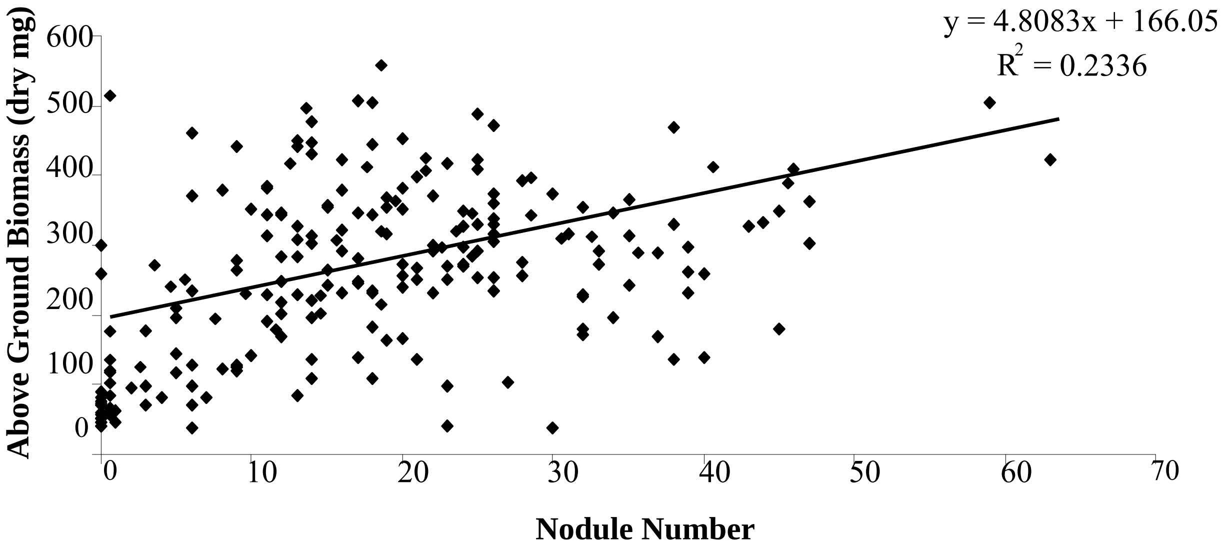

Fig 2. Correlation of nodule number to the above ground biomass in pea.

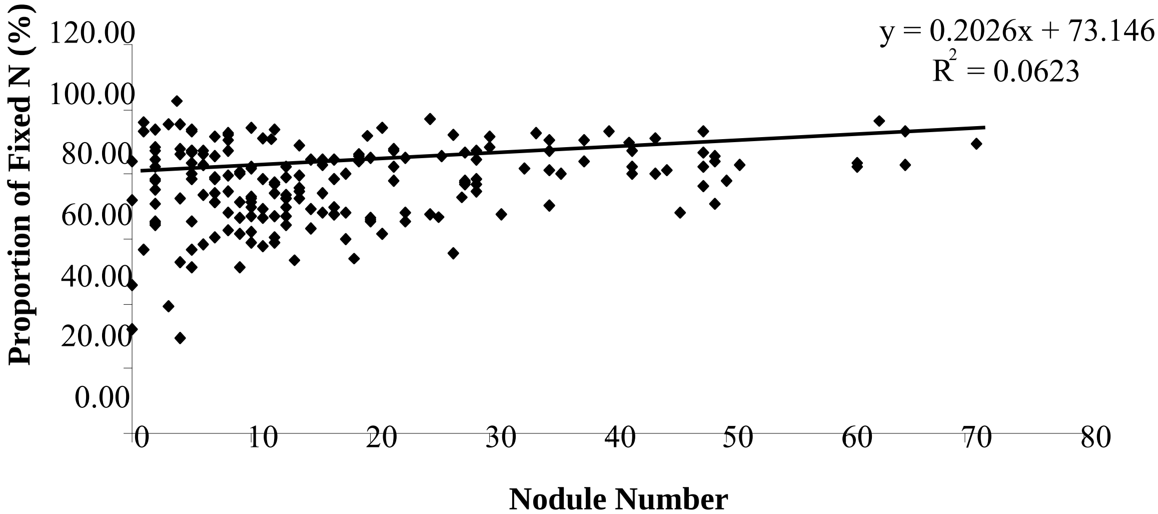

Fig 3. Correlation of nodule number to the proportion of fixed N in lentil.

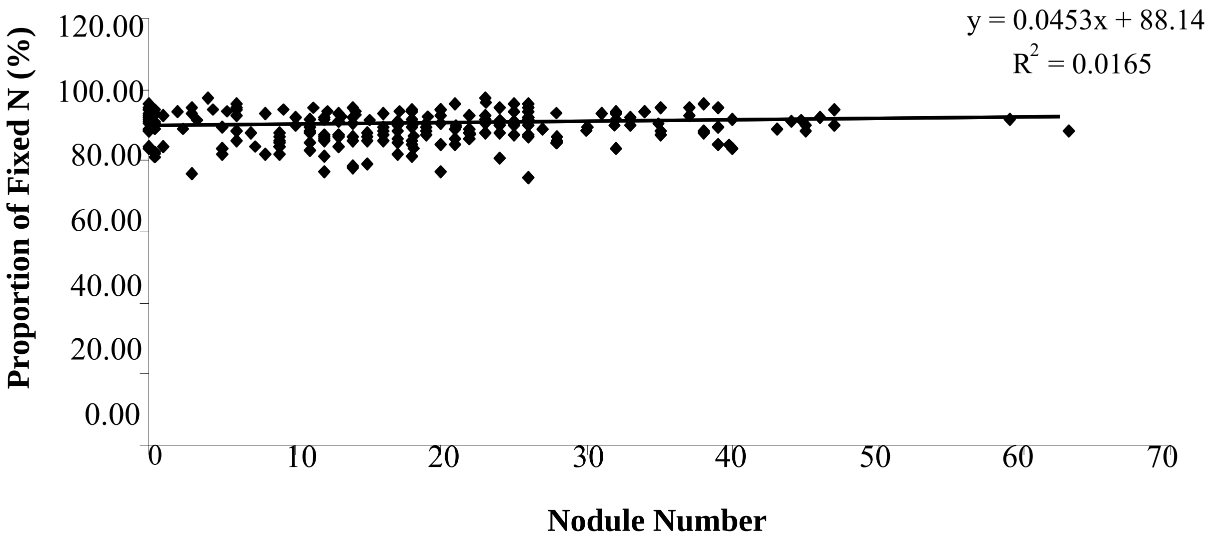

Fig 4. Correlation of nodule number with the proportion of fixed N in pea.

CHAPTER THREE

INTERACTIONS OF MIDDLE EASTERN AND COMMERCIAL STRAINS OF *MESORHIZOBIA CICERI* WITH U.S. AND MIDDLE EASTERN VARIETIES OF CHICKPEAS

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ABSTRACT

Chickpeas (*Cicer arietinum* L.) fix atmospheric nitrogen in association with *Mesorhizobium ciceri*. Neither chickpeas nor *M. ciceri* are native to North America soils, and it is not known whether the available *M. ciceri* strains are as effective or infective as other wild strains when paired with various chickpea variety hosts. This study was conducted to isolate *M. ciceri* from Middle Eastern soils and to compare their effectiveness and infectiveness versus commercial strains on U.S. and Middle Eastern varieties of chickpeas. Chickpeas were inoculated with individual strains and grown in growth chambers for 8 weeks. Plants received 2 mM $(^{15}NH_4)_2 SO_4$ (5% A) to allow the measurement of N fixation by isotope dilution. Below and above ground biomass, numbers of nodules, and the proportion of plant N provided by fixation were determined. The proportion of N fixed in plants, but not the number of nodules, was significantly influenced by different strains of mesorhizobia and various varieties of chickpeas. Averaged across all chickpea varieties, the commercial *M. ciceri* strains produced more nodules than new Middle Eastern strains. Varieties Sierra, Troy and Almaz had a greater proportion of

plant N provided by fixation, though their nodule numbers were low. Among strains, Jord-M1 contributed to more N fixed than Syr-M1. The Middle Eastern chickpea variety Arman had a particularly high number of nodules with the commercial strain NB-M7. These results showed that crop varieties have a greater effect on N fixation than strain selection. Efforts to increase agricultural N fixation should focus on varietal breeding and selection.

INTRODUCTION

Nitrogen is an essential plant element that is supplied to agronomic systems primarily through synthetic N fertilizers and legumes. The price of these fertilizers has more than tripled over the last three years due to an increase in the price of natural gas (Fertecon, NYMEX, 2008). Biological nitrogen fixation (BNF) by rhizobia-legume symbiosis within the crop rotation is an alternative to synthetic N fertilizers that presents potential economic, environmental and agronomic benefits (Silva and Uchida, 2000). Legume crops fix N from the N_2 gas in soil pores, which provides N to future crops and reduces the need for additional N fertilizers in following crops. Economic sustainability of large-scale agriculture depends on improving the sale price versus input price ratio, such as decreasing N inputs, while environmental sustainability depends on maintaining or improving natural resources. Both environmental and economic sustainability can be improved when BNF supplies a greater proportion of N needed for agriculture production, but increased research and extension efforts are needed to increase BNF.

Chickpea (*Cicer arietinum* L.), a drought-resistant legume from the Middle East, has been cultivated for over 10,000 years (Albala, 2007). This nutritious crop has high protein content (22%) and is rich in minerals such as zinc, iron, calcium and vitamins A, B, and C (USA Dry Pea and Lentil Council, 2000). In the U.S. 73,725 acres were planted with chickpeas in 2008 with a total production of 47,956 tons. The Pacific Northwest represents an area of intensive chickpea production with 32,383 tons produced on 55,264 acres in 2008 (USA Dry Pea & Lentil Council, 2008). Chickpeas form root nodules that host *Mesorhizobium ciceri* and fix atmospheric N into ammonia. In general, the atmospheric amount of N remaining in soil after a chickpea harvest is 27-33 kg/ha (Kirby, 1987; Sims, 1988; Mahler and Auld, 1989). Total N fixed by chickpeas varies with growth conditions, Beech and Leach (1988) found chickpeas fixed 38 kg N/ha in a below average rainfall year and 177 kg N/ha in an above average rainfall year in southwestern Saskatchewan, Canada. However, there has been little work to enhance the ability of chickpeas to support N fixation (Horn et al., 1996). Plant breeders may be able to improve chickpea varieties through the use of breeding lines that are better *M ciceri* hosts to increase the BNF process.

There is increasing evidence that more nitrogen can be fixed by existing legume grain crops if they are inoculated more often or with more effective strains of rhizobia (Brockwell et al. 1989). In addition, significant increases can result from the use of different commercial or native strains (Brockwell and Bottomley, 1995). *M. ciceri*, chickpea's symbiotic N fixer is not native to North American soils and the number of commercial strains is limited (Novozyme Biologicals, 2006).

The objective of this study is to increase the number of available mesorhizobia strains by isolating more of these bacteria from Middle Eastern soil. Both commercial and Middle Eastern strains of mesorhizobia were tested for association with U.S. and Middle Eastern varieties of chickpeas.

MATERIALS AND METHODS

Soil from chickpea fields in Lebanon (Terbol), Syria (Tal Hadya), Jordan (Erbid), and Turkey (Yozgat) were collected from 10-15 cm depth. To isolate *M. ciceri* from these soils, chickpea seeds were sterilized with 0.5% sodium hypochlorite for three min and germinated for 5 days on sterile filter paper. Germinated seeds were planted in 164 ml seedling cones (SC10 container, Steuwed & Sons, Inc.) filled with sterile sand and perlite (1:1 volume) and inoculated with 10 ml of 10^{-1} soil solution. The pots (4cm x 20 cm) were placed for 8 wks in growth chambers at 20° C and 16 hrs light. At harvest nodules were selected, surface sterilized for 1 min with 0.5% sodium hypochlorite, and a loop of inoculum was streaked on Yeast Extract Mannitol Agar (YEMA) (Novozyme Biologicals, 2006). Two nodules were collected from two different plants per soil, to produce a total of eight native strains (Leb-M1, Leb-M1, Syr-M1, Syr-M2, Jord-M1, Jord-M2, Turk-M1, Turk-M2). Commercial strains of mesorhizobia were also provided from: Novozyme Biologicals (NB-M4, NB-M5, NB-M6, NB-M7, NB-M8), Becker Underwood (BU-M3), and EMD (EMD-M1, EMD-M2). Three varieties of U.S. chickpeas (cvs. Myles, Troy, and Sierra) were supplied by USDA-ARS Grain Legume Genetics-Physiology Research Unit Pullman, WA. We also used three Middle Eastern varieties (cvs. Arman, Almaz, and Hashem) collected from the U.S. National Plant Germplasm System, Regional Plant Introduction Station in Pullman, WA. Five days before seed inoculation, strains were grown in 1 x yeast extract broth at 22°C on an orbital shaker (Novozyme Biologicals, 2006). Cells were collected by centrifugation at 4000 rpm for 4 minutes. An optical density (A= 0.3) corresponding to a bacterial count of 10^6-10^7, was determined using a spectrophotometer at 640 nm wavelength. Inocula were diluted to reach 10^5-10^6 cfu per ml needed for efficient nodulation. One milliliter of four native (Leb-M1, Syr-M1, Jord-M1, Turk-M1) and four commercial diluted inocula (NB-

M4, NB-M5, BU-M3, EMD-M1) were added to each cone, each with one chickpea seed. In order to increase the number of tested strains, we also selected Arman variety to be inoculated with additional four native (Leb-M1, Syr-M2, Jord-M2, Turk-M2) and four commercial strains (NB-M6, NB-M7, NB-M8, EMD-M6).

Variety x strains pairings were grown in 164 ml seedling cones filled with sand-perlite mixture (1:1 volume) using five replicates. For precise measurement of biological N fixation an isotopic 15-N method was used. Plants were watered with 10 ml 2 mM $(^{15}NH_4)_2\ SO_4$ (5% A) (Parra-Colmenares, 2005) three times a week for the first two weeks, and water thereafter. Sterile N-free Hoagland's solution was added once a week to provide all necessary nutrients except N. Root nodules were counted. Above ground biomass (AGB) and below ground biomass (BGB) were separated at the root crown, and weighed. Atom percent $^{15}N/^{14}N$ (A %) of combined AGB and BGB was measured by an isotope ratio mass spectrometer (Thermo-Finigan, Delta Plus Advantage). The atom % excess (A % - 0.366 A %) was used to calculate the proportion of N fixed (PNF) based on the method of Fried and Mellado (1977): PNF = 1-[% atom excess ^{15}N in fixing crop / % atom excess ^{15}N in non-fixing crop] x 100. Wheat was used as a control in the experiment as described by Knowles and Blackburn (1995), and Smith et al. (1987).

Treatments were a factorial design of two main factors, rhizobial strain and crop variety. Five replicates were distributed in a randomized complete block design blocked by time. Analysis of variance (ANOVA) and correlations between various parameters were run using SAS system for Windows version 9.1. Means were calculated with LSM in Proc Mixed. Data were considered significantly different at $P \leq 0.05$ according to Tukey's method in Proc Mixed.

RESULTS AND DISCUSSION

Fixed N

Varieties and strains both had a major influence on the PNF. Averaged across all strains, Sierra had greater PNF than Arman, Hashem, and Myles (Table 1). Averaged across all varieties, Jord-M1 had greater PNF than Syr-M1 (Table 2). The variation among varieties in N fixation was 11.6%; hence the selection of Sierra could increase PNF in the plant by 11.6 % more than Myles. The PNF was positively correlated to AGB ($r = 0.69$; $P < 0.001$) and BGB ($r = 0.32$; $P < 0.001$) (Table 4). The variation among strains was 3.9%; Jord-M1 could increase PNF by 3.9% over Syr-M1.

Number of nodules

The number of nodules was significantly influenced by chickpea varieties. This has been observed by other researchers where PNF is mainly related to the host plants (Hardarson et. al, 1984). The number of nodules and its logarithm violated the assumption of normal distribution as well as homogenous variation, thus preventing both parametric and non parametric statistical analysis. However, there was a highly significant influence of varieties on number of nodules ($P < 0.0001$). More nodules were produced in Myles, Hashem, and Arman than Almaz, Troy, and Sierra (Table 1). The commercial strains significantly produced more nodules than the native ones (Table 1). There was variety x strain interaction for nodule number ($P = 0.014$) detected only as a greater number of nodules (3.2) on Arman with NB-M7 strain. Several researchers have shown a specificity of interaction between particular rhizobial strains and host crop varieties (Skot, 1983; Hafeez et al. 2000). In these trials, NB-M7 strain contributed more nodules to Arman than Almaz. This good association of Arman and NB-M7 could be very critical in future studies. The genes in both Arman and NB-M7 responsible for this strong association could be determined and incorporated into improved varieties and strains. We also observed in this study that infectiveness (number of nodules) was not correlated to effectiveness (PNF). Though the number of nodules was higher in Arman, it did not correspond to greatest N fixation.

Above and below ground biomass

Varieties substantially influenced above and below ground biomass ($P < 0.0001$), (Table 1). Sierra and Troy had higher AGB than Arman, Hashem, and Myles. The AGB in Almaz was statistically similar to Sierra, Troy, and Arman and greater than Hashem and Myles (Table 1). This could be related to larger seed size of these varieties. The average weight per seed in Sierra, Troy, and Almaz was respectively 0.57g, 0.6 g and 0.5 g while Myles weighed 0.16 g (Table 4). Almaz, Arman, and Troy had higher BGB than Myles, Hashem, and Sierra. The BGB in Troy was statistically similar to Sierra, Almaz, and Arman and greater than Hashem, and Myles (Table 1). The Middle Eastern varieties were significantly greater in BGB than the U.S. varieties, which could be related to breeding for higher AGB in the U.S. The PNF was highly correlated to AGB and BGB while the number of nodules was negatively correlated to BGB ($r = -0.16$; $P = 0.02$), (Table 4).

In this study we used a non-legume crop as a control and isotope dilution methods to track the proportion of N fixed (Knowles and Blackburn, 1993), calculating PNF using Fried and Mellado's equation (1977). The total N considered to be PNF in Fried and Mellado's equation actually originates from all non-fertilizer sources. There was a negative correlation ($r = -0.589$; $p < 0.001$) between the weight of the seeds and the $^{15}N/^{14}N$ ratio in the harvested plant. An increase in the seeds' weight corresponded to a decrease in $^{15}N/^{14}N$ ratio and suggests that ^{14}N was supplied from the seeds. In this case, Fried and Mellado's equation for the determination of

PNF in plant derived from the atmosphere needs to be adjusted by subtracting the amount of N derived from the seeds.

Arman tests with four additional Middle Eastern and four commercial strains did not reveal a significant effect of these strains on the measured parameters (data not shown). There was a correlation of AGB with number of nodules ($r = 0.38$; $P = 0.02$) and fixed N ($r = 0.57$; $P = 0.0002$). Above ground biomass and BGB were also correlated ($r = 0.5$; $P = 0.002$). The mean number of nodules with different varieties varied from 0 to 3.2 with no significant influence of the various strains on PNF. The other commercial and Middle Eastern strains tested in the previous experiment (Table 1) had a significant influence on PNF. It is clear from this study that Arman can contribute to higher N fixation when inoculated with other strains such as NB-M7.

Many researchers have demonstrated a strong influence of plant variety on N fixation. Bello et al. (1980) found 70% and 25% variability in kg N fixed ha^{-1} among three soybean varieties at two sites. The survival and number of inoculant rhizobia are very critical for successful nodulation and there are limited efforts made to improve rhizobial inoculants (Brockwell and Bottomley, 1995). Furthermore, inoculated rhizobia strains may not compete well against resident rhizobia. Inoculation by commercial strains filled 5-20% of nodules on soybeans in studies by Caldwell and Vest (1970) and Kuykendall et al. (1978). Consequently, the more efficient strategy for BNF improvement may be in breeding crops for high N fixation rather than rhizobia strain selection.

In summary, varieties of chickpeas dominated the PNF in plants due to their genetic diversity and variation of N amount in the seeds. Strains had a smaller influence on PNF, and Jord-M1 contributed to more N fixation than Syr-M1. There was some interaction between varieties and strains, particularly evidenced by greater nodule formation on the Middle Eastern variety Arman with the commercial strain NB-M7. A further study of the genes involved in this crop-by- rhizobial interaction is needed to capitalize on this interaction. This study indicates the possibility to improve the efficiency of N fixation through better selection of *M. ciceri* strains but a relatively greater impact is likely through selection of chickpea varieties for hosting more infective and effective symbionts.

LITERATURE CITED

Albala, K. 2007. Beans: a history. Berg publishers. Oxford, New York.

Beech, D.F., and G.J. Leach. 1988. Aust. J of Exp. Agric. 28: 367-376.

Bello A B, Ceron-Dias W A, Nickell C D, Elsheriff E O and Davis L C 1980. Influence of cultivar, between-row spacing and plant population of fixation of soybeans. Crop Sci. 20:751-75.

Brockwell, J., and P.J. Bottomley. 1995. Recent Advances in Inoculant Technology and Prospects for the Future. Soil Biol. Biochem. Vol. 27. No 4/5: 683-697.

Brockwell, J., R.R. Gault, D.F. Herridge, L.J. Morthorpe, and R.J. Roughly. 1989. Studies on alternative means of legume inoculation: Microbiolocal and agronomic appraisals of commercial procedures for inoculating soybeans with *Bradyrhizobium japonicum*. Aust. J of Agr. Res. 40:753-762.

Caldwell, B. E., and G. Vest. 1970. Effects of *Rhizobium japonicum* strains on soybean yields. Crop Sci. 10:19-21.

Fertecon NYMEX. 2008. Nitrogen. http://www.potashcorp.com.

Fried, M., and L. Mellado. 1977. In: Int. Symp. on Limitations and Potentials of Biological Nitrogen Fixation in the Tropics. Basic Life Sciences, Vol. 10. Plenum Press, New York (1978).

Hafeez, F. Y., N. H. Shah and K.A. Malik. 2000. Field evaluation of lentil cultivars inoculated with *Rhizobium leguminosarum bv. viciae* strains for nitrogen fixation using nitrogen-15 isotope dilution. Biol Fert Soils. 31:65-69.

Hardarson, G., F. Zapata, and S.K.A. Danso. 1984. Field evaluation of symbiotic nitrohen fixation by rhizobial strains using ^{15}N isotope methodology. Plant and Soil 82:369-375.

Horn, C.P., R.C. Dalal, C.J. Birch, and J.A. Doughton. 1996. Nitrogen Fixation in Chickpeas as Affected by Planting Time and Tillage Practice. http://www.regional.org.au/au/asa/1996/contributed/317horn.htm?print=1.

Kirby, E.M. 1987. Soil Moisture depletion and wheat yield response from annual legumes in the Pacific Northwest. M.S. thesis, Agronomy and soils, Washington State Univ., Pullman.

Knowles, R., and H.T. Blackburn. 1993. Nitrogen Isotope Techniques. Academic Press, Inc. California. USA.

Kuykendall, L.D., and D. F. Weber. 1978. Genetically marked Rhizobium identifiable as inoculum strain in nodules of soybean plants grown in fields populated with *Rhizobium japonicum.* Appl Environ Microbiol. 36: 15-919.

Mahler, R.L., and D.L. Auld. 1989. Evaluation of the green manure potential of Austrian winter peas in northern Idaho. Agron. J. 81:258-264.

Novozyme Biologicals, Inc. 2006. Personal communication.

Parra-Colmenares A and Kahn M 2005. Determination of Nitrogen fixation effectiveness in selected *Medicago truncatula* isolates by measuring nitrogen isotope incorporation into pheophytin. Plant Soil. 270: 159-168.

Silva, J.A., and R. Uchida. 2000. Biological Nitrogen Fixation. Nature's Partnership for sustainable Agricultural Production. Niftal center for BNF Technologies. University of Hawai at Manoa. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm.

Sims, J.R. 1988. Research on dryland legume-cereal rotations in Montana. p.1-17. In Crop Diversification in Sustainable Agriculture Systems (Proceedings). Division of Extension, University of Saskatchewan, Saskatoon.

Skot, L. 1983. Cultivar and *Rhizobium* strain effect on the symbiotic performance of pea (*Pisum sativum*). Physiol. Plant 59:585-589.

Smith S C, Bezdicek D F, Turco R F and Cheng H H 1987. Seasonal N_2 fixation by cool-season pulses based on several ^{15}N methods. Plant Soil. 97: 3-13.

USA Dry Pea & Lentil Council. 2008. Crop production report. Vol. VIII, No 9.

USA Dry Pea and Lentil Council, 2000. *The Pea and Lentil Cookbook*. Editor: Randall Duckworth. Moscow, ID. USA.

Table 1. Mean % N fixation, number of nodules, above ground biomass (AGB), and below ground biomass (BGB) in chickpeas (n=40).

Variety	N fixed (%)	Root nodules (number plant^{-1})	AGB (dry mg plant^{-1})	BGB (dry mg plant^{-1})
Sierra	86.7^{a}	0	283^{a}	319^{bc}
Troy	85.3^{ab}	0.2	264^{a}	374^{ab}
Almaz	85.2^{ab}	0.1	255^{ab}	386^{a}
Arman	83.2^{b}	1.0	228^{bc}	357^{ab}
Hashem	82.9^{b}	1.2	200^{c}	296^{cd}
Myles	76.6^{c}	1.1	154^{d}	271^{d}
P values	<0.0001	<0.0001	<0.0001	<0.0001
<u>Contrast</u>				
U.S. varieties	82.9	0.43	234	321
Middle Eastern	83.8	0.8	228	346
P value	0.128	0.073	0.412	0.007

Letters that are the same within a column are not significantly different at $P \leq 0.05$.

Table 2. Strain effect on % of plant N supplied by fixation in chickpeas (n=30).

Strain	N fixed (%)	Root nodules (number plant^{-1})
Jord-M1	84.7^{a}	0.60
BU-M3	84.3^{ab}	1.13
NB-M4	84.3^{ab}	0.84
NB-M7	83.3^{ab}	0.82
EMD-M5	83.2^{ab}	0.63
Turk-M1	82.9^{ab}	0.32
Leb-M1	82.5^{ab}	0.39
Syr-M1	81.4^{b}	0.13
P value	0.045	0.056
Contrast		
Middle East strains	82.9	0.48
Commercial strains	83.8	0.85
P value	0.107	0.002

Letters that are the same within a column are not significantly different at $P \leq 0.05$.

Table 3. Average weight of seeds (n=20).

Variety	Average Weight of seeds (mg)
Troy	604
Sierra	568
Almaz	496
Arman	396
Hashem	261
Myles	164

Table 4. Pearson correlation coefficient (r) between various measurements in chickpeas (p value).

Nodule† /AGB††	Nodule/BGB†††	Nodule/PNF††††	PNF/AGB	PNF/BGB	AGB/BGB
- 0.11 (0.13)	- 0.16 (0.02)	0.06 (0.39)	0.69 (<0.0001)	0.32 (<0.0001)	0.63 (<0.0001)

†Nodule = Number of nodules per plant
††AGB = Above ground biomass
†† †BGB = Below ground biomass
††††PNF = Proportion of N fixed

APPENDIX I

Experimental Pictures

Rhizobial Inoculation

Plant Growth

Chickpeas Nodules

CHAPTER FOUR

EXTENSION EDUCATION FOR DRYLAND CROPPING SYSTEMS IN IRAQ

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ABSTRACT

Iraq, formerly known as Mesopotamia, is the birthplace of agriculture. The recent war and instability have significantly impacted the country's agricultural production and knowledge support systems. To support revitalization of the Iraqi agricultural system, the USDA funded a consortium of five U.S. universities (Washington State University, University of California-Davis, New Mexico State University, Utah State University, and Texas A&M University as the lead institution) to provide training to agricultural extension personnel from Iraq. Each university had a specific training area. Washington State University was responsible for training in dryland cropping systems and delivered five separate sessions to Iraqis in several Middle East locations. Questionnaires distributed during each session guided subsequent training agendas and enhanced our understanding of extension and dryland cropping systems information needs in Iraq. There is great demand for training, technology, basic farm equipment, seed, and fertilizers, since current access to resources is insufficient to satisfy the country's needs. In addition to supplying inputs and equipment, further training should introduce methods for utilizing on-farm resources. There is also a clear need for better cooperation between Iraq's universities and extension agency,

administered by the Iraq Ministry of Agriculture, in order to maximize the efficiency of research information transfer to farmers.

INTRODUCTION

Iraq, historically known as Mesopotamia, is located between the Tigris and Euphrates rivers and is commonly thought of as the birthplace of agriculture (Tisdale et al., 1985). Iraq covers 43.7 million hectares, but only 9.5 million hectares are suitable for agriculture (Schnepf, 2003). Half of the available agricultural land is used for grazing livestock, mainly sheep (*Ovis aries*) and goats (*Capra hircus*). Rain-fed agriculture dominates in the north and northeast where winter wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) are staple crops. Iraq produces 2.75 million hectares of wheat and 715,000 hectares of barley (FAOSTAT, 2007). The remaining arable lands, located in valleys of the Tigris and Euphrates rivers, are irrigated. The Iraq extension system, unlike the U.S. system, is administered by the Ministry of Agriculture instead of involving a network of universities, county, and federal government agencies.

Since the beginning of the Iran-Iraq war in 1980, economic and social conditions in Iraq have been unstable. Iraq has suffered from limited food and drinking water, limited electricity, massive unemployment, inflation, a national debt that ballooned to nearly $400 billion, destruction of infrastructure, and an agricultural system in disarray (Looney, 2003). As a result of the multiple hardships, many Iraqis have left the country, taking their resources and talents, and further weakening the country.

Although 25 to 33% of Iraq's pre-war gross domestic product came from agriculture, this sector faces many obstacles. Environmental challenges include soil and water salinity and drought, and manmade challenges include limited fertilizer supplies and aging agricultural equipment (FAO, 2000). A lack of high quality and affordable planting stock, a limited extension system, and badly deteriorated water conditions, particularly in central and southern Iraq, all present major obstacles to agricultural re-development in this region (USAID, 2006).

The European Union and the United States both have instituted programs to help Iraq rebuild its agricultural system. The U.S. Agency for International Development (USAID) was the first to implement an Agricultural Reconstruction and Development Program for Iraq (ARDI) in 2003. Currently, three other international projects involve Iraqi agricultural reconstruction: (1) the USAID agribusiness project, lead by Texas A&M University; (2) the Hawaii–Iraq partnership for Revitalizing Agricultural Higher Education and Development; and (3) the Iraq Agricultural Extension Revitalization Program (IAER), which provides training to agricultural extension personnel from Iraq. If successful, the IAER program will change the Iraqi agricultural system by encouraging cooperation between the agricultural colleges of Iraq, the agricultural extension agencies, farming associations, and rural communities.

The goals of the IAER are to promote cooperation between Iraqi agricultural colleges and governmental agricultural and extension agencies, and to provide extension training and support for Iraqi extension professionals. The program sought to help farmers across Iraq by training extension professionals who would then return to their regions and provide training for local extension professionals and communities.

The IAER is funded by the USDA and involves five universities: Washington State University (WSU); the University of California-Davis, New Mexico State University, Utah State University, and Texas A&M University as the lead institution. Washington State University was responsible for training in dryland cropping extension and developed a total of five training sessions. Questionnaires in every session were used to assess participant satisfaction with the training, their level of learning, and future training needs. This article describes the training sessions in dryland cropping systems, trainee evaluation and learning, as well as training needs assessment from throughout the IAER project.

MATERIALS AND METHODS

Overall Project Description

An initial meeting of the IAER project was held in March 2007 in Amman, Jordan. The meeting featured 130 participants, 86 from Iraq and the remainder from U.S. institutions. The meeting had three main objectives: (1) establish interactions between U.S. and Iraqi counterparts; (2) develop a working document describing the structure and function of the extension system in Iraq; and (3) develop a plan for future training sessions. Listening sessions were conducted to establish initial program subject priorities. Washington State University conducted sessions focused on dryland agriculture. These initial discussions identified soil fertility and water conservation, weed management, cultivar selection, soil reclamation, and grazing land management as areas of need.

All five universities participated in a general training session held in July 2007 at the Desert Development Center of the American University of Cairo, Egypt. Training areas were: livestock, dryland cropping, horticulture, irrigation, and agricultural extension led by Texas A&M University, Washington State University, the University of California-Davis, Utah State University, and New Mexico State University, respectively. The general training session employed a “train the trainer” model. In the first week, faculty from the U.S. institutions trained personnel from the Iraq Ministry of Agriculture (MOA) and selected Iraqi universities employing a lecture format supplemented with field and laboratory demonstrations. During the second and third weeks, the Iraqi trainers taught 71 new trainees from the MOA. These 71 were divided into five groups that rotated every 2 days to cover each topic. A list of potential subjects for future training was developed in this general session. This list was used as a survey and basis for discussion in 12 early sessions to select the topics for future sessions. Each participating university held four training sessions after the general session in Cairo. In each session, trainees completed a short questionnaire on the final day to self-assess their knowledge of the topics covered, before and after the training. The change in knowledge level before and after training was regarded as the trainees' learning in each topic.

Training Implemented by Washington State University

In addition to the multi-university session in Egypt, WSU held four additional targeted sessions, covering a broad range of topics relevant to dryland agriculture (Table 1). Approximately 30 Iraqis attended each of the subsequent WSU sessions. Participation of women in Sessions 1 to 3 was approximately 10%. To promote the involvement of more women, Session 4 involved all women trainers and trainees.

All lectures were presented by the WSU trainers in English and consecutively interpreted to Arabic. Printed copies of slides and other learning materials were distributed to trainees in both Arabic and English versions, as both electronic files and hard copies. Some supplies relevant to the lecture topics, such as fertilizer manuals, insect nets, and food thermometers were distributed to trainees in Sessions 1 to 4 (Table 2). These materials were used during the IAER training and given to the trainees for later use in community education in Iraq.

In Session 2 held at the International Center for Agricultural Research in the Dry Areas (ICARDA) in Aleppo, Syria, a multiple-choice exam was used before and after the training session to objectively evaluate the knowledge of the trainees in topics of soil fertility, composting, and variety testing. Each trainer from WSU developed a set of questions based on the information presented at the session. The questions were translated to Arabic, and trainees had 30 minutes to answer these questions both on the first morning and the last afternoon of the session.

RESULTS AND DISCUSSION

The Iraq Agricultural Extension System

Early IAER sessions further enabled assessment of Iraqi training needs in various agriculture subjects (Table 3). These data identified topics for the subsequent training. Based on responses from trainees, information on drought-tolerant crops, weed control, seeding rates and seed placement, and organic waste fertilizers is needed in Iraq. According to the agricultural status assessed by other questionnaires (data not shown), future training sessions need to also focus on fruit and vegetable production, plant disease management, use and maintenance of equipment, and financial farm management. Most of these topics were addressed in later sessions. Unfortunately the IAER phase 1 ended before some other topics such as arid land alternative crops could be covered. Further training is recommended to meet these critical needs.

Participants self-assessed their level of understanding before and after the training program (Tables 4, 5, 6, 7, and 8). Among all sessions, trainees improved their understanding by at least 1 point (on a 4-point scale) in 88% of topics. In 95% of the topics knowledge after training was rated at 3.0 or higher. Learning was excellent in many areas including soil fertility management practices, soil salinity, low-input agriculture, and biological control. The substantial knowledge improvement in these topics confirmed a high need for and interest in these areas. Iraqi extension agents were most interested in practical management solutions to their problems such as soil compaction, erosion, and salinity. Background information in weed and insect identification, differences between predators and parasitoids were not their priority (Table 6). Many trainees had good knowledge prior to training sessions for some topics including: importance of soil fertility (Table 4), pesticide labels (Table 6), deforestation, and seedbed preparation (Table 8).

Pre- and post-session exams given during the training session in Syria show an overall improvement in the understanding of soil fertility principles (30%) and composting (22%) (Fig. 1). Knowledge gained in variety testing was apparently much less, largely due to the trainees' prior education.

Before international sanctions began in 1992, Iraq had a well-developed agricultural system with three companies averaging 80,000 tons of seed sales per year, sufficient supplies of nitrogen and phosphorus fertilizers, and modern machinery (Bishay, 2003). Consequences of the current situation, including shortages in seed and fertilizer supplies, and general disrepair of the agricultural machinery, were confirmed by personal communication with trainees.

Another unfortunate consequence is the loss of agricultural information in Iraq; most records were destroyed in 2003 during the war. As a result, many scientists are not able to keep current in agricultural information or they have left the country, which led to closure of several universities. Rebuilding a science library and connecting both universities and MOA offices to online journals is highly recommended to improve the information base in Iraq.

In Iraq, as in most developing countries (Adams, 1982), governmental ministries manage the agricultural extension system. The MOA is divided geographically into departments. Three levels of administration operate the Iraqi agricultural extension system: a director housed in a governmental office in Bagdad; assistant directors at the regional, provincial, or state level; and extension officers at the district level (Adams, 1982). Historically, Iraq had seven specialized research departments (field crops, horticulture and forestry, plant protection, plant and seed certification, soil and land reclamation, drainage and irrigation, and animal resources) (AOAD–ISNAR, 1992). University faculties informally interact with the extension system but lack direct influence or lines of communication. In contrast, U.S. agricultural extension is based on state and USDA funds granted to university specialists who then communicate to farmers via county extension agents (West et al., 1980). The U.S. system allows a more direct flow of information from universities to extension agents located in rural communities.

In a 1981 survey, 43% of Iraqi farmers trusted extension agents whereas 46% had a negative attitude and 11% were neutral (Al-Chazeleh and Abed, 1981). This illustrates the need for inservice training sessions for extension personnel (Singh and Mohammed, 1979) and better collaboration with university faculty. These changes would allow extension agents to show farmers experimental data backing up their claims; increasing both their credibility in the eyes of farmers and their effectiveness as extension agents.

CONCLUSIONS

The IAER program was successful in networking with Iraq Ministry of Agriculture, Extension, and agricultural university faculty, identifying needs for updated information on agricultural knowledge and technologies, organizing training and delivering up to date and practical information for Iraqi extension personnel. Efforts should be made to strengthen links between extension agents at the MOA and Iraq's academic researchers, as was started by the Oil-for-Food program (FAO in 2003) and more recently by the IAER project. The second stage of the IAER program will focus on links between Iraqi academia and extension. Meeting these goals will help the Iraqi people rebuild their agricultural infrastructure and become more self-sufficient.

In the future when the political situation stabilizes, scientists and other displaced citizens may return to Iraq. Increased safety would also allow programs like the IAER and internal extension training sessions to be held in Iraqi communities. A calmer political situation will also make it easier to bring in supplies such as new machinery, seeds, and fertilizers in order to improve the current agricultural conditions.

LITERATURE CITED

Adams, M.E. 1982. Agricultural extension in developing countries. Longman Group Ltd., Singapore.

Al-Chazeleh, F.M., and S.K. Abed. 1981. Attitudes of cooperative farmers towards agricultural extension. A study in Alzab Alasfal and Alkaiara areas. Mesopotamia J. Agric. Iraq 16:21–40.

AOAD–ISNAR. 1992. A review of the agricultural research system in the Republic of Iraq. Country Review Rep. R54. The Hague, the Netherlands.

Bishay, F. 2003. Towards sustainable agricultural development in Iraq. Available at http://www.fao.org/docrep/006/Y9870E/y9870e00.HTM (accessed 12 May 2008; verified 27 Apr. 2009). FAO, Rome.

FAO. 2000. Assessment of the food and nutrition situation in Iraq. Global Information and Early Warning System. Available at http://www.fao.org/docrep/005/x8147e/x8147e00.htm (accessed 5 May 2008; verified 27 Apr. 2009). FAO, Rome.

FAO. 2006. Near East fertilizer use manual. FAO, Rome.

FAOSTAT. 2007. FAOSTAT. Available at http://faostat.fao.org (accessed 18 May 2008; verified 27 Apr. 2009). FAO, Rome.

Looney, R. 2003. Bean counting in Baghdad: Debt, reparations, reconstruction, and resources. Middle East Review of International Affairs (MERIA) J. 7:60–72 Available at http://meria.idc.ac.il/journal/2003/issue3/looney.pdf (accessed 23 Dec. 2008; verified 27 Apr. 2009).

Schnepf, R. 2003. Iraq's agriculture: Background and status. Congressional Research Service. Available at http://www.nationalaglawcenter.org/assets/crs/RS21516.pdf (accessed 16 Jun. 2008; verified 27 Apr. 2009). National Agric. Law Center, Univ. of Arkansas School of Law, Fayetteville.

Singh, R., and Z.H. Mohammed. 1979. A study of the training needs of extension workers belonging to northern Iraq. Mesopotamia J. Agric. Iraq 14:5–17.

Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1985. Soil fertility and fertilizers. 4th ed. Macmillan Publishing Co., New York.

USAID. 2006. Final report: Agricultural reconstruction and development program for Iraq. USAID, Washington DC.

West, F.C., R.M. Bor, J.E. Hogan, and J.R. Kramer. 1980. Compilation of statutes related to agricultural and forestry research and extension activities and related matters. U.S. Gov. Print. Office, Washington, DC.

Table 1. Topics covered in the five Washington State University (WSU) training sessions for Iraqi extension agents.

Session 1	Session 2	Session 3	Session 4	Session 5
Egypt, July 2007	Syria, January 2008	Jordan, March 2008	Jordan, June 2008	Jordan, July 2008
Soil and water sampling	soil profiles	conservation tillage	agriculture in Washington State	reclaiming agricultural land
Soil texture	soil fertility (N, P, K)	undercutter method	food-borne diseases	forage crop and pasture
Soil and water analysis	fertilizer recommendations	economics of conservation farming	sanitation	water harvesting
N, P, K fertilizer use	crop rotation	integrated pest management	global warming	deforestation reclamation
Soil pH and EC	soil pH and EC	weed identification	professional communication	annuals vs. perennials
Fertilizer recommendations	designing demonstrations	insect taxonomy and sampling	sustainability	intercropping
Global positioning system	variety testing	pesticide formulations and labels	organic waste management	grazing management
	participatory plant breeding	pesticide hazards and safety	low input/organic farming	reclamation of oil contaminated soils
	composting	weed control	crop rotation	forage processing and storage
	rhizobia	biological and chemical controls of pests	"lasagna" gardening	
			rhizobia	
			direct marketing	
			composting	

Table. 2. Materials distributed to Iraqi extension agents in four training sessions. None were distributed in Session 5.

Session 1	Session 2	Session 3	Session 4
Soil and Water Test Kit (Hach SIW-1)†	double right angle prism	insect net	handwash kit (Glo Germ 1002)
Soil auger†		dark light	rhizobium inoculum
Global Positioning System† (Garmin GPSMAP 76-S)		pesticide sprayer†	digital food thermometer
Near East Fertilizer Use Manual (FAO, 2006)			pH and chlorine strips

† Only five were distributed to selected trainees.

Table 3. Educational needs self-assessment of Iraqi extension agents. Average response in each of 12 training sessions held by various U.S. universities (1 = less needed to 5 = highly needed).

Topics	**Sessions**												
	GT†	**BK**	**GI**	**DP**	**HP**	**DR**	**FB**	**PP**	**PHH**	**PPM**	**CPPT**	**DMC**	**Avg.**
Alternative crops more adapted to arid areas	4.1	4.0	4.2	4.2	3.8	4.2	3.8	3.8	3.8	4.1	3.9	3.9	4.0
Weed control for yield and water conservation	4.7	3.6	3.9	4.2	3.7	3.9	3.7	3.7	3.6	3.9	4.2	4.0	3.9
Seeding rates and seed placement in the soil	4.1	3.9	3.5	4.9	3.7	4.0	3.7	3.7	3.6	3.8	4.0	3.6	3.8
Using manures and organic wastes for fertilizer	4.1	3.9	3.9	4.2	3.8	4.0	3.8	3.8	3.0	4.0	3.7	3.5	3.8
Dryland crop disease diagnosis and treatment	4.2	3.8	3.7	4.2	3.4	4.0	3.4	3.4	3.9	3.7	4.0	3.6	3.8
Storage and marketing to improve income	3.9	3.1	3.5	4.4	3.9	3.7	3.9	3.9	3.3	3.7	3.8	3.7	3.8
On farm testing of new crops or varieties	3.8	3.7	3.5	3.9	3.7	4.0	3.7	3. 7	3.2	3.8	3.8	4.1	3.7
Insect scouting and treatment	4.2	3.8	3.6	4.2	3.4	3.8	3.4	3.4	3.5	3.3	3.8	3.7	3.7
Fertilizer rates for crops based on soil analysis	4.2	3.7	3.8	4.3	3.5	3.7	3.5	3.5	3.2	3.7	3.3	3.2	3.6
Application and storage of farm chemicals	3.5	3.2	3.3	3.9	3.2	3.2	3.2	3.2	3.3	3.6	3.5	3.6	3.4
Residue management to add soil organic matter	3.7	3.3	3.4	4.0	3.2	3.7	3.2	3.2	3.23	3.4	3.0	3.1	3.4
Crops and varieties for water efficiency	3.9	3.7	3.7	3.6	3.0	3.5	3.0	3.0	3.2	3.5	3.2	2.9	3.3
Dryland crop nutritional requirements	3.8	3.3	3.5	3.7	2.8	3.3	2.8	2.8	2.8	3.4	3.4	3.3	3.2
Soil erosion effects on future crop yields	3.6	2.7	3.6	3.7	2.9	2.9	2.9	2.9	2.4	3.8	3.1	2.5	3.1

† GT, general training in Egypt; BK,: beekeeping; DP, dairy production; PP, poultry production; FB, farm business management; PHH, post-harvest horticulture; CPPT, crop pest management and tillage; GI, general irrigation; PPM, project planning and management; HP, horticulture pest; DMC, developing multimedia communication; DR, designing research.

Table 4. Knowledge self-assessment by Iraqi extension agents before and after the first training session in Egypt (*n* = 63; 1 = poor, 2 = fair, 3 = good, 4 = excellent).

Topics	Before training	After training	Change
Analysis of soil P	1.65	3.63	1.98
Analysis of soil N	1.68	3.55	1.88
Analysis of soil K	1.62	3.45	1.83
Analysis of soil acidity	1.82	3.63	1.82
Analysis of soil salinity	1.86	3.58	1.72
Correct procedures for soil sampling	1.92	3.54	1.62
Interpretation of soil analysis of P	1.75	3.37	1.62
Interpretation of soil analysis of K	1.68	3.29	1.62
Analysis of soil texture	1.75	3.14	1.38
Interpretation of soil analysis of texture	1.80	3.11	1.31
Interpretation of soil analysis of pH	1.98	3.25	1.26
Physical and chemical properties of soil	2.00	3.22	1.22
Importance of soil fertility	2.42	3.38	0.97

Table 5. Knowledge self-assessment by Iraqi extension agents before and after the second training session in Syria (n = 29; 1= poor, 2= fair, 3= good, 4= excellent).

Topics	**Before training**	**After training**	**Change**
Ability to assess soil quality and diagnose potential soil problems	1.90	3.48	1.59
Developing fertilizer recommendations for N, P, and K	1.97	3.52	1.55
Determining study objectives for agriculture demonstrations	1.88	3.42	1.54
Management of soil pH and salinity	2.00	3.52	1.52
“Law of diminishing return” for fertilizer applications	1.59	3.07	1.48
Developing fertilizer recommendations based on crop requirements	2.03	3.52	1.48
Use of manure or other organic sources of nutrients	2.38	3.86	1.48
Conducting crop variety testing demonstrations	1.93	3.39	1.46
Management of P and K to improve fertilizer efficiency	2.04	3.48	1.45
Development of crop rotations for several years	2.21	3.62	1.41
Equipment used in fertilizing and seeding	1.90	3.28	1.38
Broadly vs. narrowly adapted variety testing	1.57	2.93	1.36
Nutrient sources, rates, timing of applications, and soil placement	2.24	3.55	1.31
Developing an experimental design for a demonstration	1.97	3.28	1.31
Management of nitrogen to improve fertilizer efficiency	1.93	3.11	1.18

Table 6. Knowledge self-assessment by Iraqi extension agents before and after the third training session in Jordan (*n* = 29; 1= poor, 2= fair, 3= good, 4= excellent).

Topics	**Before training**	**After training**	**Change**
How to adopt a new tillage system	1.61	3.30	1.70
Use of sex pheromone to disrupt mating of pest insects	1.96	3.52	1.56
Concepts and methods of conservation tillage	1.88	3.44	1.56
Equipment and machinery needed for conservation tillage	1.62	3.12	1.50
Use of cover crops and rotation in conservation tillage	1.77	3.19	1.42
Costs and profitability of conservation tillage	1.81	3.23	1.42
Controlling weeds under conservation tillage systems	1.65	3.04	1.38
Conservation biological control	1.84	3.20	1.36
Long-term effects of conservation tillage	1.81	3.12	1.31
How pesticides get into the body and the hazards from pesticide exposure	2.40	3.68	1.28
Advantages and disadvantages of tillage operations	2.24	3.52	1.28
Sampling techniques in integrated pest management	1.92	3.19	1.27
Action thresholds	1.84	3.08	1.24
How to determine the cause of a plant problem	1.96	3.08	1.12
How to protect yourself from exposure when using pesticides	2.68	3.76	1.08
Strategies for controlling weeds in dryland crops	1.96	3.04	1.08
Degree-day information	1.75	2.75	1.00
Weed biology	2.08	3.04	0.96
Pesticide labels	2.50	3.42	0.92
Keys to identify a pest insect	2.31	3.19	0.88
Useful information for identifying weeds	2.08	2.92	0.84
Difference between a predator and parasitoid	2.68	3.48	0.80

Table 7. Knowledge self-assessment by Iraqi extension agents before and after the fourth training session in Jordan (n = 26; 1= poor, 2= fair, 3= good, 4= excellent).

Topics	Before training	After training	Change
Benefits and methods of "baklava gardening"	1.50	3.19	1.69
Methods of composting, benefits, and application	2.04	3.62	1.58
Identification of areas of the hand that are often improperly washed	2.38	3.92	1.54
Direct marketing considerations and plans	1.92	3.44	1.52
Nitrogen fixation and rhizobial inoculation	2.15	3.62	1.46
Methods of organic waste recycling and reuse	2.12	3.52	1.40
Low-input farming methods and benefits	1.96	3.35	1.38
Potential agricultural products and production corresponding to regions in Iraq	2.12	3.36	1.24
Classes of sanitizers	2.50	3.73	1.23
Practices that reduce the likelihood of food-borne illness	2.62	3.85	1.23
Basic food-borne disease characteristics	2.69	3.88	1.19
Factors that can control or enhance food-borne pathogens	2.65	3.85	1.19
Meaning of sustainability and sustainable agriculture	1.76	2.92	1.16
Criteria for written and oral professional communications	2.35	3.50	1.15
Global climate change, and potential methods of reducing greenhouse gases	2.19	3.31	1.12
Difference between cleaning and sanitation	2.69	3.81	1.12
Definition and design of crop rotation	2.38	3.46	1.08

Table 8. Knowledge self-assessment by Iraqi extension agents before and after the fifth training session in Jordan (*n* = 27; 1= poor, 2= fair, 3= good, 4= excellent).

Topics	**Before training**	**After training**	**Change**
Water harvesting techniques	1.56	3.48	1.93
Reclamation of oil contaminated soils	1.52	3.22	1.70
Microcatchment water harvesting potential	1.69	3.12	1.42
Impacts and solutions to salinity impacted soils	2.00	3.41	1.41
Nitrate poisoning	1.89	3.30	1.41
Forage quality testing procedures	2.19	3.37	1.19
Intercropping, interseeding and overseeding relationships	2.26	3.41	1.15
Seeding depth for forage grasses/legumes	2.23	3.35	1.12
Keys to harvested forage crop quality and quantity	2.04	3.15	1.11
Seasonal growth distribution of different grasses and legumes	2.30	3.37	1.07
Carrying capacity and stocking rate	2.19	3.22	1.04
Overgrazing	2.63	3.63	1.00
Improper agricultural practices	2.56	3.52	0.96
Relationship of forage quality and forage yield	2.37	3.33	0.96
Deforestation problems and solutions	2.52	3.37	0.85
Seedbed preparation	2.74	3.37	0.63

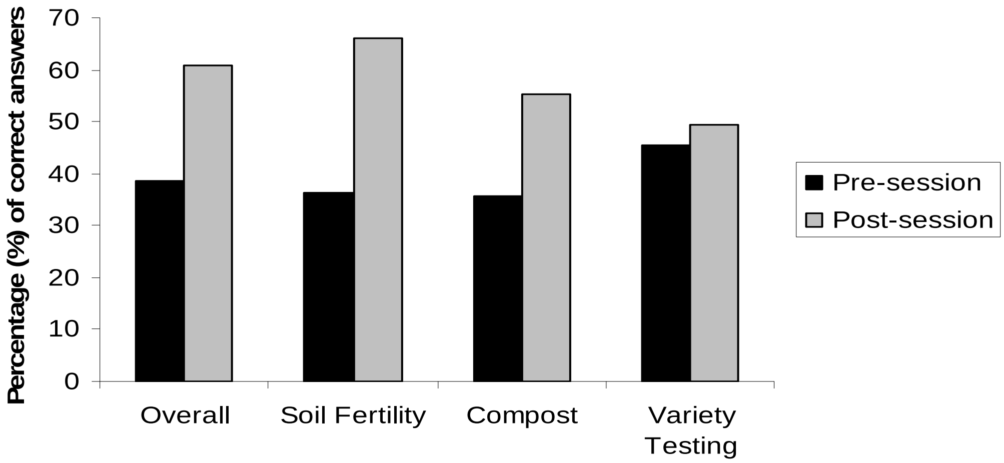

Fig 1. Exam scores of Iraqi extension agents in soil fertility, composting, and crop variety before and after training on these topics in Session 2 in Syria (*n* = 29).

APPENDIX II

Pre and post questionnaire at ICARDA session

Circle the most correct answer to each question.

1. In more arid (dry) climates, white deposits in soil frequently indicate the presence of
    a. Nutrients
    b. Carbonates
    c. Organic matter
    d. Nitrogen

2. Soil pH is a measure of
    a. The nutrient content of soils
    b. Soil formation
    c. Acidity or alkalinity of soil
    d. Nutrient availability in soil

3. The law of the minimum states
    a. Production is limited mainly by nutrients
    b. Production is limited mainly by water availability
    c. Production cannot be greater than that allowed by the most limiting factor
    d. Yield is not limited by soil factors

4. Phosphorus is needed by wheat plants most importantly at this growth stage
    a. Seed germination and emergence
    b. Elongation of the stem
    c. Flowering
    d. Grain filling

5. Soil tests measure
    a. The total nutrient content of soil
    b. The level of plant-available nutrients in soil
    c. Nutrients contained in the soil solution only
    d. Nutrients contained in solid mineral forms only

6. Nutrients that are not mobile in plants have the following symptoms
    a. Yellow stripes on leaves
    b. Brown edges on leaves
    c. Symptoms appearing on older leaves first
    d. Symptoms appearing on younger leaves first

7. A nutrient deficiency symptom characterized by leaf yellowing between green veins on the younger leaves of plants is associated with
    a. Nitrogen
    b. Potassium
    c. Copper
    d. Iron
8. Band placement of fertilizer is most important for
    a. Nitrogen

b. Potassium
c. Nutrients that are immobile in soil
d. Nutrients that are mobile in soil

9. The law of diminishing returns states that
    a. Yield is limited by the most limiting factor
    b. Yield increases are less with each successive increase in an input
    c. Yield will continue to decline the longer a crop is grown on a field
    d. Yield is increased by the most limiting factor

10. Applying the total amount of nitrogen in several separate applications is important when
    a. Farming in very dry regions
    b. Growing wheat
    c. Farming in very wet regions or with irrigation
    d. Farming in very cold regions

11. The presence of soluble salts in soil can be identified by
    a. White deposits that react with acid
    b. White deposits that do not react with acid
    c. Dark deposits that react with acid
    d. Dark deposits that do not react with acid

12. High soil pH can result in deficiencies of the this nutrient even though the nutrient is present in soil
    a. Calcium
    b. Magnesium
    c. Zinc
    d. Sulfur

13. The three numbers associated with a fertilizer label are
    a. The percent phosphorus, potassium and nitrogen in the material
    b. The percent nitrogen, sulfur and phosphorus in the material
    c. The percent nitrogen, phosphorus and potassium in the material
    d. The percent sulfur, potassium and nitrogen in the material

14. Banding fertilizer can do the following
    a. Increase crop yield
    b. Reduce the amount of fertilizer required to achieve optimum yield
    c. Improve early season growth
    d. All of the above

15. The maximum amount of nitrogen + potassium that should be placed with the seed of a crop planted in the spring is
    a. 40 kg per hectare
    b. 20 kg per hectare
    c. 10 kg per hectare

d. No nitrogen or potassium should be placed with the seed

16. Phosphorus and potassium cycles in soil are strongly controlled by
    a. Water content and availability
    b. Cropping systems and rotations
    c. Reactions involving soil minerals
    d. Reactions involving organic matter

17. Compost is used in soil to
    a. Add nutrients for crops
    b. Reduce moisture-holding
    c. Improve soil texture
    d. Both a and b
    e. Both a and c

18. What organisms are most active in composting materials
    a. Bacteria
    b. Nematodes
    c. Fungi
    d. Both a and b
    e. Both a and c

19. Composting produces
    a. CO_2
    b. Heat
    c. Oxygen
    d. Both a and b
    e. Both b and c

20. Selection of cereal varieties often depends upon:
    a. Yield potential
    b. Yield stability
    c. Disease resistance
    d. Cultural preferences
    e. Quality
    f. All of the above

21. 'Variety by environment' interaction is important because:
    a. Varietal performance is the usually the same regardless of location
    b. Differences in soil, climate and disease pressures have an effect on varietal performance
    c. Different varieties often perform similarly in favorable environments

22. The type of cropping system (low-input, high-chemical or fertilizer input, organic) makes a difference in the choice of variety
    a. True

b. False

23. Participatory plant breeding (PPB) is different from variety testing because
    a. Farmers are included in PPB only
    b. There is no difference
    c. PPB offers more genetic variation to select from

24. In on-farm testing, a positive control is included in the comparison for the following reason
    a. To test the new product against nothing
    b. To test the new product or practice against other new products or practices
    c. To test the new product or practice against the current standard
    d. To test the new product or practice in a new environment

25. In on-farm testing, blocking of treatments is recommended to
    a. Account for natural field variability in the installation of the experiment
    b. Ensure all treatments are replicated
    c. Arrange treatments in an order that facilitates installation
    d. Reduce the level of difference between treatments and the control

CHAPTER FIVE

EXTENSION EDUCATION AND THE ROLE OF WOMEN IN IRAQI AGRICULTURE

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ABSTRACT

The Iraq Agriculture Extension and Revitalization project offered training sessions for Iraqi extension agents in 2007-2008. Surveys of participants in a majority male session and a women's session assessed the current status and changes over the past 10 years in agricultural supplies and information, and the role of women in Iraqi agriculture. Perceptions of change in access to supplies, technology, and information appear to be highly place-dependent and may reflect the significantly different recent histories in various parts of Iraq. Women extension agents hold different views than men concerning the role of professionals and community members in training local farmers.

INTRODUCTION

Iraq occupies 43.7 million ha, of which only 9.5 million ha is suitable for agriculture. The major crops are grains, including wheat and barley, with significant vegetable, tree fruit and vine (fig, grape, olive and date) production as well (Shnepft, 2003). Iraq is diverse geographically, ranging from rich alluvial plains of the Southern Tigris-Euphrates valley to the mountainous domain in Kurdistan (KRG) characterized by rivers and cultivated terraces. Foothills have poor fertility and moderate rainfall. One-fifth of the country is occupied in the northwest by the Jazira plateau, arable land that is susceptible to drought. Desert constitutes 40% of the country's land area, inhabited by semi-nomadic agro-pastoralists (EIU, 2007).

Outputs from Iraq's agriculture and food production systems have declined from their peak production attained in 1991 (EIU, 2007). This decline has resulted in the destruction of the agricultural infrastructure. Iraq once had three seed companies producing 80,000 tons of seed per year, was self-sufficient in nitrogen (N) and phosphorus (P) fertilizer production, and had modern farm machinery (Bishay, 2003). Now, there is a shortage of seeds and N and P fertilizers, and seed quality is poor. Agricultural equipment, when available, is old. Tillage has contributed to physical degradation of soil structure. Erosion and the removal of crop residues for animal feed have depleted the soil organic matter (Bishay, 2003). Soil salinity has worsened due to a lack of high quality water and irrigation equipment, and poor water management. Many people have left rural areas causing a labor shortage which further exacerbates the decline in agricultural productivity (Shnepft, 2003). Currently 80% of available food is imported from neighboring countries (McChesney, 2008).

With the deterioration of agricultural infrastructure it is obvious that Iraq will continue to depend upon imported products for some time. In order to help in revitalization of the agricultural system, training sessions for Iraqi extension agents were developed by organizations such as the United Nations, and countries including the United States and Australia. The recent USDA-funded Iraq Agricultural Extension Revitalization project (IAER) - aimed to: i) promote collaboration between the Iraqi Ministry of Agriculture (MOA) and universities and ii) train extension professionals to deliver courses to farmers in their communities (Abi-Ghanem et al., 2009). These sessions were designed to help Iraq regain its agricultural self-sufficiency through updating the training of its community agricultural professionels.

The roles and opinions of women in Arab agriculture are seldom addressed, and facts often contradict stated ideals. For example, according to the Arab Charter on Human Rights, there should be no discrimination between men and women who are equal in terms of occupation (Cotula, 2006). However, in most Arab countries women own less farm land and plot sizes are smaller than men's. In Jordan, women own 28.6% of land; 4.9% in the United Arab Emirates; and only 0.4% in Oman. Women receive 2.8% of agricultural loans in Turkey, 6% in Jordan and 15% in Iran (Cotula, 2006). In most Arab countries, men dominate extension positions due to cultural obstacles. For example, in Syria women need their husbands' approval for employment (Cotula, 2006). Given the current shortage of food, self-sufficiency, farm labor, management, and education, more effort is needed to increase women's involvement in agriculture in Iraq. In order to increase the potential role of women in Iraq's agricultural redevelopment, a special IAER training session was held for women from the MOA.

The purpose of this paper is to report the results of a self-assessment survey given to Iraqi men and women in two sessions of the IAER program. Respondents assessed changes in the agricultural situation in Iraq over the last 10 years and the role of women in this sector.

MATERIALS AND METHODS

Texas A&M University led the IAER program, which included four other land grant universities: Washington State University (WSU); University of California-Davis, New Mexico State University, and Utah State University. Each university held multiple training sessions in the Middle East, where two to five university faculty members trained 25 to 30 MOA agents for an average of 6 days per session (Abi-Ghanem et al., 2009).

In two WSU sessions trainees completed questionnaires to assess the agricultural situation in Iraq. The first group to complete the questionnaire was twenty-nine trainees from the MOA, of whom only 4 were women. This group attended a session in January 2008 at the International Center for Agricultural Research in the Dry Areas (ICARDA) at Aleppo, Syria. The ICARDA session (IS) featured topics of soil fertility, composting, and crop variety testing. The second group to complete the questionnaire was twenty-six women from the MOA who attended an all-women's session (WS) in June 2008 in Amman, Jordan. This training featured topics of sustainable agriculture, composting, food safety, and scientific communications. These topics were chosen based on interest from previous training surveys.

In each session, participants answered the same set of questions, designed using methods by Brace (2004), regarding agriculture in their country. This questionnaire included 17 questions to assess the agricultural infrastructure in Iraq and its changes over the last 10 years, access to information, basic inputs, and new technologies, methods of bringing information to growers, and the role of women in Iraq agriculture.

RESULTS AND DISCUSSION

The IS was 86% male and 14% female while the WS was 100% female. In both of these trainings approximately half of the participants were from KRG and half from the remainder of Iraq (Table 1), reflecting the two separate MOAs, one in Erbil and one in Baghdad. In both sessions, southern Iraq (Al-Muthanna and Basra governorates) had the lowest representation at 12-13%. At the IS, 55% of the participants were in the 30 to 40–year old age class while in the women session (WS) 52% were in the 20 to 30-year age class (Fig. 1). At the IS, 87% of trainees held a BS degree in agriculture while in the WS only 62% had a BS degree and 31% graduated from technical school (data not shown).

International sanctions imposed since 1992 significantly restricted the flow and availability of agricultural supplies and products. Both groups felt that access to agricultural inputs, such as seeds and fertilizers, is currently insufficient in Iraq (70% in IS, 98% in WS; Fig. 2). Although many responses in both IS (66%) and WS (50%) reported that access to inputs is better now than 10 years ago (Table 1), even more indicated that they are still insufficient. This shows a tremendous need to improve the availability of inputs in Iraq.

Although the majority response among participants was that access to both information and inputs is better in 2008 than in 1998 (Tables 1 and 2), there was some disagreement, particularly with regard to access to new technologies. Trainees in IS indicated that access to new technologies has improved compared to 10 years ago in most regions of Iraq. In the WS, respondents from all regions, but especially KRG, indicated that new technologies have become less available over the same time period. Many of the women from Northern Iraq are new graduates, which may cause their technology expectations to be higher. The generally younger age class for the WS may explain some of the differences in answers between the groups. Respondents under 30 also have little professional experience prior to the current political conflict, which may further affect their perceptions. Participants generally indicated that both they and farmers had more access to basic agricultural information compared to 10 years ago with the exception of some farmers in KRG and central Iraq (Salaheddin and Baghdad), who had less access (Table 2). In central Iraq this is related to unstable conditions that make it unsafe for extension personnel to visit farmers and either access or distribute information.

Discussions with training participants revealed differences in the recent history in various regions in Iraq that help to explain these aforementioned perceptions. In the northern region, agriculture during 1997-2003 was promoted and well supported with new technologies from both international organizations and the KRG government. At the initiation of the new conflict in 2003, international organizations had to abandon their programs and so only governmental support was available. Southern Iraq, especially Basra, possessed advanced vegetable and crop production practices prior to sanctions being imposed in 1992 (www.globalsecurity.org). Today, this sector is much less productive and has not recovered. Al-Muthanna, which borders Saudi Arabia in the South, is more successful economically compared to neighboring regions. The higher per capita income originates from sheep herding. The annual Islamic pilgrimage through this region provides for better trade along the Saudi border and sales of lamb and other products at this time are a significant industry. Although the Euphrates flows through Al-Muthanna, agriculture in this area is less productive than near Basra because of high soil salinity. Areas bordering Iran have poor agricultural systems due to the 1980-1988 Iraq-Iran war. The exception is Wasit, which has maintained an advanced agricultural system due to access to rivers that allow trade in goods and technology.

Participants in both sessions agreed that agricultural education for farmers is needed in Iraq. Trainees at IS indicated high demand for farmer education in plant protection, fruit and vegetable production, machinery use and repair, row crop production, and soil fertility (Fig. 3). Participants in the WS indicated nearly the same needs except soil fertility was replaced with weed control as a high priority. Open-ended questions during training also found soil salinity, seed production, and deforestation as major concerns.

According to trainees in both sessions, farmers in Iraq greatly prefer to obtain information through face-to-face interaction with extension personnel (Fig. 4), as access to the internet and written materials is limited. Iraqi extension personnel need to focus more on organizing workshops for farmers and in-situ demonstrations.

Opinions regarding the means by which farmers acquired agricultural education differed by gender among the Iraqi extension personnel. More trainees in both sessions thought that most farmers are trained by other local farmers and members of their own family (Fig. 5), and do not have college education or specialized agricultural training. However only a slightly lower number of trainees in the IS session indicated that farmers in their governorate had no agricultural education, whereas this was the least common answer in the WS. As the regional representation of trainees was similar in both sessions, this difference in answers is more likely perception than fact. Women in the MOA might be approached less by uneducated farmers and proportionately more by educated farmers, leading to a perception that most farmers are educated. Or, the WS may consider training by family members, mentors, and extension workshops as legitimate sources of farmer education, while the IS considered the farmers in their areas as uneducated if their training was from these sources.

The survey question concerning women's roles led to uncertainty, discussion, and some debate, particularly in the IS. In both sessions most participants concluded that in their governorate women commonly contribute as farm labor, but few manage agricultural lands on their own (Fig. 6). Only one participant in each session believed women were not highly involved with agriculture in their region. Four participants at IS and five in WS believed that women manage at least 10% of farms in their areas. Some trainees interviewed in the WS stated that relatively few women own land, generally obtained through inheritance, and all have family members to help manage the farm. Still, these findings indicate that women are thought to be significantly involved in farming in Iraq. Yet the wide range in answers to this question in both sessions suggests that women's roles in managing farms are poorly understood or quantified.

It is clear from both survey results that Iraq is lacking both basic and advanced agricultural resources. All areas including KRG have rehabilitation needs, although the severity and specifics of those needs is highly place-dependent. In-person training is the most preferred method of extension education. In order to meet the needs identified in this study, future international effort should focus on reversing the physical and chemical damage to Iraq's soil and environement, and increasing access to machinery, inputs, and education.

LITERATURE CITED

Abi- Ghanem Rita, Lynne Carpenter-Boggs, Richard Koenig, Christopher Pannkuk, William Pan, and Robert Parker (2009). Extension Education for Dryland Cropping Systems in Iraq. Journal of Natural Resources and Life Sciences Education. 38:133-139.

Bishay, Fahmi (2003). Towards Sustainable Agricultural Development In Iraq. Food And Agriculture Organization Of The United Nations. Rome. Available at www.fao.org/docrep/006/Y9870E/y9870e00.HTM (retrieved 17 December 2008).

Brace, Ian (2004). Questionnaire Design. 1st ed. Kogan Page LTD. London.

Cotual, L (2006). Gender and Law. Women's rights in agriculture. Food and Agriculture Organization Of The United Sates. Rome.

Economist Intelligence Unit, 2007. Final report: Iraq. Available at www.eiu.com (retrieved February 10 2009).

McChesney, John (2008). U.S Military Aims to Help Iraqi Farmers. NPR news May 26, 2008. Available at www.npr.org/templates/story/story.php?storyId=90824321 (retrieved February 16 2009).

Schnepf, Randy (2003). Iraq's agriculture: Background and Status. Available at www.nationalaglawcenter.org/assets/crs/RS21516.pdf (retrieved18 December 2008).

Table 1. The relationship between location of Iraqi extension personnel in ICARDA session (IS) and women's session (WS) to their assessment of access to basic agricultural inputs and new technologies

			Current access to basic agricultural inputs compared to 10 years ago						**Current access to new technologies compared to 10 years ago***					
Region	**Number of respondents**		**More**		**Similar**		**Less**		**More**		**Similar**		**Less**	
	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS
South Iraq	4	3	4	1	0	0	0	2	3	1	0	0	1	2
Central Iraq	10	7	5	2	2	0	3	5	6	1**	2	2	2	3
Kurdistan	14	14	10**	10	2	2	1	2	6**	1	3	4	3	7
No answer	2	2	1	0	1	1	0	1	1	0	1	1	0	1
Total	30***	26	20	13	5	3	4	10	16	3	6	7	6	13

* One participant in IS and two in WS did not answer this question.
**One respondent marked 2 answers; this respondent was discarded for this question.
***One administrator took the survey in IS.

Table 2. The relationship between location of Iraqi extension personnel in ICARDA session (IS) and women's session (WS) to their assessment of access to agricultural information

			Current access to agricultural information compared to 10 years ago											
			For extension agents						For farmers*					
Region	**Number of respondents**		**More**		**Similar**		**Less**		**More**		**Similar**		**Less**	
	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS
South Iraq	4	3	4	3	0	0	0	0	3	2	1	0	0	1
Central Iraq	10	7	9	3	0	2	1	2	9	4	1	1	0	2
Kurdistan	14	14	12**	9	0	4	1	1	9	7	0	3	2	4
No answer	2	2	2	0	0	2	0	0	2	1	0	1	0	0
Total	30***	26	27	15	0	8	2	3	23	14	2	5	2	7

* One participant in IS and two in WS did not answer this question.
**One respondent marked 2 answers. This respondent was discarded for this question.
***One administrator took the survey in IS.

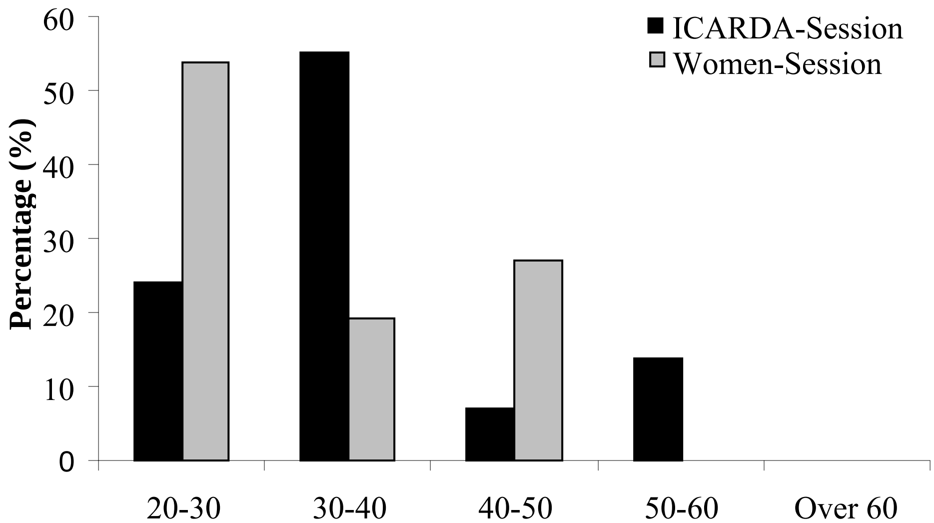

Fig 1. Age range of survey participants (IS n = 29, WS n = 26).

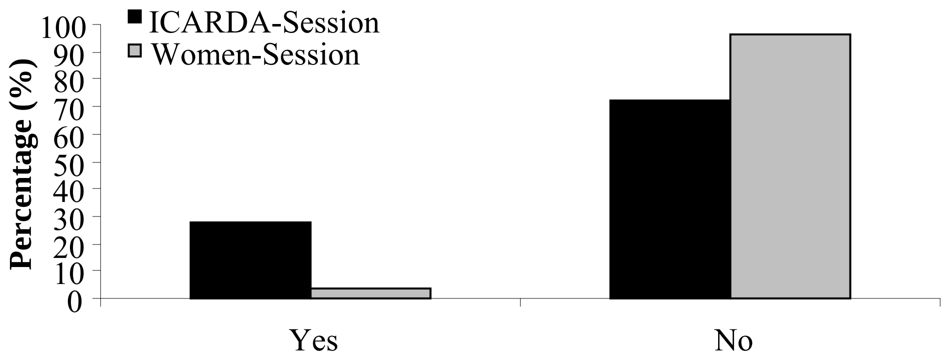

Fig 2. Iraqi extension agent's answers to the question "Is the current level of access to basic agricultural inputs such as seed and fertilizer sufficient?" (IS n = 29, WS n = 26).

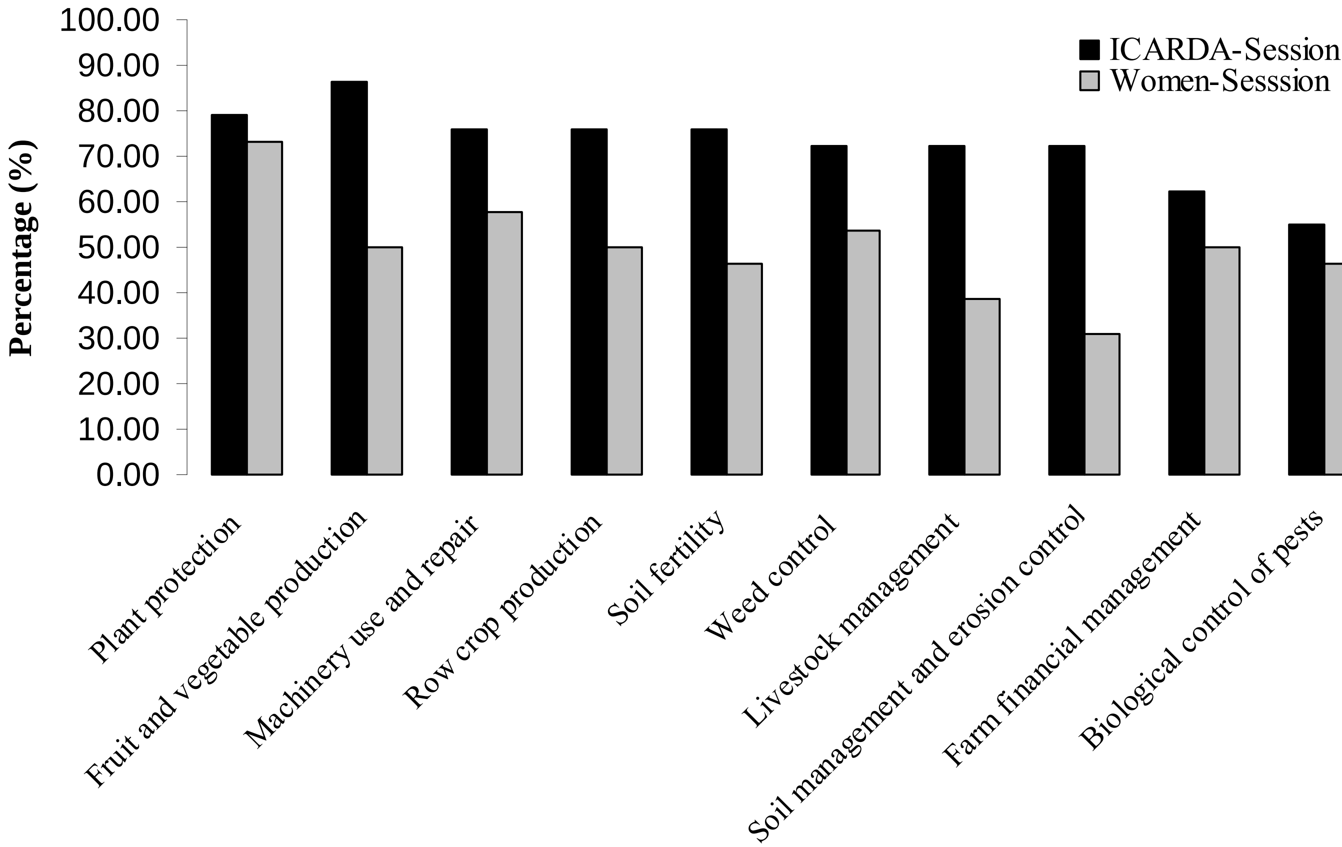

Fig 3. Iraqi extension personnel assessment of agricultural educational topics requested or needed by farmers in their Governorate (IS n = 29, WS n = 26).

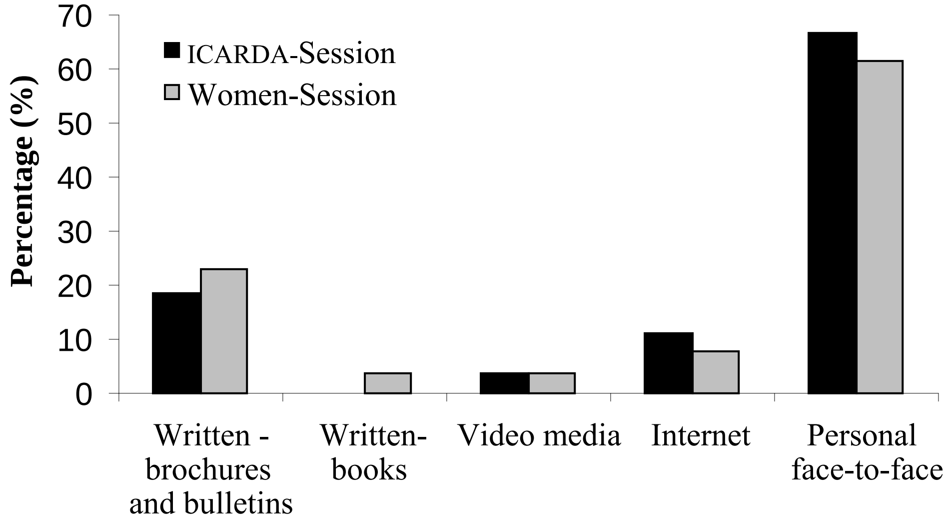

Fig 4. Iraqi extension personnel assessment of Iraqi farmers' most preferred format to obtain agricultural information (IS n = 29, WS n = 26).

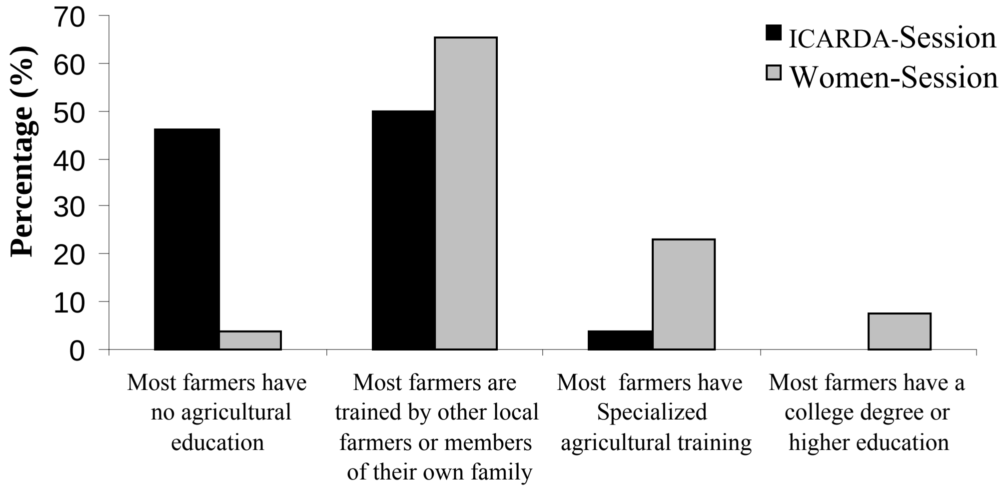

Fig 5. Iraqi extension personnel assessment of the agricultural education of farmers in their governorate (IS n = 29, WS n = 26).

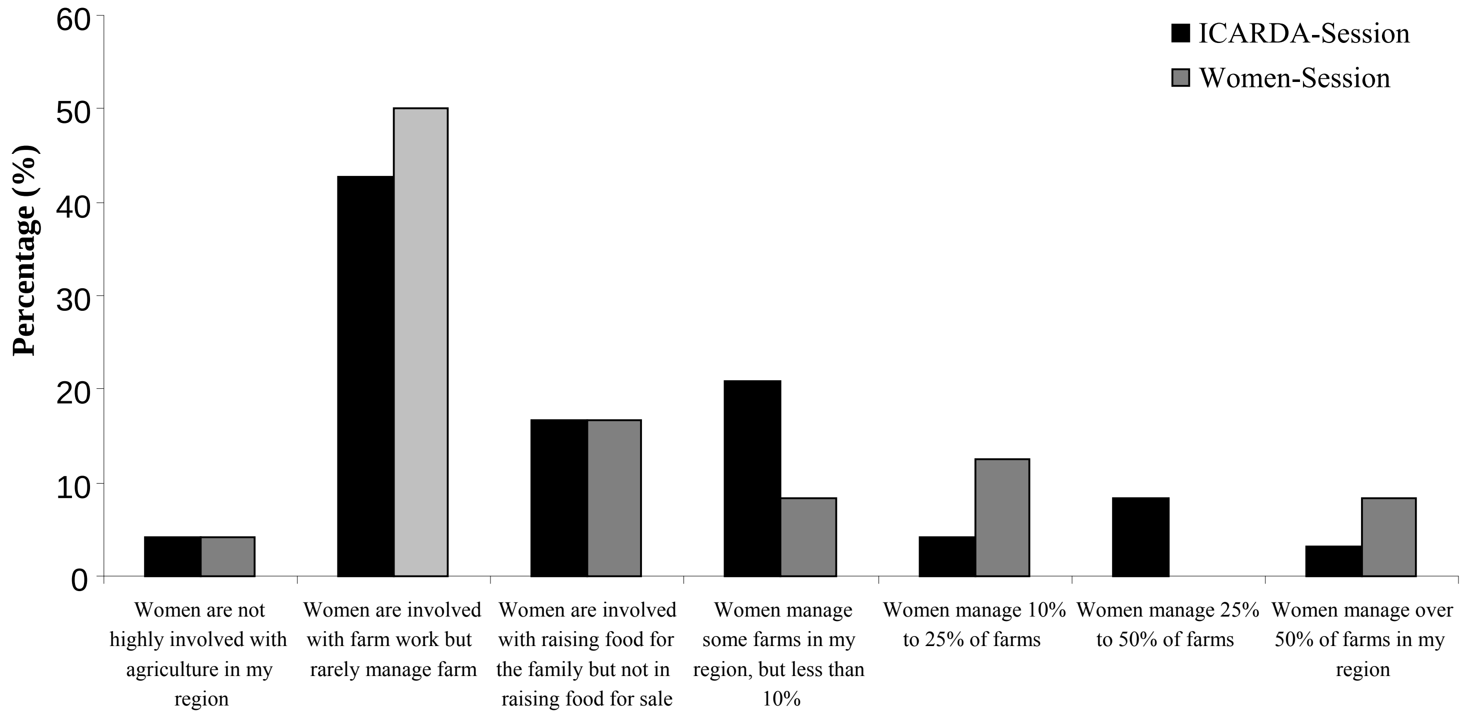

Fig 6. Iraqi extension personnel assessment of the involvement of women in Iraq agriculture (IS n = 29, WS n = 26).

APPENDIX III

Questionnaire to evaluate the Agriculture Extension program in Iraq

1. What formats do you prefer to use to obtain agricultural information? Please rank: 1= most preferred to 5 = least preferred.

_____ Written – brochures and bulletins
_____ Written – books
_____ Video media
_____ Internet
_____ Personal face-to-face

2. What strategies do you prefer to deliver agricultural extension information to farmers? Please rank: 1= most preferred to 5 = least preferred.

_____ Written – brochures and bulletins
_____ Written – books
_____ Video media
_____ Internet
_____ Personal face-to-face

3. What agricultural education topics are commonly requested or needed by the farmers you work with?
Mark all that apply.

____ Soil fertility
____ Soil management and erosion control
____ Row crop production (grains, pulses)
____ Fruit and vegetable production
____ Livestock management
____ Plant protection – chemical controls of pests, diseases
____ Biological and other non-chemical control of pests, diseases
____ Weed control
____ Farm financial management
____ Machinery use and repair
____ Economics of farm management
____ Other: __________________________

4. What are the sizes of farms in your region?
Please rank: 1= most common to 5 = least common.
____ 0-1 ha
____ 1-5 ha
____ 5-50 ha
____ 50-500 ha
____ over 500 ha

5. What percentages of farms producing crops for sale also grow other crops as food for their family?
a. less than 10%
b. 10% - 25%
c. 25% - 50%
d. 50% - 75%
e. Over 75% also produce other crops as food for the family

6. How are women involved with agriculture in your region? (choose the closest)
a. Women are not highly involved with agriculture in my region
b. Women are involved with farm work but rarely manage farm
c. Women are involved with raising food for the family but not in raising food for sale.
d. Women manage some farms in my region, but less than 10%
e. Women manage 10% to 25% of farms
f. Women manage 25% to 50% of farms
g. Women manage over 50% of farms in my region

7. How has access to new technologies in farm machinery, irrigation, chemicals, and technologies like global positioning systems (GPS), changed in the past 10 years?
a. There is more access now to new technologies
b. It is similar to 10 years ago
c. There is less access to new technologies

8. How has access to basic agricultural inputs such as seed, fertilizer, and chemicals changed in the past 10 years?
a. There is more access now to basic inputs
b. It is similar to 10 years ago
c. There is less access to basic inputs

9. Is the current level of access to basic agricultural inputs such as seed and fertilizer sufficient?
a. Yes, current access to basic inputs is sufficient
b. No, it is not sufficient

10. How has access to agricultural information changed in the past 10 years, both for you and for farmers?

For myself and other agricultural professionals:
a. There is more access now
b. Access to information is similar to 10 years ago
c. It is more difficult to obtain information now

For farmers:
a. There is more access now
b. Access to information is similar to 10 years ago
c. It is more difficult to obtain extension information now

11. In your region has agricultural production changed over the 10 years? (please describe)
a. A lot more _____
b. A little more _____
c. Same _____
d. Little less _____
e. More less _____

12. Has women role in agricultural production changed over the 10 years? (please describe)
1.
a. A lot more _____
b. A little more _____
c. Same _____
d. Little less _____
e. More less _____

13. Describe the agricultural education of farmers in your region:
a. Most farmers have no agricultural education.
b. Most farmers are trained by other local farmers or members of their own family
c. Most farmers have specialized agricultural training
d. Most farmers have a college degree or higher education

The last questions are for statistical correlation purposes only, and will be kept confidential:

14. Are you an extension agent?
a. Yes
b. No

15. What is your primary governorate of extension work? _____

16. Please tell us your age range:
a. 20-30
b. 30-40
c. 40-50
d. 50-60
e. Over 60

17. What is your highest earned level of education:
a. High school
b. Technical degree
a. BS
b. MS
c. PhD
a. Others, (please specify) _____

CHAPTER SIX

GENERAL CONCLUSIONS

The incorporation of legumes in crop rotation can be a successful tool to provide available N to following crops and reduce the need for synthetic N fertilizers. As the cost of fertilizers increases, the value of improving biological N fixation (BNF) also increases. This study investigated many varieties of the common Palouse pulse crops and many strains of rhizobia in search of varieties, strains, and trends that can be used to increase BNF. Varieties highly influenced the proportion of plant N provided by fixation (PNF). There was no significant interaction between varieties and strains in both lentils and peas. In lentils, Eston and Meritt contributed to the highest PNF respectively at 80.8% and 80.5%. Planting Eston could increase PNF by 12.6% or more, over Riveland. In peas, PNF reached 91.3 % and 90.5% in Shawnee and Bohatyr, respectively. Also, Shawnee could increase PNF by 4.49% over Lifter. In chickpeas, Sierra had 11.6 % greater PNF than Myles. Although PNF in chickpeas varied between varieties, it was correlated to N originated from seeds. Fried and Mellado's equation used to evaluate N fixation needs to be adjusted by subtracting N stored in the seeds. Strains in lentils had a relevant influence in N fixation, and the variability among the tested ones was 20.7 %. Otherwise, strains generally had less effect on the range of PNF than did varieties.

This research found the number of nodules to be positively correlated with PNF in the varieties and strains tested. In this case, infectiveness (the ability to form nodules) was highly correlated to effectiveness (the efficiency in N fixation). These findings suggest that in peas, lentils, and chickpeas, variety selection may potentially improve PNF, leading to higher yield, higher protein content, and/or more residual N for following crops.

Extension education and behavioral change are two other aspects needed to increase N fixation, convincing farmers to apply these techniques of inoculation and use of better N fixing varieties. In countries that have a limited access to synthetic fertilizers, incorporating legumes in crop rotation may be the only source for N supply. In this project I undertook extension education for BNF with agriculturalists both in Washington and in Iraq.

All regions in Iraq need both basic and advanced agricultural resources to rebuild the agricultural infrastructure. Most participants indicated that basic agricultural inputs are insufficient across Iraq, although regions bordering Saudi Arabia have better access to inputs. In Iraq and as a result of the current circumstances, access to N fertilizers is challenging, and improving BNF can result in better N residue for the following crop. The other area of highly needed information and technology are in: Plant protection, food and vegetable production, machinery use and repair, row crop production, and soil fertility. Iraqi farmers prefer face-to-face communication with extension personnel, since access to the internet is limited and many agricultural reports and bulletins have been destroyed by war. Most participants believed that women are involved with farm work, but rarely manage farms. Although Iraqi women can own farms, few do. Women extension agents' views are different than men concerning the role of professionals and community members in training local farmers. These views should be taken into account when developing future training sessions.

Future international efforts should focus on restoring the physical and chemical damage to Iraq's soil such as salinity and erosion, and increasing access to machinery, inputs, and education. Efforts should also be made to strengthen links between extension agents at the MOA and Iraq's academic researchers and encourage scientists to return to Iraq.