Productivity and biological nitrogen fixation of different species of vetches (*Vicia* spp.) under the rainfed conditions of West Asia

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ABSTRACT

The low rainfall areas of West Asia are characterized by pastoral production system primarily based on small ruminants (sheep and goats). Rangelands serve as the main source of feed. With increasing population, the demand for livestock products has increased. As a consequence, the stocking rates have soared, increasing the pressure on rangelands. Rangeland degradation has therefore been increasing threatening the sustainability of livestock production system and the livelihood of the people dependent on it. Production of additional feed is essential to reduce the pressure on rangelands. Vetches (*Vicia* spp.) are endemic in the area and can be potential source of nutritious forage and feed. The International Center for Agricultural Research in the Dry Areas (ICARDA) holds a large collection of germplasm of vetches from the region and has done its evaluation for productivity and nutritive value. The selected lines have been tested in international testing program for their adaptation to different agro-ecological conditions. Some of these selected lines were evaluated for their productivity, nutritive value and biological nitrogen fixation at the Tel Hadya research station of ICARDA in Northern Syria. Large variability observed for these traits provides opportunity for development of promising cultivars for diverse ecological conditions.

Key words: Biological nitrogen fixation, Dry areas, Feed and forage production, Small ruminants, Vetches (*Vicia* Spp.), West Asia

Introduction

West Asia region, comprising of Syria, Jordan, Iraq, Lebanon, Palestine, and parts of Iran, Egypt and Turkey, has a long history of settled agriculture. It is also one of the regions with lowest per capita availability of water. Characterized by a Mediterranean type of climate, rainfed agriculture in this region is practiced during the cool wet winters, when low temperatures put additional limitation on plant growth. A very large proportion of the area receives rainfall that is too low for economic crop production. In the areas with annual precipitation of less than 300 mm, barley (*Hordeum vulgare* L.) based cropping system prevails, where barley is grown in rotation with one or two cycles of fallow, depending on the rainfall. These areas also have large stretches of rangelands, which permit raising livestock, mainly small ruminants – sheep (*Ovis aries*) and goats (*Capris hircus*). Barley straw provides supplementary forage and barley grains serve as valuable concentrate feed for sheep and goats. Grazing in rangeland is often coupled with grazing on crop-residues left in the fields after harvest in the adjoining higher rainfall areas. Migration of livestock in search of feed and water is common.

The West Asia region has one of the highest rates of population growth. Spurted by rising demand for livestock products by the rapidly growing human population in the region, the rangelands of the West Asia region have come under tremendous amount of grazing pressure because of sharp rise in the population of small ruminants (FAO, 1987). The productivity of mono-cropped barley in these low rainfall areas has also gone down because of loss of soil fertility and buildup of soil-borne pathogens and pests, aggravating the shortage of feed for sheep and goat (Amri *et al.*, 2011). Sustaining a viable small ruminant production in these low rainfall areas, therefore, requires augmenting production of alternate sources of nutritious feed, which would not only take away pressure from rangelands but would also permit development of feed banks to enhance the resilience of livestock producers in the face of frequent droughts common in the region (Solh, 2011). In the face of global climate change, which has resulted in increase of frequency and intensity of drought events, the need for ensuring dependable supply of feed has become vital.

Fortunately, there are several forage legume species that are indigenous to the area and are widely distributed in the form of landraces and wild types (Abd El Moneim, 1987). Many have evolved to adapt to the harsh environmental conditions and withstand the grazing pressure of the small ruminants. Vetches (*Vicia* spp.) and chickling (*Lathyrus* spp.) are particularly important in this regard (Abd El Moneim *et al.*, 1988) because they can be grazed at an early stage of growth in winter, can be harvested at flowering and early pod-setting stage in spring for hay making, or allowed to grow to full maturity and harvested for grain and straw at the end of the growing season (Thompson *et al.*, 1992). Some of these species and their local land races are adapted to grow in the low rainfall (seasonal precipitation of 250-350 mm) regions that fall between the steppe and the higher rainfall cropping areas. They can provide a break to the barley mono-cropping and an influx of biologically-fixed combined nitrogen in the production system, thus help in arresting the decline of productivity of dryland cereals (barley and durum wheat, *Triticum durum*), when introduced to replace the fallow phase of the rotation (Abd El Moneim *et al.*, 1990b; Abd El Moneim and Ryan, 2004). These species have, therefore, been included in the research mandate of the International Center for Agricultural Research in the Dry Areas (ICARDA). Some of work done at ICARDA on genetic resources and germplasm enhancement of vetches for dry areas of West Asia, and similar ecological conditions elsewhere, is presented in the text that follows.

Different vetches and their adaptation

The vetch species commonly found in West Asia include common vetch (*Vicia sativa*), underground vetch (*Vicia sativa* ssp. *amphicarpa*), narbon vetch (*Vicia narbonensis*), wooly-pod vetch (*Vicia villosa* ssp. *dasycarpa*), bitter vetch (*Vicia ervilia*), Hungarian vetch (*Vicia panonica*), and Palestinian vetch (*Vicia palestina*). They are adapted to different environments and are used in different ways for feeding livestock (Table 1). As they have mostly been wild types, there was a need to improve their traits for enhancing their usage as animal feed. One of the major efforts of ICARDA has been to collect diverse germplasm of these species, evaluate them for various traits (Robertson *et al.*, 1996; Amri *et al.*, 2011) and undertake crop improvement research for identifying/developing superior types for multi-location testing by the national programs, who then can identify cultivars adapted to their agro-ecological conditions (Abd El Moneim, 1987). Of the large collection of vetches that ICARDA holds in its genebank, more than 400 accessions have thus been selected and have been used in the crop improvement research.

Procedure adopted for developing promising cultivars

Developing cultivars from wild species (Robertson *et al.*, 1996) involves preliminary evaluation of germplasm for desired characters and progeny tests for selected genotypes,

Table 1. Adaptation, usage and crop-improvement research objective of various species of vetches at ICARDA

Species	Usage	Adaptation	Research thrust
Common vetch	Grain, Straw, Hay, Grazing	~300 mm rainfall, mild cold	Non-shattering pod, leafiness, resistance to foliar diseases & nematodes, drought tolerance, low B-cyno-alanin content
Underground vetch	Grazing	250 mm rainfall, mild cold, marginal lands	High biomass yield, hard seeds
Narbon vetch	Grain, Straw	<300 mm rainfall, mild cold	Earliness, high harvest index, resistance to foliar diseases, low tannin content
Wooly-pod vetch	Grazing	~300 mm rainfall, high elevation	Earliness, high leaf retention, cold tolerance, drought tolerance
Bitter vetch	Grain, Straw	~300 mm rainfall, cold	Pod retention, high harvest index, drought tolerance
Hungarian vetch	Grain, Straw, Grazing	~300 mm rainfall, high elevation, severe cold	High harvest index, foliar disease resistance, drought tolerance
Palestinian vetch	Hay, Grazing	~300 mm rainfall, mild cold	Non-shattering pods, drought tolerance, cold tolerance

evaluation of selections in preliminary micro-plot field trials, evaluation of promising selections in advanced yield trials at two contrasting sites, that is, Tel Hadya (long-term seasonal precipitation 330 mm) and Breda (280 mm), and multi-location testing of promising lines in different agro-ecological zones. The genetic improvement work is done in a multidisciplinary manner involving the input of such disciplines as crop physiology, microbiology, pathology and entomology. Breeding objective also includes improving the quality. Therefore, nutritive value of the herbage, hay, grain, and straw is evaluated in the laboratory and palatability and biological utilization assessed through feeding trials involving small ruminants (Abd El Moneim *et al.*, 1990b).

Large variability in phenological traits (days to start flowering, 100% flowering and maturity) and such agronomic traits as seedling vigor, winter growth, susceptibility to cold, spring-season growth and leafiness were observed as the diverse accessions of vetches available in the ICARDA genebank were evaluated. Based on those initial observations diverse lines were selected for multi-location multiyear evaluation on large plot size. The results for 25 selected lines of each of common vetch, bitter vetch and wooly-pod vetch are given in Table 2. The results showed the possibility of identifying lines on phenological and agronomic considerations different dryland environmental conditions.

Developing improved cultivars, through direct selection and/or through further breeding, necessitated further evaluation for their productivity and nutritional quality. This was done through multi-location (ICARDA research sites at Breda and Tel Hadya), multi-year testing, in replicated advanced yield trials, using large plots to get reliable measure of the performance of different lines (Abd El Moneim, 1993a; Abd El Moneim *et al.*, 1988). The results of these evaluations are presented in the section that follows.

Performance of common vetch

Common vetch can be utilized in various forms. It can be grazed at early stage of growth in winter when the availability of animal feed is limited for sheep and goat. It can be allowed to come to advanced stage of reproductive growth, during spring, when it can be harvested for nutritious hay making; or it is allowed to grow to full maturity at the onset of summer and harvested for grain and straw. For each of these types of usage special selection criteria are necessary. For grazing, high seedling vigor and winter growth and ability to withstand grazing are important. For hay making, high leafiness is desirable. For harvest at maturity, high pod retention and non-shattering pod habits are desirable (Abd El Moneim, 1993b).

The performance of 25 selected accessions in terms of hay production and seed and straw yield and quality parameters is given in Table 3. Some accessions yielded as high as 3t/ha hay with high crude protein content. When allowed to grow to full maturity, grain yield of more than 1.5t/ha with a crude protein content exceeding 30% and a straw yield of 4t/ha with a crude protein content exceeding 10% could be obtained. The digestibility of the hay and straw was also high.

Performance of wooly-pod vetch

Like common vetch, wooly-pod vetch can also be grazed, and used for hay making or for

Table 2. Variability in phenological and quantitatively scored traits (measured on a 1 - 5 scale, where 1 is poor and 5 is best, except for the cold effect, where 1 is little and 5 is severe cold damage) in 25 selected genotypes of three vetch species in multi-location, multiyear trials at ICARDA sites

Species	Traits	Range	Means ± SM
Common vetch	Days to start flowering	105-115	110 ± 1.03
(Vicia sativa)	Days to 100% flowering	134-160	147 ± 1.10
	Days to maturity	170-189	160 ± 1.18
	Seedling vigor	2.5-4.5	3.79 ± 0.30
	Winter growth	3.0-5.0	4.01 ± 0.40
	Cold effect	2.1-4.5	3.60 ± 0.31
	Spring growth	4.3-5.0	4.46 ± 0.37
	Leafiness	3.5-5.0	4.05 ± 0.40
Bitter vetch *(Vicia*	Days to start flowering	95–109	102 ± 1.02 125
ervilia)	Days to 100% flowering	115–130	± 0.95
	Days to maturity	122–140	131 ± 1.09
	Seedling vigor	1.9-3.5	3.01 ± 0.30
	Winter growth	2.5-5.0	3.75 ± 0.46
	Cold effect	0.5-2.0	1.01 ± 0.10
	Spring growth	2.1-5.0	3.55 ± 0.30
	Leafiness	2.0-5.0	3.70 ± 0.28
Wooly-pod vetch	Days to start flowering	114–136	120 ± 1.10 165
***(Vicia villosa* ssp.**	Days to 100% flowering	140–168	± 1.20
dasycarpa)	Days to maturity	162–196	180 ± 1.28
	Seedling vigor	1.1-3.2	2.72 ± 0.20
	Winter growth	0.9-1.0	1.57 ± 0.13
	Cold effect	0.5-1.5	1.01 ± 0.10
	Spring growth	0.6-5.0	3.42 ± 0.26
	Leafiness	1.0-5.0	3.13 ± 0.30

Table 3. Variations in grain, straw and hay yield (kg/ha dry matter) and nutritional quality (crude protein, CP; acid detergent fibre, ADF; neutral detergent fibre, NDF; and digestibility, DOMD; all in g/kg dry matter) in 25 selections of common vetch (*Vicia sativa*)

Product	Yield &quality attributes	Range	Mean	± SE
Hay	Yield (kg/ha)	2245-3383	2782	198.2
	CP (g/kg)	141-188	170	7.7
	ADF (g/kg)	262-287	274	6.3
	NDF (g/kg)	364-435	405	14.7
	DOMD (g/kg)	725-782	754	10.4
Grain	Yield (kg/ha)	808-1743	1472	182.7
	CP (g/kg)	266-316	290	14.5
Straw	Yield (kg/ha)	2572-4028	3324	292.6
	CP (g/kg)	62-127	95	19.1
	ADF (g/kg)	324-353	338	8.0
	NDF (g/kg)	378-505	443	33.9
	DOMD (g/kg)	437-511	474	13.9

producing grain and straw. The performance of 25 selected accessions, tested in advanced yield trials, is shown in Table 4. Wooly-pod vetch showed the ability to produce even higher hay yield than common vetch. Some of the accessions yielded more than 3.5t/ha of hay with a crude protein content of more than 29% and good digestibility. When allowed to grow all the way to maturity, it produced a grain yield exceeding 1t/ha, which was lesser than that achieved with common vetch. The straw yield exceeding 3.5t/ha was again lower than that of common vetch. The digestibility was also slightly lower than common vetch

Performance of narbon vetch

Narbon vetch is better adapted to lower rainfall areas (Abd El Moneim, 1992). It is generally grown for producing protein-rich grains and straw for stall-feeding livestock. It is therefore specifically suited for replacing fallow in the barley-based systems of dry areas of West Asia. The performance of a set of 25 narbon vetch selections in the advanced yield trials is shown in Table 5. The gain yield of this vetch was higher than that of the other above mentioned vetches. Also, the crude protein content was relatively higher, but its tannin content is a concern in the feeding of grains to small ruminants. Efforts are, therefore. underway to breed cultivars with low tannin content utilizing selections that already have low tannin content in their grains. Straw yields are also quit high and the straw is rich in crude protein and has high digestibility. Hence, it is quite suited for feeding small ruminants in mixture with barley straw.

Performance of underground vetch (*Vicia sativa* ssp. *amphicarpa*)

An interesting feature of some of the native forage legumes in West Asia is their ability to set pods underground and the seeds formed have a range of dormancy period, permitting only some of them to germinate in a season (Christiansen *et al*., 1996). Perhaps, this is an evolutionary response to grazing pressure in the rangelands and steppes in the dry areas. Underground vetch is such an amphicarpus species of vetches that is widely distributed in the region, particularly on the marginal lands with rocky surface. Collection of wild types of underground vetch from the region was made at ICARDA and the accessions evaluated for

Table 4. Variations in grain, straw and hay yield (kg/ha dry matter) and nutritional quality in 25 selections of wooly-pod vetch (*Vicia villosa* ssp. *dasycarpa*)

Product	Yield &quality attributes	Range	Mean	± SE
Hay	Yield (kg/ha)	3310-4855	3566	299.5
	CP (g/kg)	174-183	178	2.6
	ADF (g/kg)	264-278	272	4.1
	NDF (g/kg)	417-433	425	5.2
	DOMD (g/kg)	683-708	696	6.4
Grain	Yield (kg/ha)	820-1099	910	55.8
	CP (g/kg)	280-303	292	6.5
Straw	Yield (kg/ha)	3324-3746	3521	161.7
	CP (g/kg)	107-122	114	3.6
	ADF (g/kg)	330-388	340	15.0
	NDF (g/kg)	457-484	472	6.8
	DOMD (g/kg)	384-435	414	12.4

CP=Crude protein; ADF=acid detergent fibre; NDF=neutral detergent fibre; DOMD= digestibility. All in g/kg dry matter.

their growth, herbage yield, recovery after grazing and creation of seed bank and its survival under different degrees of grazing pressure and time span. The idea was to select cultivars suitable for a kind of ley-farming with barley, as is practiced with medics (*Medicago* spp.). Several promising selections were made and seeds multiplied for large scale field evaluation. Table 6 presents the results of a study with one of the promising selections at Tel Hadya research station with large plots to permit actual grazing. The details of procedure followed are given in the heading of the table.

The yield of barley grown after vetch is compared with barley after barley. The seed bank of vetch in the ground at the beginning and the end of the barley phase (1989/90) and herbage yield of self-regenerated vetch in the1990/91 season, as affected by grazing treatments in the establishment year.

The results (Table 6) showed that the selection gave good herbage yield in the establishment year if it was not grazed. When

Table 5. Variations in grain and straw yield (kg/ha dry matter) and nutritional quality in 25 selections of narbon vetch (*Vicia narbonensis*)

Product	Yield &quality attributes	Range	Mean	± SE
Grain	Yield (kg/ha)	1470-1831	1674	96.2
	CP (g/kg)	307-331	318	3.0
	Tannin (g/kg)	3.38-4.47	3.95	0.277
Straw	Yield (kg/ha)	3311-4256	3693	243.0
	CP (g/kg)	153-170	161	4.1
	ADF (g/kg)	253-269	262	3.6
	NDF (g/kg)	436-469	452	9.4
	DOMD (g/kg)	468-532	504	17.9

CP=Crude protein; ADF=acid detergent fibre; NDF=neutral detergent fibre; DOMD= digestibility. All in g/kg dry matter.

Table 6. Performance of underground vetch (*Vicia sativa* ssp. *amphicarpa*) as affected by the time of grazing during the establishment year 1988/89 and the effect of these treatments on subsequent barley crop in the 1989/90 season.

Yield (kg/ha)	Time of grazing of vetch				Barley	±SE
	Feb'89	Mar'89	Apr'89	No grazing		
Vetch herbage in 1988/89	830	730	860	2030	-	57
Barley grain in 1989/90 season	1966	2035	1925	1909	1599	98
Barley total biomass in 1989/90	4346	4193	3847	3877	3143	215
Vetch seed bank in barley season:						
Start of season	50	130	160	240	-	27
End of season	32	95	141	218	-	34
Regenerated vetch herbage yield in 1990/91	3258	3879	3708	3900	-	320

grazing was done the yield of herbage declined, and the time of grazing from end of winter to early spring had little effect on the herbage yield of vetch. Interestingly, the barley yield after vetch was better than after barley perhaps reflecting better soil fertility status after vetch as compared to barley. Reasonable seed bank was formed from the underground pods, as revealed by soil sampling before the start of subsequent barley season, but earlier the grazing was done in 1988/89 season lower was the seed bank. During the barley phase some of the vetch seeds germinated. Thus the seed bank at the end of the barley phase was lower than at the beginning. However, it was sufficient to let a good regeneration of vetch occur in the next season. The herbage yield of the regenerated vetch well reflected the status of seed bank. The study demonstrated good potential of underground vetch for incorporation in the barley mono-cropping system and augmenting forage production in the dry areas.

Biological Nitrogen Fixation (BNF) potential in different vetch species

As indicated earlier, one of the major advantages of incorporating vetches in the dryland cropping system is their role in providing an influx of combined nitrogen through their symbiotic nitrogen fixation. There are factors associated with the genotype of the host (legumes) and the symbiont (nodule bacteria), and their interaction, that determine the magnitude of nitrogen fixation. Intra- and inter-specific variation in BNF in the *Vicia* spp. was examined using the selected accessions that were being evaluated for yield and quality parameters, as described in the earlier sections. Isotopic dilution technique was employed, using ^{15}N and barley as the non-nodulating reference crop. No artificial inoculation with rhizobia culture was done. So, the roots of tested vetch accessions were exposed to native rhizobia populations, which presumably have co-evolved with the host plants over the long period of their domestication. The results are

Table 7. Inter- and intra-specific variations in the yield of total nitrogen and of biologically fixed nitrogen in *Vicia* spp. at Tel Hadya, Syria, 1994/95 season

Vicia spp.	Accessions tested	Total N (kg/ha)		BNF (kg/ha)	
		Range	Mean	Range	Mean
V. sativa	48	70-102	83	52-80	64
V. villosa ssp. *dasycarpa*	24	74-120	107	54-90	71
V. narbonensis	24	56-102	81	38-80	62
V. ervilia	24	71-120	96	54-91	73
V. palestina	24	45-100	70	29-74	50

presented in Table 7. A high proportion of total nitrogen yield was derived from BNF. Wooly-pod vetch and bitter vetch showed higher BNF than the other vetches. There was also large intra-specific variation in BNF. Thus, there appears to be a potential for improving BNF through breeding.

Prospects for developing improved vetch cultivars for dry areas

Existence of large range in phenology and various agronomic traits in the studied accessions of different types of vetches provided a good scope for identifying suitable cultivars for different agro-ecological conditions. Sharing of this variability with the national research programs in the dry areas of West Asia and North Africa region and similar ecologies elsewhere resulted in these national programs releasing cultivars for general cultivations in their respective regions. For example Syrian national program started a very successful program of promoting improved common vetch for grazing, hay-making and grain and straw production in the areas dominated by small ruminant production (Christiansen *et al*., 2000a; 2000b; Thompson *et al*., 1992) and the area under vetches expanded rapidly. The advanced selections of common vetch, wooly-pod vetch and narbon vetch were sent to the Chinese national program in Lanzhou, as a part of the International Nursery Testing Program of ICARDA. The region has large tracts of dry alpine areas where livestock production is an important source of livelihood for the people. Evaluation by the researchers at four Alpine grassland sites resulted in identification of four lines of common vetch and one of narbon vetch that had potential for good production of seed and forage under those ecological conditions (Nan *et al*., 2006). This provides a pointer to the possibility of introduction vetches for augmenting feed production in the cold desert environmental conditions in the highlands of India and other countries having similar ecological conditions.

The crop improvement work at ICARDA is now geared to incorporating resistance to foliar diseases and further improving the nutritional quality of different vetches in high and stable yielding backgrounds for different agro-ecological conditions in the dry areas. International collaboration would enable the dryland farming communities to benefit from this program coordinated by ICARDA.

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