Quantitative evaluation of above-ground plant biomass, forage availability and grazing impact assessment combining satellite image processing and field survey in a dry area of north-eastern Syria

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Abstract

The field survey and satellite image processing were conducted to estimate the total available forage over the whole study area (95,034 ha), north-eastern Syria, and then assess grazing impact in the entire study area. The above-ground plant biomass were measured by quadrat method at 3 sites in each vegetation class. Available forage was measured by excluding woody parts of shrubs from the whole aerial plant parts. The total above-ground plant biomass and available forage were estimated by extrapolating the measured point data to the whole target area using classified vegetation data by satellite image processing. Grazing impact was assessed as the change rate by calculating differences between the total available forage at the end of growing season and the end of dry season. The estimated total available forage in the entire study area was 55,628,000 $\pm$ 12,920,000 kg DM and 30,007,000 $\pm$ 2,437,000 kg DM at the end of growing season and dry season, respectively. Although the area of the cereal fields covered only 31.5% of the surveyed area, about 69% and 82% of available forage existed in the harvested cereal fields at the ends of growing season and dry season, respectively. The integration of cereal fields and rangeland is therefore a normal land use system for livestock management in the study area. The higher coverage of herbaceous vegetation types showed higher values of change rates which were –81.7 $\pm$ 19.9%. Although these dense herbaceous vegetation types could possibly produce more available forage, they would incur more intensive grazing impact on the rangeland. On the other hand, lighter grazing impact would occur with the higher coverage of shrub vegetation types. The sustainability of shrubs can help to maintain plant cover over the grazing rangeland and protect the land against soil erosion.

Introduction

Most semi-arid and arid marginal lands and rangeland in Western Asia are permanent pastures (1.16 million km^2), 85% of which are considered to be in danger of desertification (UNEP, 1984). These marginal lands are subject to human activities. They are vulnerable to hazardous land use practices, such as overgrazing, fuel cutting, and inadequate cultivation. Although quantitative forage evaluation is essential to asses grazing impact on rangeland, it is seldom reported because of the difficulties in measuring forage availability over large areas and identifying grazing impact from natural factors, such as defoliation and seed shedding.

Since herds of small ruminants led by Bedouins move over large areas for grazing throughout the year and affect the whole ecosystem on a large scale, forage evaluation and grazing impact assessment must be conducted over large areas with a high vegetation diversity. This makes measurement of available forage and grazing impact assessment on such large and diverse areas difficult. To evaluate the highly diverse rangeland in a large scale, it first needs to be classified into vegetation types. The importance of vegetation mapping and classification is clearly stated in a number of works (Kuchler *et al.*, 1988). Satellite image processing is now one of the most powerful tools to appraise and monitor natural resources on a large scale (Ram *et al.*, 1993). After conducting initial vegetation classification, plant biomass evaluation and grazing impact assessment in a large scale may be quantitatively appraised by conducting ground surveys in each classified vegetation type. The purpose of this study is to estimate the total available forage with the help of satellite image processing over the Abdal Aziz Mountain study area, north-eastern Syria, and then assess grazing impact from end of growing season to end of dry season in the entire study area. The strategy (Figure 1) for accomplishing is, 1) vegetation classification in the entire study area by ground surveys combined with satellite image processing, 2) measuring available forage at selected and representative sites at the end of growing season and dry season, 3) extrapolating point data of available forage to the whole target area using classified vegetation data to estimate the total available forage in the entire study area, and then 4) conducting grazing impact assessment between the end of growing season to dry season. The differences between the total available forage at the end of growing season and dry season in each vegetation class were calculated as "change rate", in order to

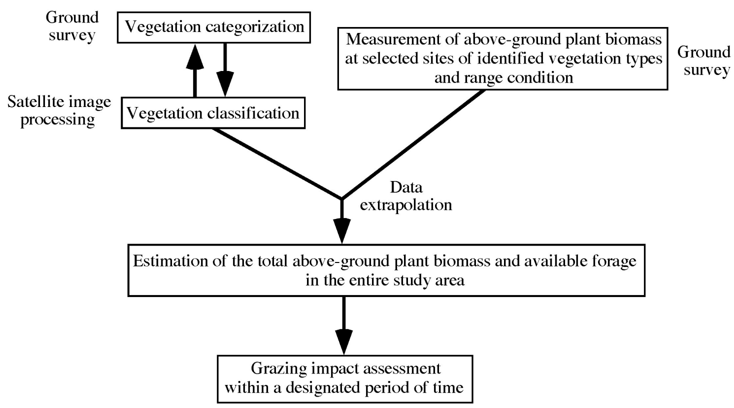

Figure 1
Process to estimate the total above-ground plant biomass, total available forage and grazing impact assessment in the entire study area.

assess grazing impact on the rangeland during this period.

Study area

The size of the Abdal Aziz Mountain study area is 95,034 ha (33.7 km east-west and 28.2 km north-south), located in the Hassakeh Province of north-eastern Syria. The average annual precipitation is only 200 mm to 300 mm (Syrian Arab Republic, 1997) (Figure 2). The color composite image (Figure 3) was developed using the principal component analysis of the Landsat 5 TM image (path: 172, low: 35) for 13 April 1994. The study area is an orographic zone (maximum altitude: 912 m) with steep northern slopes and moderate southern slopes, bordered by plains to the North and the South.

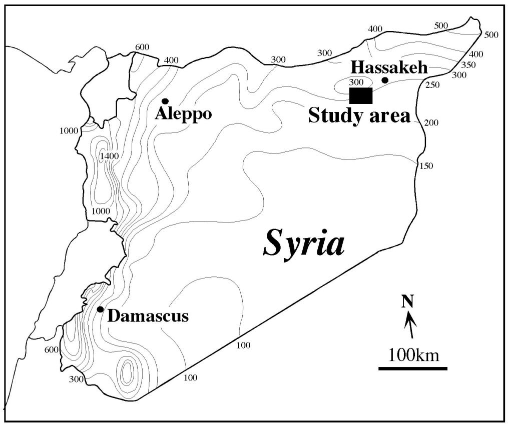

Figure 2
Distribution of annual precipitation (mm/year) of Syria (from Syrian Arab Republic, 1977) and location of the Abdal Aziz Mountain study area.

Cropping land

On the northern and southern plains, arable land is scarce and has poor soil. It is usually cropped with rainfed barley. In the mountain, rare depressions and foothills flats are also cropped with rainfed barley (blue sections in Figure 3) and fallow land (brown). Barley stubble/straw is largely used for sheep and goat production by direct grazing from summer to autumn after harvesting, while harvested barley grain/straw are used for supplementary livestock feeding during winter (Thomson, 1987; Gintzburger *et al.*, 1997; Hirata *et al.*, 1998).

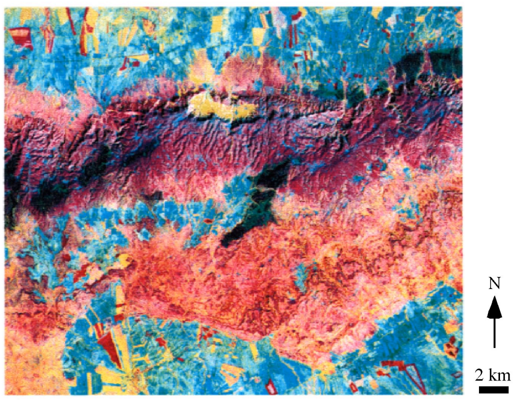

Figure 3
Color composite image using principal component analysis on Landsat TM5 satellite images dated 13 April 1994 in the study area.
Component 1, 2, and 3 were assigned red, green, and blue colors, respectively.

Rangeland

The mountainous and rocky areas are used for rangeland grazing by local flocks mainly from autumn to spring. Purple and orange areas (Figure 3) are mainly *Artemisia herba-alba* and *Noaea* *mucronata* dominant rangeland; Blue areas are dense herbaceous rangeland; Dark areas are densely vegetated rangeland because they have been protected from livestock grazing for afforestation projects during several years; Yellow areas are highly degraded mostly by overgrazing and fuel wood gathering by local Bedowins; Yellow narrow lines are wadies (dry river beds). The soils of the area are predominantly sandy-loam to loam. They are shallow and classified as Lithic Xerorthents and Typic Calcixerepts (Soil Survey Staff, 1998), derived from consolidated carbonate sediments, e.g. limestone, dolomite and marl (FAO-UNESCO, 1977), as described by Shinjo *et al.* (2000). The calcareous crust or hardpan is often exposed on piedmont sites.

Climate and weather conditions

The climate of the study area is typically semi-arid Mediterranean with a monomodal cool and wet winter and a hot and dry summer (Le Houérou, 2004). During the study, this is verified with a self-recording rain gauge (Campbell Scientific, Inc.) equipped with a rain tipping-bucket (0.1 mm precision) and recording temperature sensors established on north-eastern foothill of the mountain. The rainy season lasted from November of 1995 to April of 1996, and the dry season from May to October of 1996 (Figure 4). Total precipitation for 1995/96 was 252 mm. When the rainy season started in November, minimum air temperature fell to below 0℃, and continued into late February (winter). Air temperature gradually rose from late February to late April, creating moderate conditions (spring). When the dry season started in May, maximum air temperature suddenly jumped to over 30 ℃, continuing into September (summer). Minimum and maximum air temperatures were -7.5℃ on 17th of December and 41.5℃ on 17 of July.

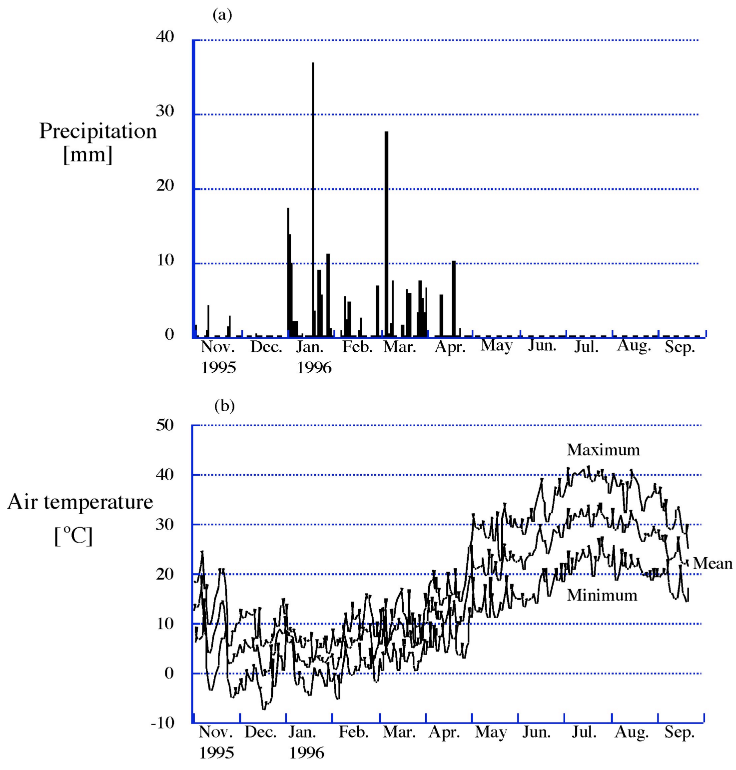

Figure4
Precipitation (a) and air temperature (b) from November of 1995 to September of 1996 in the study area.

Seasonal native plant growth

New shoots of native vegetation appear in December to January after the late-autumn rainfall. There is little growth until February because of cold air temperature, then native vegetation grows considerably from February to May during spring when temperatures increase. Most vegetation ceases growth by the end of spring, early May, and then aerial plant biomass decreases over time

(Hirata *et al*., 2000).

Artemisia herba-alba and *Noaea mucronata* are the two representative shrubs in the study area. Their new shoots appear usually in December or January. Although there is little growth until February, there grow exponentially from February to May. After starting dry season in May, the small growth of *A. herba-alba* can be observed until September, but *N. mucronata* continues to grow until September. Both *A. herba-alba* and *N. mucronata* may shed their leaves and stems as a drought evading mechanism during dry season.

Materials and Methods

Vegetation classification and areas of each vegetation class

As the result of vegetation categorization in the winter of 1995/1996 according to plant contacts (counting plants at every 50 cm intervals along a 25 m line) of *A. herba-alba* (A) and *N. mucronata* (N) at 75 sites, rangeland under grazing was categorized into 4 vegetation classes; 1) High *A. herba-alba* and Low *N. mucronata* (HALN), 2) Middle *A. herba-alba* and Middle *N. mucronata* (MAMN), 3) Low *A. herba-alba* and Middle *N. mucronata* (LAMN) and 4) Low *A. herba-alba* and Low *N. mucronata* (LALN) (Figure 5). High (H), Middle (M), and Low (L) mean the plant contact is more than 20%, from 10% to 20%, and less than 10%, respectively. High *A. herba-alba* and High *N. mucronata* appeared on the protected rangeland and was assigned as D-Vege.

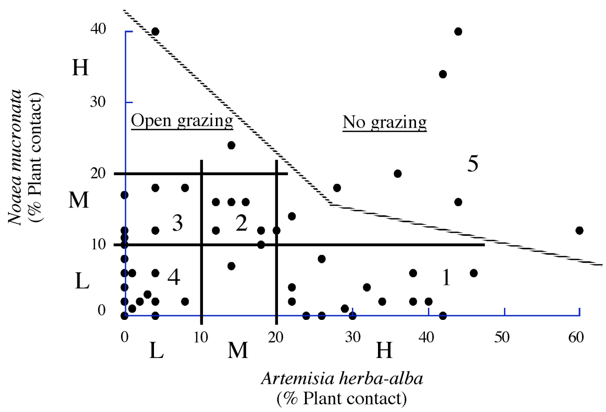

Figure 5
Categoriztion of rangeland condition in relation to shrub contacts (%) of *Artemisia herba-alba* and *Noaea mucronata* on selected sites of the study area in the winter of 1995/96 (from Hirata *et al*., 2001).

Open grazing rangeland
1. HALN : High *Artemisia* - Low *Noaea*
2. MAMN : Middle *Artemisia* - Middle *Noaea*
3. LAMN : Low *Artemisia* - Middle *Noaea*
4. LALN : Low *Artemisia* - Low *Noaea*

No grazing rangeland
5. D-Vege : Dense Vegetation

The supervised classification was conducted using ILWIS 2.2 software (ITC, 1998) with the 2, 3 and 4 bands of a Landsat TM 5 image acquired 13 April 1994, according to the vegetation index categorized by the contact values of *A. herba-alba* and *N. mucronata* (Hirata *et al*., 2001). In the supervised classification, thirty-four training sites were selected which represented relevant vegetation classes in the study area. Cereal field (Cereal) and Fallow land (Fallow) classes were also added to this classification as cultivated land use types. In this classification, the LALN vegetation class was further categorized into two classes by high (more than 70%) and low (less than 70%) contacts of herbaceous plants, which were assigned as LALNHH and LALNLH, respectively. These two classes showed large differences in above-ground plant biomass and spectral reflectance. Finally, the rangeland and cultivated fields in the study area were classified into 6 classes and 2 classes (Figure 6). The average ground verification accuracy was 81% in this supervised classification. The map of vegetation classification and the areas of each vegetation class were used to evaluate the total available forage and assess grazing impact in the entire study area. We assumed that the 1996 season was very similar to the 1994 season and that no major changes in the land use occurred between April 1994 and spring – autumn 1996.

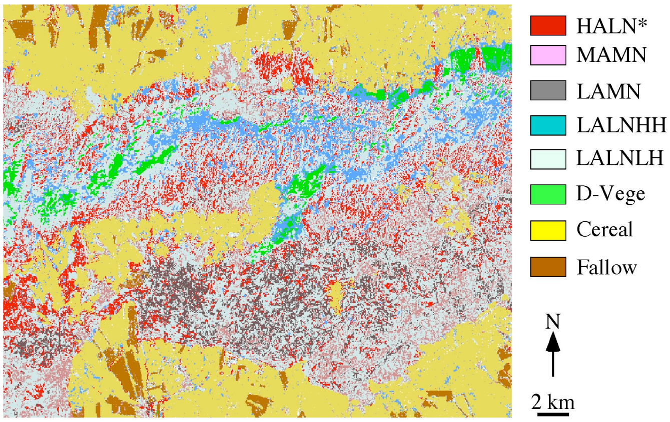

Figure 6
Vegetation classification by the supervised method using Landsat TM5 satellite images dated 13 April 1994 in the study area (from Hirata *et al*., 2001).

* Abbreviation;
HALN : High *Artemisia* - Low *Noaea*
MAMN : Middle *Artemisia* - Middle *Noaea*
LAMN : Low *Artemisia* - Middle *Noaea*
LALNHH : Low *Artemisia* - Low *Noaea* - High Herbaceous plant
LALNLH : Low *Artemisia* - Low *Noaea* - Low Herbaceous plant
D-Vege : Dense Vegetation
Cereal : Cereal field
Fallow : Fallow land

Ground surveys and estimation of the total above-ground plant biomass and available forage at the end of growing season and dry season

The above-ground plant biomass were randomly measured at 3 sites of each vegetation class classified by satellite image processing, in the last week of May (the end of growing season) and the middle of October (the end of dry season) of 1996. Whole aerial parts of herbaceous plants and shrubs on the rangeland, residues and weeds in harvested cereal fields, and fallow were collected at ground level. Two 1 m x 0.25 m quadrats for herbaceous plants, residues, weeds and two 5 m x 2 m quadrats for shrubs were used for measurements at each site, respectively. The collected plants were then separated between woody parts and green parts, then oven dried (at 85° for 24 hours) to estimate dry matter (DM) for each woody and green parts.

Available forage on dry rangeland, which is the available parts of plants used by ruminants (Vallentine, 1990), is defined as the whole aerial parts of herbaceous plants and yearly new shoot parts of shrubs, according to the grazing behavior of sheep and goats (Thalen, 1979). Hence, available forage on the rangeland was calculated by excluding woody parts of shrubs from the whole aerial parts of herbaceous plants and shrubs. In the case of *N. mucronata*, since the young and green spine become hard and unavailable for sheep/goat grazing after June (Hirata *et al*., 2000), new shoot parts of *N. mucronata* were also excluded from available forage at the end of dry season.

The total above-ground plant biomass and available forage were estimated by extrapolating the point data at 3 selected sites in the each vegetation class to each whole target area using classified vegetation data by satellite image processing.

Grazing impact assessment on the rangeland

Change rates (%) of the estimated total above-ground plant biomass and available forage between the end of growing season and dry season were used as an index for grazing impact assessment on the rangeland. The change rate contains both a grazing factor such as local livestock grazing and a defoliating factor of leaves and stems through seasonal-climatic changes. The change rate was calculated by the equation as the total above-ground plant biomass or the total available forage at the end of {(dry season - growing season)/growing season} x 100.

Results and Discussion

Vegetation classification and areas of each vegetation class

Using the vegetation classification by satellite image processing, the area and ratio of each vegetation class within the study area could be evaluated (Table 1). Rangeland and cultivated fields occupied 63.1% and 34.7% of the whole study area, respectively. Unclassified areas resulted in only 2.2% in this classification. It was clarified that the LALNLH (Low *A. herba-alba*, Low *N. mucronata*, Low Herbaceous plant) was the dominant vegetation condition class. It occupied 55.6% of the rangeland. After ground checking, the average accuracy on this vegetation classification over the entire study area was 84%. It indicates that a successful classification was conducted (Knick *et al.*, 1997).

Table 1. Areas and ratios of each vegetation class analyzed by satellite image processing in the study area (from Hirata *et al* ., 2001).

Vegetation class	Area (ha)	Ratio (%)		Plant composition (% contact)		
		Total	Rangeland	A.**	N.	H.
Grazing area						
HALN*	7,767	8.2	13.0	>20,	<10,	
MAMN	4,724	5.0	7.9	10-20,	10-20,	
LAMN	5,078	5.3	8.5	<10,	10-20,	
LALNHH	6,862	7.2	11.4	<10,	<10,	>70
LALNLH	33,348	35.1	55.6	<10,	<10,	<70
Protected area						
D-Vege	2,172	2.3	3.6	>20,	>20,	
Cultivated field						
Cereal	29,965	31.5				
Fallow	3,048	3.2				
Non-classified	2,071	2.2				
Total	95,034	100.0	100.0			

* Abbreviation: See Figure 6

** A.=*Artemisia herba-alba* , N.=*Noaea mucronata* , H.=herbaceous plants

Estimation of the total above-ground plant biomass and available forage

Table 2 shows the results of the above-ground plant biomass and available forage (kg DM/ha), and the estimated total above-ground plant biomass and available forage (1,000 kg DM) in each vegetation class at the end of growing season in 1996, when available forage is larger. Available forage in the LALNHH class was 506 ± 551 kg DM/ha. It had a larger variation and more available forage than those on the other grazing rangeland. Hence, dense herbaceous vegetation could have the possibility to produce a larger quantity of forage on the rangeland. It was reported that grazing rangeland productions in the arid areas of North Africa and West Asia were from 75 to 1,000 kg DM/ha (Le Houérou and Hoste, 1977; Thalen, 1979). Since available forage of the study area was 153±64 to 506±551 kg DM/ha on grazing rangeland, the study area has the almost same forage productivity as other sites in the Mediterranean Basin.

Table 2. The above-ground plant biomass and available forage per hectare (kg DM/ha) , and the estimated total above-ground plant biomass and available forage (1,000 kg DM) for each vegetation class at the end of growing season in 1996 in the study area.

Vegetation class	Measurement of				Area	Estimation of total			
	above-ground plant biomass (kg DM/ha)		available forage (kg DM/ha)			above-ground plant biomass (1,000 kg DM)		available forage (1,000 kg DM)	
	Mean	SD	Mean	SD	[ha(proportion)]	Mean (%)	SD	Mean (%)	SD
Grazing area									
HALN*	650	172	348	152	7,767 (8.2)	5,046 (7.7)	1,338	2,700 (4.9)	1,183
MAMN	514	165	195	15	4,724 (5.0)	2,427 (3.7)	778	921 (1.7)	69
LAMN	392	204	153	64	5,078 (5.3)	1,991 (3.0)	1,037	775 (1.4)	326
LALNHH	506	551	506	551	6,862 (7.2)	3,472 (5.3)	3,783	3,472 (6.2)	3,783
LALNLH	303	81	179	62	33,348 (35.1)	10,093 (15.4)	2,705	5,980 (10.7)	2,052
Protected area									
D-Vege	1,572	413	1,253	465	2,172 (2.3)	3,414 (5.2)	897	2,721 (4.9)	1,010
Cultivated field									
Cereal	1,289	774	1,289	774	29,965 (31.5)	38,615 (58.8)	23,200	38,615 (69.4)	23,200
Fallow	204	177	145	148	3,048 (3.2)	623 (0.9)	540	443 (0.8)	451
Non-classified					2,071 (2.2)				
Total					95,034 (100)	65,680 (100)	12,610	55,628 (100)	12,920

* Abbreviation: See Figure 6

On the other hand, available forage measured on the protected rangeland class (D-Vege) was obviously much more than that on the rangeland open to grazing. Many trials for rangeland improvement have been conducted in the Mediterranean basin mainly by using phosphorus-nitrogen fertilization and/or reseeding appropriate plant species (Berg *et al.*, 1989; Osman and Bahhady, 1994; Ghassali *et al.*, 1995; Gintzburger *et al.*, 2000). However, these studies indicate that available forage on the degraded rangeland could recover to the level of the D-Vege class only by protecting the land against grazing for several years.

The total available forage over the entire study area was estimated at 55,628,000 ± 12,920,000 kg DM at the end of growing season. Since the LALNLH class was dominant on the rangeland, the estimated total available forage in the whole LALNLH class was more than those in the other classes of rangeland in spite of the smaller available forage per unit area.

Table 3 shows results of the above-ground plant biomass and available forage (kg DM/ha), and the estimated total above-ground plant biomass and available forage (1,000 kg DM) in each vegetation class at the end of growing season in 1996, when available forage is smaller. Available forage in the HALN class and the MAMN class were 165±10 kg DM/ha and 103±38 kg DM/ha, respectively, which was more than those in the other classes of the grazing rangeland. A denser *A. herba-alba* vegetation type contributed to more available forage in this season. In the meager feed resource season lasting from autumn to winter, new shoots of *A. herba-alba* supply precious forage resouces for sheep and goats. Since available forage in the LAMN, LALNHH, and LALNLH classes were less than 100 kg DM/ha, forage seldom remained in these vegetation classes in this season. The total available forage over the entire study area was estimated at 30,007,000± 2,437,000 kg DM in this season.

Table 3. The above-ground plant biomass and available forage per hectare (kg DM/ha) , and the estimated total above-ground plant biomass and available forage (1,000 kg DM) for each vegetation class at the end of dry season in 1996 in the study area.

Vegetation class	Measurement of above-ground plant biomass (kg DM/ha)		Measurement of available forage (kg DM/ha)		Area	Estimation of total above-ground plant biomass (1,000 kg DM)		Estimation of total available forage (1,000 kg DM)	
	Mean	SD	Mean	SD	[ha(proportion)]	Mean (%)	SD	Mean (%)	SD
Grazing area									
HALN*	629	182	165	10	7,767 (8.2)	4,885 (11.8)	1,414	1,284 (4.3)	80
MAMN	457	242	103	38	4,724 (5.0)	2,159 (5.2)	1,142	486 (1.6)	177
LAMN	281	139	38	9	5,078 (5.3)	1,425 (3.5)	707	191 (0.6)	44
LALNHH	44	45	44	45	6,862 (7.2)	302 (0.7)	307	302 (1.0)	309
LALNLH	139	97	55	21	33,348 (35.1)	4,635 (11.2)	3,243	1,845 (6.1)	706
Protected area									
D-Vege	961	220	466	235	2,172 (2.3)	2,087 (5.1)	477	1,012 (3.4)	510
Cultivated field									
Cereal	840	330	820	338	29,965 (31.5)	25,181 (60.9)	9,874	24,581 (82.0)	10,115
Fallow	207	180	99	172	3,048 (3.2)	632 (1.5)	549	303 (1.0)	524
Non-classified					2,071 (2.2)				
Total					95,034 (100)	41,306 (100)	8,261	30,007 (100)	2,437

* Abbreviation: See Figure 6

Although the area represented by cereal crops was only 31.5% of the entire study area, about 69% and 82% of the total available forage existed on the harvested cereal fields at the end of growing season and dry season, respectively. The main forage was available in harvested cereal fields, not on rangeland, in the study area. Over the past 40 years, the integration of cereal fields and rangeland for livestock management has been a widespread practice in the barley belt of Syria (Thomson, 1987).

The total available forage in the whole study area could be estimated at 55,628,000± 12,920,000 kg DM and 30,007,000±2,437,000 kg DM at the end of growing season and dry season, respectively. If the study area had 150 thousand sheep and goats (personal communication from Mr. M. Darwish, agricultural scientist, ICARDA) and if each sheep and goat consumed 1 kg DM/day of forage (ICARDA, 1984), a simple assumption could be made that the entire study area could have the potential to feed the flock of sheep and goats for 185±43 days at the end of growing season during the summer and for 100±28 days at the end of the dry season during the early autumn and winter, assuming a conservative 50% use of available forage (Le Houérou, 2004). It may indicate that there was little risk of overgrazing in the study area in this 1995-96 season.

Grazing impact assessment on the rangeland

Change rates (%) of the estimated total above-ground plant biomass and available forage for each vegetation class between the end of growing season and dry season are shown in Table 4. Change rates of the whole above-ground plant biomass increased at some areas of the HALN and MAMN classes, which means that some areas in those classes were able to increase the above-ground plant biomass during this period. Although herbaceous plants stopped growing in May and total mass decreased mainly because of grazing after May, *A. herba-alba* displayed little growth on the grazing rangeland and *N. mucronata* showed a continuous growth throughout summer. The increasing weight, due to the growth of shrubs, was more than the decreasing biomass of herbaceous plants in some areas of the HALN and MAMN classes. However, the change rates of available forage decreased in these classes because new shoots of *N. mucronata* were counted as unavailable forage in October, due to those becoming hard and unpalatable after June. Some areas of the Fallow class also increased the change rates of the whole above-ground plant biomass. This increase took place due to the growth of unpalatable shrubs and the low accessibility of flocks to these areas during this period.

Table 4. Change rates (%) of the estimated total above-ground plant biomass and available forage from the end of growing season to dry season in 1996 in the stury area.

Vegetation class	Change rate (%) of			
	above-ground plant biomass		available forage	
	Mean	SD	Mean	SD
Grazing area				
HALN*	0.3	30.4	-47.1	18.6
MAMN	-16.1	23.8	-47.7	16.6
LAMN	-27.9	4.9	-73.0	8.8
LALNHH	-81.7	19.9	-81.7	19.9
LALNLH	-55.4	23.2	-63.8	24.8
Protected area				
D-Vege	-36.3	20.2	-62.9	9.1
Cultivated field				
Cereal	-29.7	13.1	-32.0	11.4
Fallow	1.4	1.1	-33.0	71.2

* Abbreviation: See Figure 6

Change rates of the estimated total available forage in all classes of grazing rangeland indicated a decrease and those values varied from –81.7±19.9 to –47.1±18.6%. The defoliation of *A. herba-alba* and herbaceous plants from summer to autumn was observed on the grazing rangeland. Not only grazing factors, but also some natural factors due to drought evading systems (leaf and stem shedding) induced the decrease of available forage in all classes on the grazing rangeland. On the other hand, change rates of the whole available forage in the D-Vege class, which is under non-grazing, also decreased and had the value of –62.9±9.1%. The defoliation of plants and the unavailability of new shoots of *N. mucronata* caused these decreases on this protected rangeland.

Available forage in the LALNHH class decreased more than those in other vegetation classes, of which the change rate was –81.7±19.9 %. It was considered that heavier land use mainly by grazing would occur in these two classes. Although a dense herbaceous vegetation type in the LALNHH class could possibly produce more available forage, this vegetation type would receive more intensive grazing impact because almost all aerial parts in this vegetation type is highly palatable and available for grazing by small ruminants. On the other hand, lighter grazing impact would occur with a higher coverage of shrub vegetation types, such as the HALN and MAMN classes. All aerial parts of not only *N. mucronata*, but also any other shrubs, could not be used for grazing due to their woody or spiny branches. From the viewpoint of sustainable land use, shrubs are key plants for keeping native plants on the grazing rangeland. On denser shrub rangeland, this sustainability and resilience of shrubs would keep a good plant cover over the grazing land and would contribute more efficiently to the protection of the land against soil erosion by wind and water (Shinjo *et al*., 2000).

Change rates of available forage in harvested cereal fields decreased less than those on the grazing rangeland. Although 82% of the total available forage at the end of dry season came from harvested cereal fields, grazing areas mainly changed to the rangeland after September. Most flocks grazed the much smaller forage on the rangeland in this season, but seldom grazed on cereal fields, which are finally plowed or burned in preparation for next year cropping. The utilization of cereal residues late in the autumn must be considered instead of being burned. This would be to achieve a more effective land use, to increase livestock production and better protect the rangeland, especially in season of scanty feed resources.

Conclusions

With the help of satellite image processing, the total available forage in the entire study area (95,034 ha) was estimated at 55,628,000±12,920,000 kg DM and 30,007,000±2,437,000 kg DM at the end of growing season and dry season, respectively. The main source of forage was obtained from harvested cereal fields and not from the rangeland in the study area. If the study area had 150 thousand sheep and goats which are herded by semi-sedentary pastoralists, a simple assumption could be that the study area could have the potential to feed sheep and goats for 185±43 days and for 100±28 days at the end of growing season and dry season, respectively, considering a 50 % conservative use of available forage to avoid overgrazing and ensuing soil erosion.

Although dense herbaceous vegetation types could possibly produce more available forage, they would receive a more intensive grazing impact on the rangeland. On the other hand, lighter grazing impact would occur with a higher coverage of shrub vegetation types. Although the availability of shrubs for grazing was inferior to that of the herbaceous plants, the sustainability and resilience of shrubs were superior to that of the herbaceous plants due to the woody parts and spiny branches that remain unavailable for grazing.

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