Potential legume alternatives to fallow and wheat monoculture for the Mediterranean environments

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Abstract

Growing populations and increasing intensification of land-use in West Asia and North Africa (WANA) is prompting a need for viable alternatives to fallow and cereal mono-cropping common in dry areas. The sustainability and economic viability of such rotations can only be assessed accurately using long-term trials. Thus, a two course rotation experiment was established in 1986 at Khamishly in northeastern Syria, comparing yields and profitability of wheat (*Triticum aestivum* L.)-fallow and continuous wheat, with wheat grown after forages [a grazed mixture of medic species (*Medicago spp.*) and vetch cut for hay (*Vicia sativa* L.)] over ten growing seasons. The trial was modified in 1991 to include nitrogen fertilization of the cereal phase, vetch for grain and straw, lentil (*Lens culinaris* M.) and watermelon (*Citrullus vulgaris* L.). Compared with wheat grown after fallow, wheat grain yields declined following all legumes (lentil, vetch and medic) and watermelon (due to moisture-depleting effect) in three of the ten seasons which were drier than average. Compared with continuous wheat over the ten seasons, the grain yield increase following fallow in these three dry seasons compensated for the yield 'lost' during the fallow every second year. In the alternative phase, medic pasture yields were similar to vetch, with no effect of stocking rate, while seed yield of lentil was highest. Replacing of fallow with vetch for hay production increased the average gross margin by \$126 USD ha^{-1} yr^{-1}, while growing vetch for hay in rotation with wheat produced \$254 USD ha^{-1} greater profit than continuous wheat. The wheat-vetch for grain and wheat-lentil rotations were especially profitable, at least twice that of wheat-fallow and three times that of continuous wheat. This experiment added to the growing body of field data in Syria and in Australia that showed forage and grain legumes are excellent alternatives to the wheat-fallow rotation and continuous wheat production in areas that experience a Mediterranean–type environment, and support more efficient and sustainable cropping systems.

Key words: Forage legumes, Mediterranean production systems, nitrogen, fertilization, rainfed cereal cropping, sustainable land use

Introduction

Many dry areas of the world are particularly fragile and of tenuous sustainability (Stewart and Robinson 1997; Godfray et al. 2010), and the challenges of producing sufficient food while minimizing environmental impacts are particularly acute in West Asia and North Africa (WANA), which ironically is one of the centers of origin of settled agriculture (Harlan 1992). The dryland cropping systems in the region are traditionally based on cereals, either bread wheat (*Triticum aestivum* L.) or durum wheat (*T. turgidum* L. var. *durum*) or barley (*Hordeum vulgare* L.), in rotation with grain or forage legumes, or fallow (Cooper et al. 1987). Similar rotations are also common in the southern region of Australia (Anderson and Angus 2011) which experience Mediterranean-type environments.

Fallow is used to stabilize crop yields in dry regions by allowing the soil profile to recharge with water in the absence of any crop production in one season to benefit the crop sown in the following season (Gibbon 1981). Fallow may be justified when arable land is not a major limitation, but the increased global demand for agricultural production stemming from population growth is making fallow less common in southern Australia and to some extent in WANA. In recent decades land–use intensification gave rise to continuous cereal mono–cropping at the expense of fallow, a practice, which is deemed unsustainable because of the buildup of diseases, weeds and insect pests, and increased requirements for nitrogen fertilizer inputs (Jones and Singh 2000a).

The inclusion of food or forage legumes in cropping rotations enhances the sustainability and efficiency of the agricultural production through biological nitrogen fixation, disease breakdown and improvement of soil physical properties in Mediterranean regions (Peoples et al 2005; Martiniello 2012). Since the late 19th century, pastures based legumes have been grown widely in rotation with cereals and other crops in Australia where production of a range of recently developed grain legume such as narrow-leafed lupin (*Lupinus angustifolious* L.) has also been increasing rapidly (Donald 1965; Siddique and Sykes 1997; Siddique et al. 1999; Doyle et al. 2000; Howieson et al. 2000). There have been several developments in the past few decades in WANA to promote the use of forage legumes to reduce the feed gap for the increasing livestock populations, particularly sheep (*Ovis aries*) but with limited success (Ates et al. 2013).

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Due to increasing concern for the unsustainability of continued cereal cultivation and increasing demand for animal feed in the region, food and feed legumes were a component of many of the long-term experiments. The initial studies in the region focused on forage legume quality and yields in the low to medium rainfall zones with less than 350 mm rainfall p.a. (Jones and Singh 2000a, Ryan et al. 2008a; Larbi et al. 20011a&b, Christiansen et al. 2011). While crop yields and economic return are the primary criteria for the assessment of crop rotations (Ryan et al. 2010), water–use efficiency (Pala et al. 2007) and soil quality components, such as soil organic matter (Ryan et al. 2008b) and soil nitrogen (N) forms (Ryan et al. 2009) are of relevance in the assessment of long-term trials. There was however little attempt to address the influence of the legumes on subsequent cereal yields, profitability and related factors.

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In 1986 a long-term experiment was established in a favourable rainfall area (350-600 mm p.a.) at Khamishly in north-eastern Syria to assess the yields of wheat, in rotation with current and potential cropping rotations, and to evaluate the potential for sheep production from forages in this rainfall zone. In this study, we analyze the results of this experiment over a 10-year period, focusing on the grain and straw yields of wheat and alternative crops in the rotation, and their cost-effectiveness. As the experiment had completed five rotation cycles, it was deemed appropriate to assess the various yield trends independently of rainfall for each rotation over time. The benefit of forage legumes on sheep production will be examined in a separate publication.

Materials and Methods

Location, rainfall and soil type

In 1986 a multi−year, wheat−based rotation experiment was established near Khamishly (sometimes spelled “Qamishli”) (37^{o}03’ N, 41^{o}13’ E, 270 m a.s.l.) at the Hemo Agricultural Experimental Station, under the auspices of the Syrian General Commission for Scientific and Agricultural Research, Douma. The station is located in one of Syria's more favorable rainfall zones (350-600 mm p.a.), known as agricultural stability zone 1a (Figure 1). The climate is typically Mediterranean, merging to a continental, with considerable variation in the annual rainfall showing seasonal. The long−term mean annual rainfall of this site is 464 mm, and during the 10 year experimental period rainfall ranged from 719 mm in 1988 to 243 mm in 1989.

The soil at the site is a Vertisol clay, over 3 meters deep, which is typical of the Khamishly area, other areas of the country and the Mediterranean area in general (Kassam 1981). Properties of the soil are: pH (1:5 soil−water ratio) of 7.5−8.0, about 30% calcium carbonate, 1.0−1.5% organic matter in the upper 20 cm layer and the Olsen available P level of about 9 mg kg^{-1}, i.e., considered low but not deficient. Prior to establishment of the experiment, the site was cropped mainly with wheat as is the case in such favorable rainfed areas of Syria.

Treatments

Two course rotations were implemented with durum wheat (cv. “Cham 3”) as the primary crop alternated with either fallow, grazed medic pasture (mix of *Medicago rigidula*, *M. polymorpha*, *M. rotata, and M. noena* L.), or common vetch (*Vicia sativa* L.) cut for hay, in addition to continuous wheat. The grazed medic treatments included three stocking rates (5, 9 and 12 sheep ha^{-1}). The experiment was set up as a randomized complete block design containing six two−course wheat rotations as treatments:

(1−3) medic grazing at three stocking rates,
(4) vetch cut for hay,
(5) clean-tilled fallow and
(6) continuous wheat

Both phases of each rotation are present each year, and there were three replications of each treatment. The initial plots were 20m x 50m. The crops were generally sown in November or December, depending upon the timing of rainfall, and the majority of the crop growth occurred in the following year. For brevity, the growing season is referred to as the year when most of the growth occurred, not the year it was sown e.g. the 1986/87 season is abbreviated to 1987.

Based on the initial assessment of experiment data, and experience gained elsewhere from concurrent cropping system experiments in other rainfed areas of Syria (Ryan et al. 2010; 2012; Christiansen et al. 2011), a number of treatments were introduced. These additional treatments were as follows:

a) using a split-plot design the wheat plots included treatments of 0 and 60 kg N ha^{-1} as urea (1991/92),

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b) introducing lentil to the alternative non–cereal phase (1990/91) as a food legume of increasing importance in dryland areas,

c) incorporating vetch for grazing or harvested for grain/straw (1992/93), in addition to the original cut vetch for hay (vetch grain and straw were assessed by a 10 × 5 m strip left to grow to maturity) using a split-plot design, and

d) addition of watermelon as a summer crop (1992/93) grown by residual soil moisture from a winter fallow.

Crop management

Prior to establishing the treatments, the land was prepared with a disk–plough to a depth of 30 cm, with subsequent tillage using a "ducksfoot" cultivation to a depth of 10 cm. Superphosphate was broadcast before cultivation at a rate of 26 kg P ha^{-1} on all land in the year of establishment and thereafter it was applied to the pasture phase (medic, vetch, wheat but not the fallow) based on soil test levels targeting an Olsen P level of 10 ppm. In the first few years of the trial, N was applied at 60 kg ha^{-1} as urea to all cereal plots half immediately after sowing and half during the mid to late tillering stage of the crop in spring. A nil N treatment was also introduced in 1991/92 growing season. Wheat and vetch (and later lentil) were sown at 120 kg h^{-1} in November. The seeds of wheat were treated with a fungicide before planting. Subsequently, weeds in the wheat plots were controlled by application of herbicides (difenzoquat) to control wild oats and a herbicide (2,4-Dichlorophenoxyacetic acid ester) to control broad-leafed weeds. Various selective herbicides were applied to the legume forages and crops to manage grass weeds. As is the common in the region, weeds were not controlled in the fallow plots, however unlike farmer practice, they were not grazed. No major weed or disease infestations were noted throughout the experiment.

Pasture management

For the establishment of medic pastures, the seed was inoculated with rhizobia (strain M29) and sown at a rate of 30 kg h^{-1}a followed by rolling. Prior to the wheat phase, the medic plots received a shallow "ducksfoot" cultivation to avoid deep burial of the medic seeds, which would hinder regeneration in the following season. Likewise the plots were not cultivated after the wheat to avoid any further burial of the medic seed.

The initial phase of the experiment involved medic−based rotations grazed at three stocking rates or grazing intensities (5, 9, and 12 sheep per ha) during the early spring to early summer grazing period (February – May). During winter, and prior to gaining access to the medic pastures, the sheep were barn−fed with concentrate rations. The low (5 ewes ha^{-1}), medium (9 ewes ha^{-1}), and high (12 ewes ha^{-1}) stocking rates were achieved by manipulating the area grazed with a constant number of sheep, i.e., 12 Awassi ewes with their single lambs on medic pasture plots of 2.4, 1.33, and 1.0 ha, respectively. The ewes and their lambs remained on the medic pasture until the lambs were weaned at about 30 kg live weight. All animals were removed from the plots at the onset of flowering of the medic to ensure a satisfactory seed bank of at least 200 kg ha^{-1} medic seed for regeneration in the following year. Because of an abnormally dry season and poor medic growth in the 1988 the medic plots were re−sown in 1992/93.

Measurements

Grain and straw yields of wheat, vetch and lentil were measured on five quadrats (0.5 × 0.5 m) taken from each plot after maturity (typically in June) which were oven dried at 60^{o}C for 12 hours before threshing and weighing. Wheat plots were also harvested using a combine−harvester but only the quadrat data are presented here. Vetch and lentil plots were also hand−harvested - the common local practice is to pull the plants by hand before threshing. Forage herbage yield was obtained from quadrats of 0.5 ×

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0.5 m from 10 representative cages per plot. A crude estimate of water-use efficiency for grain production (WUEgr) was calculated by dividing the grain yields by the rainfall less 110mm for soil evaporation (Zhang et al. 1998). In all years, almost no rainfall occurred outside the October to May growing period.

Gross margin

The average gross margin (income from grain and straw, less production costs) were estimated for the various rotation treatments over the course of the experiment, except those including medic because no prices were available for medic hay in Syria. The prices and costs of production for wheat were obtained from a survey of 200 farmers conducted in northern Syria in 2009, at least two years before civil conflict disrupted production and markets. The production costs included tillage operations, seed, fertilizer, herbicides, machine harvest, bags, labor and transport.

The wheat grain price in Syria, which was fixed by the government, was $400 USD t^{-1}, while the average price for wheat straw was $70 t^{-1}. The average cost of wheat production was $228 ha^{-1}. Prices and costs for vetch and lentil were estimated from a much smaller subsample of farmers. The prices of vetch hay, vetch grain and vetch straw were $300, $1,000 and $150 USD t^{-1}, respectively, while the cost of vetch production was estimated at $280 ha^{-1}. The prices of lentil grain and lentil straw were $1,200 and $140 USD t^{-1}, respectively, and the cost of lentil production was estimated at $320 USD ha^{-1}. Vetch and lentil had greater production costs than wheat because of additional costs associated with seed and the need to harvest these crops by hand. The cost of one tillage operation at $24 USD ha^{-1} was assumed for the fallow phase.

Statistical analysis

In analyzing the results, the total variation was partitioned (Yates 1954) to obtain a) two strata assessing effects of rotations and N overall years, and b) two plot × year strata to detect rotation treatment interaction with time. The years were further partitioned into 'series', 'cycle' and 'series × cycle' interactions (Cady and Mason 1964; Jones and Singh 2000b; Ryan et al. 2010), where series represents cereal or non−cereal phase for a given two−course rotation.

The cycle is the rotation treatment effect when assessed yearly, through the cereal yields, first on the cereal phase and then on the non−cereal phase. For example, under wheat/vetch rotation there were two series of five years each (wheat yields in 1987,

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1989, 1991, 1993 and 1995 or in 1988, 1990, 1992, 1994 and 1996 from the same cereal plot) and five cycles of two years (yields in 1987-1988, 1989-1990, 1991-1992, 1993-1994 and 1995-1996 from cereal and non–cereal phases in the first year of each rotation treatment).

Using the experimental design structure, an analysis of variance (ANOVA) was obtained where the interactions of rotations, N, rainfall or rainfall × rainfall with years were separated into series and cycles. All pairwise multiple comparisons between rotations, year−wise and over all the years, were performed using a Bonferroni test at an overall 5% level of significance. Crop yield trends over time indicate the sustainability of the cropping systems. For the short time series of yield data such as those in the present study, Jones and Singh (2000b) estimated the linear time trend while adjusting for the seasonal effects of other variables such as a quadratic relationship in rainfall. Models used by Ryan et al. (2010) also were linear in time and quadratic function in rainfalls during two time periods. The linear time trend for each rotation was estimated by modeling the mean yield with (two year) cycles of the rotation after accounting for linear and quadratic effects of rainfall. The computations were carried out using Genstat statistical software (Payne 2009).

Results

The mean grain yields of wheat are presented in Table 1 in relation to various rotations during the ten years of the experiment. On average over the course of the experiment, the highest (P<0.05) wheat grain yields were following fallow (2.57 t ha^{-1}), lowest in continuous wheat (mean 1.14 t ha^{-1}), and intermediate for wheat following medic and vetch (1.90-2.01 t ha^{-1}). The grazing intensity (stocking rate) treatments on the medic pasture had no effect (P>0.05) on the following wheat yields in all seasons. The superiority of wheat following fallow was particularly evident in 1989 when the annual rainfall was only 243 mm and wheat after fallow produced 1.52 t ha^{-1} compared with 0.05-0.17 t ha^{-1} in the other rotations. The yield of wheat following fallow was also greater (P<0.05) than wheat after medic or vetch in 1990 and 1994. But in the other seven years wheat after fallow was no better (P>0.05) than wheat after the legume. The estimated WUE for wheat grain production varied from

3.65 kg ha^{-1} mm^{-1} in the continuous wheat rotation to 8.83 kg ha^{-1} mm^{-1} after fallow (Table 1).

The straw yields of wheat following the various rotations are presented in Table 2. The influence of rotations on mean wheat straw yield over the 10 seasons was significant ($P<0.05$) and followed the same trends as for grain yields: after fallow (4.73 t ha^{-1}) ≥ after vetch and medic (4.27 and 3.85-4.02 t ha^{-1} respectively) ≥ continuous wheat (2.64 t ha^{-1}). As for grain yields, the wheat straw yield after fallow was only greater (P<0.05) than the other treatments (apart from ontinuous wheat) in the dry seasons of 1989, 1990 and 1994.

Table 3 shows the wheat yield data collected after the additional experiment treatments were added in 1994-1996. As watermelon was only grown in the above–average rainfall years, due to limited residual summer moisture, that rotation behaved similar to fallow as it was essentially clean tilled and un-cropped in the alternative year. In any given year, there were no significant differences (P>0.05) between the mean wheat yields following the two vetch management systems, i.e., vetch for hay (for grazing) or vetch harvested for grain (mean 2.52 and 2.60 t ha^{-1} respectively). Yields of wheat after lentil were generally lower (P<0.05) (mean 2.22 t ha^{-1}) than after vetch, and were similar to those of medic. The overall mean effect of added N was found to increase (P<0.05) wheat grain yield by 0.41 t ha^{-1} (19%) or 6.8 kg ha^{-1} kg^{-1} N applied, and straw yield by 0.93 t ha^{-1} (23%) or 15.5 kg ha^{-1} kg^{-1} N applied.

Mean grain yield of the rotational crops, as well as the associated straw yields, and the dry matter produced by vetch and medic pastures which included native weeds as well, are presented in Table 4. Grain yields of lentil, vetch, and continuous wheat (in the non-cereal phase) were closely related to seasonal rainfall, with yields being greatly restricted in the low rainfall seasons (1991 and 1994) and generally highest in the high rainfall years (1995 and 1993). Similarly, the mean yield of medic biomass was lowest in 1991 and 1994 and highest in 1995 and 1993. Averaged over the six seasons, lentil and vetch produced higher (P <0.05) grain yields than either continuous wheat, while in the three high rainfall seasons vetch produced higher (P <0.05) straw yield than continuous wheat. The estimated WUE for grain production varied from 3.65 kg ha^{-1} mm^{-1} in continuous wheat rotation to 5.01 kg ha^{-1} mm^{-1} for lentil after wheat (Table 4).

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There was no effect ($P > 0.05$) of stocking rate on medic dry matter yields. Overall the years, the mean medic dry matter yield was significantly ($P < 0.05$) higher than straw yields of lentil and wheat, and vetch hay, but not higher ($P > 0.05$) than vetch straw. Year-wise comparisons showed that the mean yield of medic pasture was significantly ($P < 0.05$) higher than the lentil straw in five out of the six years; when compared with vetch and wheat straw yields, it was significant ($P < 0.05$) only in two years while in comparison with vetch hay in four years.

Based on data for the 10-year period, prediction equations were developed for the different cropping systems or rotations (Table 5), i.e. estimates of the time-trend (coefficient 'd') for the three systems of types of rotations: legumes, fallow and continuous cereal. The time-trend estimate was positive for the fallow system and the legume based system, but was negative under continuous wheat. The estimate of time-trend for fallow system was higher than that of the legume system, indicating that yields of cereal–fallow rotations were increasing at a faster rate than that of cereal-legume rotations. The negative time-trend in continuous cereal indicated a general yield decline independent of rainfall.

The average gross margins during the experimental period of 1987-1996 for the continuous wheat, fallow-wheat, and wheat-vetch hay rotations were $415, $555, and $669 USD ha^{-1} yr^{-1} respectively. During 1991-1996, which were generally wetter seasons with higher yields than the previous seasons, the average gross margin for continuous wheat, fallow-wheat, wheat-vetch grain and wheat-lentil grain rotations were $499, $709, $1,505 and $1,688 USD ha^{-1} yr^{-1} respectively.

Discussion

This study clearly illustrates that wheat rotations including vetch hay, or vetch and lentil grown for grain and straw, can be more productive and profitable than continuous wheat or fallow-wheat rotations in a favourable rainfall zone of northern Syria (350-600 mm p.a.). These results generally concur with those from other similar long-term experiments conducted during the same period in Syria's low to medium rainfall zones where rainfall is less than 350 mm (Christiansen et al. 2011; Ryan et al. 2012).

In the present study, wheat grain and straw yields were strongly correlated with rainfall, and even in this favourable rainfall zone, the use of fallow boosted the grain yield of the following wheat crop in some years. During the ten seasons of this

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study, wheat grown after fallow produced higher grain yields than wheat after medic, vetch or wheat, in three seasons when rainfall was below average. Two of these responses followed seasons where the rainfall was above average, and there is little doubt that significant amounts of soil moisture were conserved to benefit the following wheat crop. However, in 1990 when the annual rainfall was only 309mm, which followed the dry 1989 season (243mm), wheat after fallow produced 2.14 t ha^{-1} compared with 0.91-1.07 t ha^{-1} in the other rotations. It is probable that the amount of soil moisture conserved from 1989 was low, and not enough to explain the entire yield boost in 1990. Even though wheat following fallow only out-yielded continuous wheat in three out of ten seasons, the extra wheat yields produced after fallow were enough to compensate for the yield lost in the fallow seasons. However, grain yields of the vetch and lentil, and the production of medic pastures grown in rotation with wheat were more productive than the wheat fallow rotation.

Another important result was that trends in crop straw yields strongly reflected the grain yield results in our study. Crop straw, especially of legume crops, is highly valued as a stockfeed and can be worth more than the grain in dry seasons (Ben Salem and Smith 2008). This was certainly the case in 1989 in our study when grain yields of wheat were less than 0.2 t ha^{-1}. So it is critical that any assessment of crop profitability take straw yields and prices into account. Straw prices tend to be much lower in wetter years when feed supplies are not limited and conversely much higher in drought years. Straw can be as valuable or even more valuable than grain in drought conditions (Nordblom and Halimeh 1982, Magnan et al. 2012). For simplicity we chose straw prices that represent an average over a 5-6 year period before the outbreak of civil unrest in Syria rather than vary the straw price according to rainfall.

The estimated WUE data also confirmed the yield data. Although very little rain occurred outside the growing period of October to May, the WUE data need to be treated with caution because no attempt was made to estimate soil moisture storage from one season to the next, which was probably significant in some seasons, especially after the fallow treatments. The estimated WUE*gr* in this study were low, but within the range reported by Zhang et al. (1998) in Syria and Sandras and Angus (2006) in southern Australia. This could be because any stored soil moisture at sowing was not taken into account, or other factors such as weeds, disease, nutrition or poor management limited crop yields.

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Rotation with the lentil resulted in a significant decline (P<0.05) on the subsequent cereal grain and straw of wheat compared with after fallow, but produced acceptable yields of lentil grain as well as lentil straw. Given the nutritional value of lentil, and the human demand for food, lentil is an attractive option in dryland, cereal-based rotations in Syria, and in the Mediterranean region as well, especially if breeders develop more upright varieties that can be mechanically harvested. As watermelon cultivation is based on adequate residual moisture, its role in cereal-based rotations is precarious due to seasonal rainfall fluctuations. In fact, the crop was removed from consideration in one wheat-based trial in Syria’s medium rainfall zone (Ryan et al. 2010) due to several years without sufficient moisture to support this summer crop.

Our study also highlights an overall reduction in productivity when wheat is grown continuously – over the ten years of the experiment mean grain yields of wheat grown after legumes were 75% greater than wheat grown continuously. The yield trend analysis over time showed declining yields independently of the effect of rainfall in the continuous wheat, while there was an increasing yield trend when wheat was grown after fallow or legumes. Although no major weeds or diseases were noted throughout the experiment in any treatments, low levels of infection not recorded may have started limiting yields in the continuous wheat especially towards the end of the ten year study period.

The estimated gross margins for the various rotations reinforce the benefits of including legumes in wheat rotations. Over the ten years of this experiment (effectively 20 seasons of rotations because each phase was included each year), the replacement of fallow with vetch for hay production increased the average gross margin by $114 USD ha^{-1} yr^{-1}, while growing vetch for hay in rotation with wheat produced $254 USD ha^{-1} greater profit compared with continuous wheat. The profitability of the wheat-vetch for grain and wheat-lentil rotations were especially profitable, at least twice that of wheat fallow and three times continuous wheat. The increase in profitability was not so much from the rotational benefit of the vetch and lentil for the following wheat, but because of their high grain and straw prices, and moderate productivity compared with wheat. These grain legume phases of the rotations generated around 65% of the total net income when grown in rotation with wheat.

Annual forage legumes in cereal rotations produced acceptable biomass for animal feed in this study which was similar to the values reported by El Moneim and Cocks (1986) and Pala et al. (2008). Five out of ten years of the experiment, subsequent grain production of wheat was enhanced at various levels compared with continuous cereal cultivation. In most years, the grain production followed by vetch or medic rotation was similar to the grain production after a fallow year. A number of positive effects of forage legumes in rotation with cereal crops were reported by earlier studies; increased production (Ryan et al. 2010); protein quality of cereals (Ryan et al. 2008c); improved soil quality in terms of soil N (Ates et al. 2013); soil organic matter (Ryan et al. 2008b); physical properties such as aggregate stability and infiltration (Masri and Ryan 2006). Despite their high potential in crop-livestock farming systems, medic pastures face a serious obstacle in being widely adopted in WANA due to social, economic and technological constraints (Nordblom et al., 1994; Christiansen et al., 2000). In particular, uncontrolled grazing, which is a common practice in the region, through the flowering and seed set stages of plant growth hinders the medics persistence in medic-cereal rotations. The successful management of medic pastures in the Australian ley farming system is achieved with the aid of fencing whereas fences are largely unused in the WANA due to the small and segmented structure of farms. Regenerating medic pastures also face an added problem because tillage to 10cm or more is common which buries the medic seed and makes it unviable. Thus, it is suggested that incorporation of *Vicia* and/or *Lathyrus* into forage rotations, may be a better alternative than medic pastures under WANA conditions, even though these are not self-regenerating (Oram and de Haan, 1995; Ates et al. 2013).

Conclusions

The study demonstrates the limited potential of wheat-fallow and continuous wheat rotations in the medium rainfall zones of Syria, and highlights forage and grain legumes as viable inclusions in crop rotations. The inclusion of vetch and lentil for grain production in rotation with wheat boosted profits two or three fold compared with wheat-fallow or continuous wheat rotations. Forage and grain legumes have been widely adopted in southern Australia for many decades, and greater effort should be devoted to promoting their use in the WANA region.

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Table 1 Wheat grain yields following the various rotation treatments in the two course experiment at Khamishly, Syria (1987-96). Estimated WUE for grain production (WUEgr) is also presented.

Year	Rainfall[†] mm	Cycles	Wheat grain yield (t ha^{-1})[@] Medic Grazing[$] Low	Medium	High	Fallow	Vetch Hay	Wheat
1987	331	1	1.21	1.05	1.31	1.35	1.15	1.23
1988	719	1	1.49	1.32	1.24	1.38	1.39	1.30
1989	243	2	0.10 b	0.11 b	0.18 b	1.52 a	0.17 b	0.05 b
1990	309	2	0.96 b	1.02 b	0.91 b	2.14 a	1.07 b	0.91 b
1991	307	3	1.25 ab	1.40 ab	1.41 ab	2.00 a	1.76 ab	1.06 b
1992	439	3	3.19 a	2.86 a	3.13 a	3.24 a	2.65 a	1.72 b
1993	577	4	4.01 a	4.34 a	3.99 a	4.42 a	3.91 a	1.21 b
1994	330	4	1.05 bc	1.25 bc	1.64 b	2.79 a	1.11 bc	0.76 c
1995	632	5	3.73 a	3.35 a	3.34 a	3.39 a	3.08 a	1.34 b
1996	497	5	3.07 ab	3.18 ab	3.15 ab	3.54 a	2.75 a	1.80 c
SE (DF=80)					±0.18			
Mean			2.01b	1.99b	2.03b	2.57a	1.90b	1.14c
SE (DF=20)					±0.063			
WUEgr kg ha^{-1}mm^{-1}			5.00	5.83	6.11	8.83	5.76	3.65

[†] Long-term annual rainfall was 464mm.

[$]Low, medium, and high reflect stocking rates of 5, 9, and 12 sheep per ha.

[@]Rotation means, within any given year or over all the years, indicated with a common letter(s) are not statistically different ($P < 0.05$).

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Table 2 Wheat straw yields following the various rotation treatments in the two course experiment at Khamishly, Syria (1987-96).

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			Wheat straw yield (t ha^{-1})					
Year	Rainfall† mm	Cycles	Medic Grazing Low	Medic Grazing Medium	Medic Grazing High	Fallow	Vetch Hay	Wheat
1987	331	1	3.23 bc	2.46 c	4.37 ab	2.85 c	4.97 a	2.77 c
1988	719	1	2.98 ab	3.30 ab	3.23 ab	3.15 ab	4.05 a	2.63 b
1989	243	2	1.24 b	1.03 b	1.25 b	3.14 a	1.54 b	1.05 b
1990	309	2	3.40 b	3.23 b	3.19 b	5.72 a	3.59 b	3.17 b
1991	307	3	3.03	3.09	2.97	3.83	3.13	2.60
1992	439	3	4.99 a	5.01 a	4.54 a	4.84 a	3.84 ab	2.98 b
1993	577	4	5.79 a	5.63 a	5.46 a	6.79 a	5.90 a	1.84 b
1994	330	4	3.35 b	3.23 b	3.55 b	5.70 a	3.88 b	2.65 b
1995	632	5	5.85 a	5.31 a	5.59 a	4.85 ab	5.03 ab	3.69 b
1996	497	5	6.15 a	6.19 a	6.08 a	6.39 a	6.78 a	3.50 b
SE (DF=80)			±0.33					
Mean			3.99 b	3.85 b	4.02 b	4.73 a	4.27 b	2.69 c
SE (DF=80)			±0.095					

Table 3. Wheat grain and straw yields following the various rotation treatments after the inclusion of the additional rotation treatments (mean of the N treatments), and mean effect of nitrogen at Khamishly, Syria (1994-1996).

Year	Medic Grazing			Fallow	Vetch	Wheat	Lentil	Vetch	Vetch	Melon
	Low	Medium	High					grain	hay	
Wheat grain yield (t ha^{-1})[@]										
1994	1.11 bc	1.15 bc	1.40 bc	2.80 a	1.19 bc	0.64 c	1.11 bc	1.59 b	1.40 bc	1.74 b
1995	3.09 a	3.06 a	3.02 a	3.10 a	2.74 a	1.14 b	2.80 a	3.09 a	3.20 a	3.28 a
1996	2.98 a	2.96 a	2.78 a	3.25 a	2.63 a	1.45 b	2.76 a	3.13 a	2.96 a	3.26 a
SE (DF=38)	±0.17									
Mean	2.39 bc	2.39 bc	2.40 bc	3.07 a	2.19 c	1.08 d	2.22 c	2.60 ab	2.52 ab	2.76 ab
SE (DF=36)	±0.096									
Wheat straw yield (t ha^{-1})[@]										
1994	4.81 a	4.95 a	5.21 a	4.44 a	4.51 a	2.83 b	4.54 a	4.93 a	4.93 a	5.01 a
1995	2.99 cd	2.86 cd	2.91 cd	5.26 a	3.54 bc	2.42 d	3.17 bc	3.66 bc	4.03 ab	4.26 ab
1996	5.81 a	5.74 a	5.22 a	6.01 a	6.32 a	2.94 b	5.14 a	6.17 a	6.47 a	6.11 a
SE (DF=38)	±0.29									
Mean	4.54 bc	4.52 bc	4.45 bc	5.24 a	4.79 bc	2.73 d	4.28 c	4.92 ab	5.15 a	5.13 ab
SE (DF=36)	±0.17									

Nitrogen	Grain	Straw
+N	2.57	5.04
-N	2.16	4.11
SE (DF=40)	0.029	0.05

[@]Rotation means, within any given year or overall the years, indicated with a common letter(s) are not statistically different (P <0.05). Nitrogen effect is statistically significant (P<0.05).

Table 4. Grain, straw, hay or pasture dry matter yields (t ha^{-1}) associated with the non-cereal phase of the wheat-based rotation[@] at Khamishly, Syria. Estimated WUE for grain production (WUE_{gr}) is also presented.

Year	Rainfall	Medic Pasture[†] t ha^{-1}				Hay t ha^{-1}	Grain t ha^{-1}			Straw t ha^{-1}		
	(mm)	Low	Medium	High	Mean	Vetch	Lentil	Vetch	Wheat	Lentil	Vetch	Wheat
1987	331	-	-	-	-	2.49	-	-	-	-	-	-
1988	719	-	-	-	-	2.35	-	-	-	-	-	-
1989	243	1.73	1.87	1.50	1.70	1.18	-	-	-	-	-	-
1990	309	4.30	4.28	4.20	4.26	3.02	-	-	-	-	-	-
1991	307	2.69	2.97	2.12	2.59	2.53	0.57	0.75	0.53	1.37 b	2.86 a	2.04 ab
1992	439	5.78	5.15	4.66	5.20	2.28	2.26	1.93	2.39	3.21 b	2.88 b	4.73 a
1993	577	5.57	5.37	5.01	5.32	2.64	1.86 ab	2.23 a	1.44 b	7.04 a	5.85 a	1.95 b
1994	330	2.45	2.81	2.41	2.55	2.65	1.35	1.24	0.82	2.34	2.50	2.37
1995	633	7.25	6.11	5.69	6.35	3.18	2.30 a	1.93 a	0.99 b	4.01 ab	4.76 a	2.76 b
1996	497	3.08	3.09	3.36	3.18	3.88	2.17 a	1.67 ab	1.21 b	4.43 ab	4.91 a	3.43 b
SE			±0.20		±0.27	±0.20		±0.17			±0.37	
Mean		4.47	4.25	3.88	4.20	2.86	1.75 a	1.63 a	1.23 b	3.73 a	3.96 a	2.88 b
SE			±0.21		±0.11	±0.08		±0.069			±0.15	
WUE kg ha^{-1}mm^{-1}							5.01	4.72	3.65			

[†]Low, medium, and high reflect stocking rates of 5, 9, and 12 sheep per ha.
[@]Rotation means within any given year or over all the years, indicated with a common letter(s) are not statistically different ($P < 0.05$), for grain and straw yields. The effect of the stocking rates on pasture was not statistically significant ($P > 0.05$). The vetch for grazing and medic pasture using the hay and pasture means are statistically significant if associated with different letters ($P < 0.05$).

Table 5. Prediction equations for legume, fallow and continuous cereal systems modeled in terms of rainfall (R) and time as number of 2-year rotation cycles at Kamishly, Syria (based on data from 1987 to 1996).

Model	**Yield (t ha^{-1}) = a + bR + c R^2 + d Cycles of 2 years**							
	Grain				**Straw**			
Rotation	a	bx10^2	cx10^5	d	a	bx10^2	cx10^5	d
Legume System	-8.770	4.380	-4.092	0.194	-8.543	5.21	-4.926	0.098
Fallow System	-4.673	2.778	-2.714	0.375	-2.493	2.68	-0.276	0.470
Continuous Cereal	-3.743	2.376	-2.266	-0.183	-1.393	1.77	-0.170	-0.025

Standard errors of the regression coefficients are not included to keep the equations simple.

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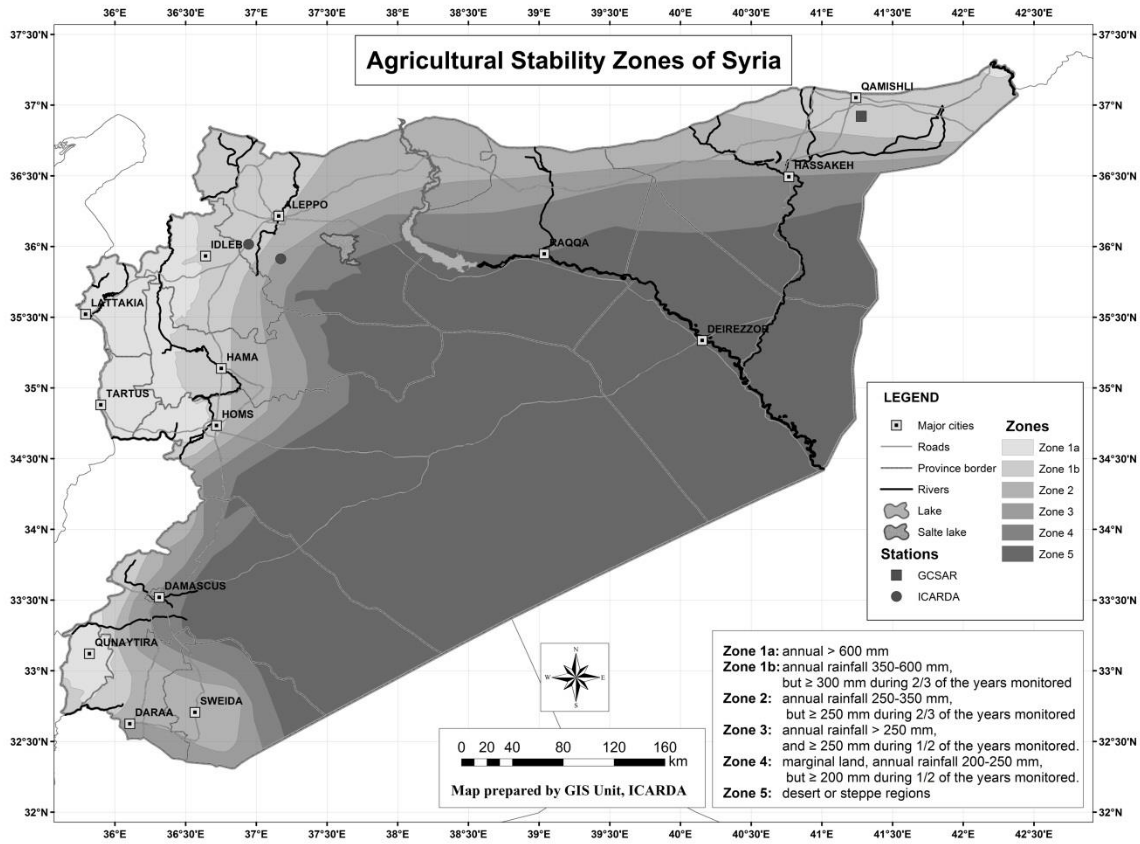

Figure 1. Map of Syria showing the agricultural stability zones based on mean long-term seasonal rainfall data and the location of Khamishly ("Qamishli"), near the location of the experiment in northeastern Syria (Zone 1)

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