LAND USE CLASSIFICATION WITH HIGH-RESOLUTION SATELLITE RADAR FOR ESTIMATING THE IMPACTS OF LAND USE CHANGE ON THE QUALITY OF ECOSYSTEM SERVICES

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KEY WORDS: Ecosystem, Land Use, Classification, Radar, Multi-temporal

ABSTRACT:

Ecosystems provide several services for human well-being. The quality of these ecosystem services is among others affected by agriculture, the main land user in Europe. Thus, it is essential to provide information about land use in agricultural areas.
In this research, land use classification of agricultural areas is carried out based on high-resolution Spotlight TerraSAR-X images (TSX-images) of two different polarisations (HH and VV). A stack of several radar images taken during the vegetation season is used for multi-temporal classification of land cover. The typical phenology of agricultural vegetation types and their individual phenological development during the year cause differences in the backscatter of the radar signal over time.
Two different study areas are investigated, one in the North East of the city of Hannover, Germany called “Fuhrberger Feld” and one in the “Gorajec area” in the very South East of Poland. These two areas represent extremely diverse European regions with regard to agro-technological level, population density, cultivation form as well as geological and geomorphological conditions. Thereby, the radar signal backscatter for different regions is tested.
Preliminary results show significant differences in the backscatter of crop types in SAR data of about 3 m, especially for grasslands, grain and broad-leaved crops. Furthermore the VV polarised radar signal has clearly lower backscattering for grains during summertime and for grasslands in general than for broad-leaved crops.

1. INTRODUCTION

Ecosystems have an important function for the quality of human life. They provide material goods and intangible values as “ecosystem services” for human well-being. They comprise all basic requirements for human well-being, e.g. food, water, air, climate, or recreation. Ecosystem services base on a complex system of ecosystems and their interactions. They enable security, health, basic material goods, and good social relationships (Millennium Ecosystem Assessment, 2005; Myers & Reichert, 1997).
Ecosystem services are affected by different direct and indirect drivers of change. Beside natural drivers, also human impacts influence the ecosystem services; one important impact is land use (Millennium Ecosystem Assessment, 2005). Although land use and ecosystem services interacted since the beginning of land cultivation, there has been an unprecedented increase of intensity in land use in the twentieth century (Poh Sze Choo et al., 2005; Ramankutty et al., 2006). This leads to numerous negative impacts on ecosystems services (Poh Sze Choo et al., 2005; Ramankutty et al., 2006; DeFries, 2004). To assess the impacts of land-use changes on ecosystem services, it is indispensable to provide precise and up-to-date information about land use and land-use change. Remote sensing affords the opportunity to derive this information. New high-resolution sensor types are particularly suitable to improve land use classification results (Poh Sze Choo et al., 2005; Ramankutty et al., 2006). One of the new sensors is the TerraSAR-X satellite based radar sensor.
TerraSAR-X allows acquisition of multiple polarized radar images (products) with a high ground resolution of up to one meter (DLR, 2007; Fritz & Eineder, 2009). As a satellite-based radar system it is able to provide reliable and regular information about earth surface. Hence, it is especially suitable for multi-temporal land-use classification. The basic idea of the multi-temporal land-use classification is to use a stack of several products during the vegetation period. Different phenological conditions of the vegetation cause an individual backscatter of radar signal in time. In this way, a higher content of information for the classification method is available. Studies with elder systems like ERS 2 or ENVISAT-ASAR showed already the general feasibility of this approach (Schieche et al., 1999; Foody et al., 1988; Borgeaud et al., 1995; Tavakkoli Sabour et al., 2008).
The objective of this study is to conduct a multi-temporal land-use classification of TerraSAR-X images and to examine the suitability of the classification results for assessing impacts of land-use change on ecosystem services. Individual temporal backscatter patterns are identified for different crop types. Observations concentrate on European agricultural areas and on two selected ecosystem services, namely biodiversity and soil.

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2. METHODOLOGY

2.1 Study areas

Two study areas have been chosen to test the robustness and transferability of the approach. The test sites vary strongly in their sociological, ecological, economic, and geomorphological conditions. The Fuhrberg area ("Fuhrberger Feld") is situated in Germany, in the North East of the city of Hannover (52.56 N, 9.84 E), while the second area ("Gorajec") is located in the very South East of Poland (50.68 N, 22.85 E). The German study area is characterised by intensive agriculture, modern production methods, and large fields. The terrain is flat and the share of field margin strips, hedgerows and other habitat structures is low. The area is a water protection area and its ground water is provided as drinking water for the region of Hannover.

In contrast, in the Polish study area traditional production methods are applied and technical and agrochemical equipment standard is low. The region belongs to the least developed regions in Europe concerning its agricultural production methods (Palang et al., 2006). According to this, landscape structure is dominated by a mosaic of habitat structures, and the size of fields is exceptionally small. The characteristic land relief and loess soils of the Gorajec region cause strong soil erosion processes (Jadczyszyn 1997).

2.2 Data sets

For both study areas TerraSAR-X images were acquired in High Resolution Spotlight Mode (HS) during the growing season of the year 2009 (Table 1). The images were taken in dual polarisation VV and HH and delivered as ground range products with equidistant pixel spacing in azimuth and ground range direction (Fritz & Eineder 2009). Seven images are available for the Gorajec area and only five for the Fuhrberg region because no images could be ordered for the Fuhrberg region in August and September 2009. For the Polish Gorajec area all acquisitions are taken at an incidence angle of 31.72 °, those for the Fuhrberg area at an incidence angle of 34.75 °. Ground range resolution is 2.1 meters for Fuhrberg and 2.3 meters for Gorajec. Resolution in azimuth direction is 2.4 meters for both areas. The extent auf the scenes is 5 kilometers in azimuth and 10 kilometers in ground range according to the HS-Mode.

study area	**month**	**day**
Gorajec	March	14
Fuhrberg	March	11
Fuhrberg	April	13
Gorajec	Apri	27
Fuhrberg	June	18
Gorajec	June	10
Gorajec	July	13
Fuhrberg	July	10
Gorajec	August	4
Gorajec	September	6
Gorajec	October	9
Fuhrberg	October	17

Table 1: Availability of TerraSAR-X images

2.3 Ground truth

Ground-truth data were collected in both areas during the year 2009. Vegetation mapping was conducted to generate ground-truth information. In the Fuhrberg region, vegetation mapping was conducted on the exact acquisition dates. Therefore 152 fields have been visited regularly. Additional 46 fields were mapped in July. This results in a total number of 198 test fields for the Fuhrberg region.

In the Gorajec area, ground truth information was collected on three dates during the vegetation period of the year 2009. They covered the acquisition dates for Gorajec in April, August and October. 135 fields were mapped in the Polish study area.

The size of the investigated fields differs considerably between both study areas (Table 2). The mean size of the fields in the Fuhrberg region is 5.27 ha whereas the fields in the Gorajec area have a mean size of only 0.70 ha.

	Fuhrberg (GER)	Gorajec (PL)
sum	1048.34	94.34
max	24.36	3.12
min	0.37	0.03
mean	**5.27**	**0.70**

Table 2: Size of ground truth areas [ha]

During the field campaigns several parameters were recorded for each investigated field in a check list:

- Local situation of crop type and its phenological stage, according to the BBCH - scale for the description of growth stages of mono - and dicotyledonous plants (Meier & Bleiholder, 2006)
- Cultivation practices
- Other relevant observations (e.g. weed content, crop residues)

GPS-referenced pictures of all fields were taken. For each acquisition date the local weather conditions and moisture of surface area were recorded.

2.4 Data processing

After co-registration and georefencing of the datasets, the multi-temporal DeGrandi filter was applied on both sets. The described procedures were performed with ENVI SARSCAPE Software.

Radiometric calibration was done according to INFOTERRA (2008):

$$\sigma^0{}_{[dB]} = 10 * \log_{10}(CalFact * DN^2) + 10\log_{10}(SIN\theta_{loc})$$

Where: $\sigma^0{}_{dB}$ = the calibrated pixel value in decibel
CalFact = the calibration and processor scaling factor
DN = the pixel intensity value
θ_{loc} = the local incident angle which is the angle between the radar beam and the normal to reflecting surface.

3. RESULTS

3.1 Results of ground truthing

The described differences of the study areas lead to different characteristics of crops with regard to the type of cultivated plants and their appearance. This is reflected by the results of taken ground truth on-site.

15 (Fuhrberg) and 16 types of crops (Gorajec) have been recordered (Table 3). In the Fuhrberg area the presence of weeds is low on most fields. Nevertheless a gradient in the amount of weeds between different potato-fields has been detected. Some of them are completely free of weeds while others contain a certain amount of various species of weeds. The differences cannot be attributed to plant diseases. In Gorajec the amount of weeds is explicitly higher than in the Fuhrberg area. Most fields contain different kinds of weeds. Most potatoes in the Polish study area suffer from a disease.

Fuhrberg (GER)		Gorajec (PL)	
crop type	**count**	**crop type**	**count**
grasslands and meadows	43	grasslands and meadows	4
oat	4	oat	7
rye	33	rye	12
barley	20	barley	24
maize	13	maize	2
spelt	1	grain mixture: barley, wheat, oat	18
wheat	9	wheat	25
winter rape	8	turnip rape	2
sugar beets	18	sugar beets	3
potatoes	24	potatoes	6
fallow land	5	fallow land	3
strawberries	3	black currant	5
asparagus	12	tobacco	13
beans	1	beans	4
Lolium perenne	4	trefoil	4
		grain mixture: wheat, rye	3

Table 3: Type and quantity of crops

3.2 Measurement of signal backscatter

Measured backscatter of radar signal differs for different crops and different acquisition times. Thus an individual pattern of backscatter can be derived for every single crop type. In the following, first results of backscatter patterns (means per field) for selected crops are presented.

3.2.1 Fuhrberger Feld area

Broad-leaved crops and asparagus: The comparison of HH polarised mean backscatter values per field exhibits high backscatter values for broad-leaved crops (Fig.1). Sugar beets have high backscatter values (-6 dB) during full development of leaves in June (BBCH-codes 31-39). In July, during full phenological development, values exceed -6 dB yet. Images with sugar beets have been available in June, July and October. Values of maize and potatoes rise up to -8 dB when leaves cover the ground. Potatoes reached this value in June when flowering started (BBCH-codes 60-65). In April, after sowing, backscatter values are dispersed over the whole range between -7.5 and -14 dB. Maize also reached the development state of closed canopy in June (BBCH-codes 30-32) and HH-polarised backscatter is equal to the one of potatoes. Backscatter distri-

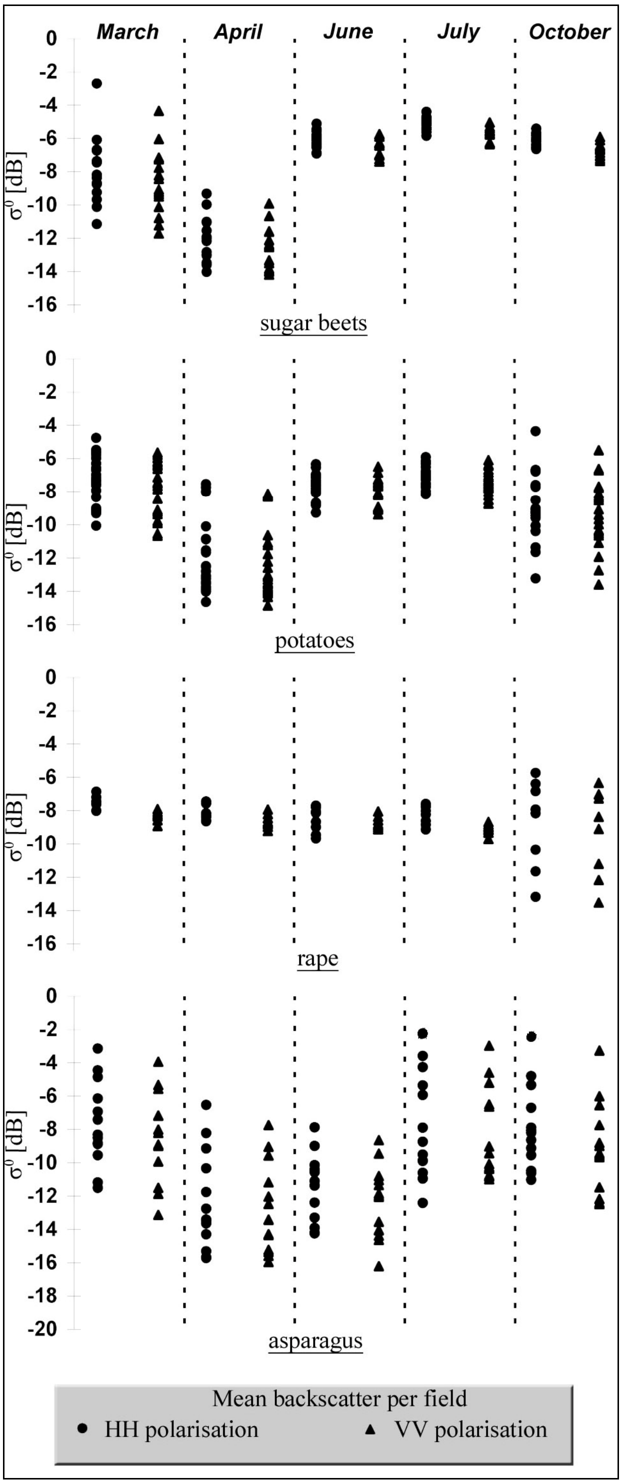

Figure 1: Backscatter distribution for broad-leaved crops and asparagus in the Fuhrberg area

bution for potatoes and maize has a wide range in October after harvesting due to differences in surface conditions. On winter rape fields, the ground was already covered in March when seven to nine leaves occurred (BBCH-codes 17-19). Accordingly, backscatter values average >-8 dB and remain on a high level of -10 dB or more up to July before harvesting started. The values for the different crops show that discrimination of broad leaved crops from those with narrow leaves is possible due to the clear difference in backscatter values. Furthermore, one can even differentiate within the

broad-leaved crops due to the time difference in development of ground covering leaves. For asparagus there is a widespread backscatter distribution recognizable for all acquisition months. The maximum backscatter values (up to -2 dB) are reached in March, July and October. Lowest values (below -14 dB) were noticed in April and June. The structure of the asparagus plant and the plantation in rows seems to influence the reflection strongly.
The analysis of the VV polarised signal shows a very similar backscatter for broad-leaved crops when compared to the HH polarised signal. Just a minor decline of values occurs at all dates.

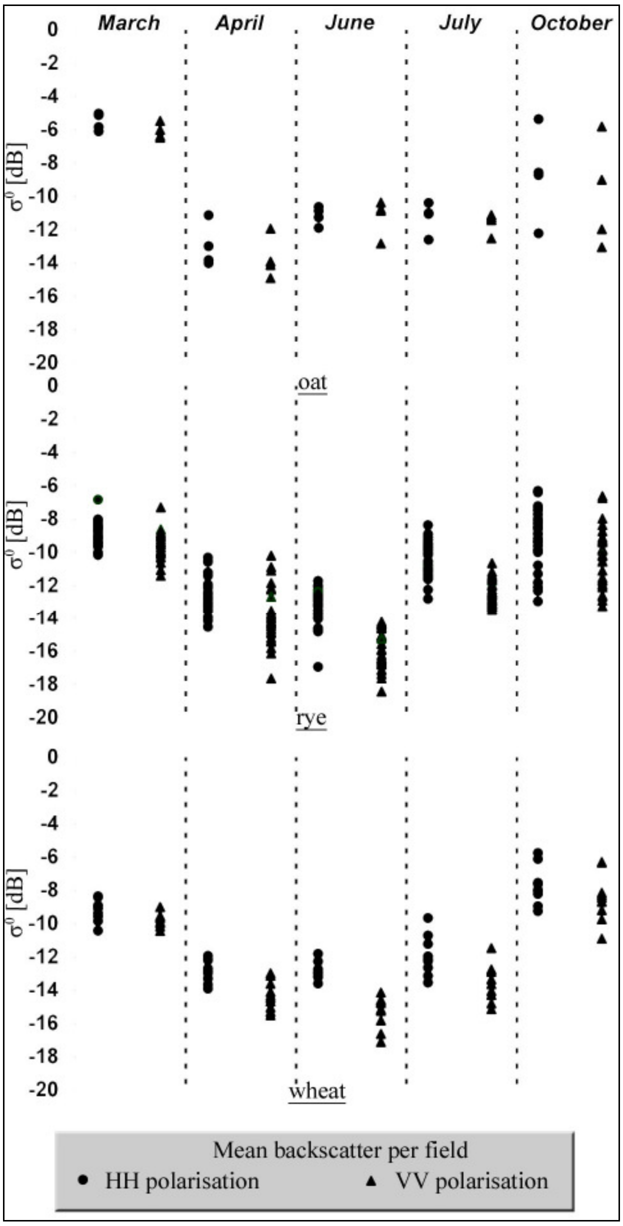

Figure 2: Backscatter distribution for grains in Fuhrberg area

Grains: Backscatter values for grains (Fig 2) differ decisively from broad-leaved crops. In April, the values exhibit a decline to <-10 dB despite of the different phenological stages for spring and winter grains. In April 2009, spring grain started the development of first leaves (BBCH-codes 11-14), while winter grain finished the development of tillers and started elongation (BBCH-codes 29-31). But, these strong differences in the canopy structure and ground cover between winter and summer grains are not mirrored in the backscatter. After development of closed canopy in June, backscatter values remain on low level (<-11 dB) except from most oat fields where values remained above -12 dB. The backscatter of some barley and rye fields declined to -15 dB, while wheat and oat never cross the line of -14 dB. During June acquisition, all grains began flowering or fruit development (BBCH-codes 61-75). The values for barley and rye in July rose to >-12 dB. Most barley fields have a mean backscatter distribution of -9.5 to -12 dB. Rye fields have a mean backscatter from -8 dB to -12 dB. The backscatter values for wheat and oat remain on the level of June. Nearly all grains finished flowering and fruit development and were at stage of ripening (BBCH-codes 83-89) in July. Distribution of mean backscatter during October acquisition differs on wide range due to different dates of harvest.
Except for oat, backscatter of VV polarised measurement show a strong decline of approx. -2 dB in June and July compared to HH polarised data. For other months and for oat this effect cannot be recognized or the decline is not as strong.
Within the group of grains, oat is clearly discriminable because the backscatter values in June do not decrease.
Grasslands and meadows: For grasslands and meadows there is a characteristic low backscattering of the radar signal in March (Fig. 3). Its distribution ranges from -10.6 to -14.3 dB. The values are lower than for most other crops at this time. Thus, grassland could be easily discriminated from grains, bare soil in preparation and intertillage crops which existed on other fields during March acquisition. Backscattering during acquisitions in April, June and July is similar to the one of grains. In April and June, the mean backscatter is <-12 dB. It is equally distributed up to -16 dB. In July, backscatter values reach >-12 dB; the phenology varied because of previous swathe. October values then reach the level of March again.
In VV polarised mode measured backscatter signal is lower than HH polarised signal for all acquisition month. This effect is strongest in July: VV values differ from HH values by approx. 2 dB. Due to the low backscatter values in March differentiation of grasslands/ meadows and grains is possible.

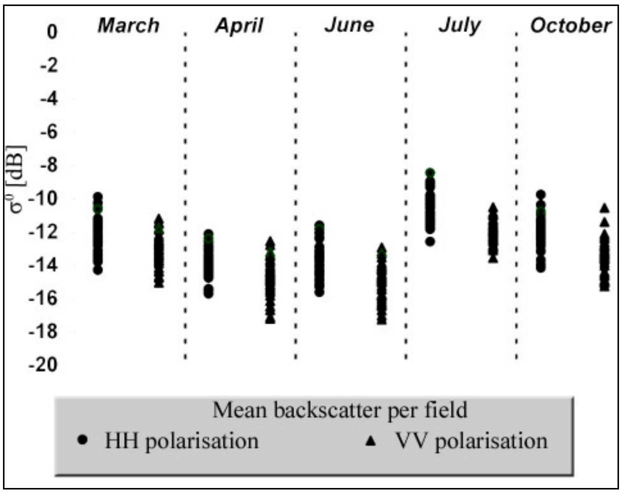

Figure 3: Backscatter distribution for grassland and meadows in the Fuhrberg area

3.2.2 Gorajec area:

Broad-leaved crops: Sugar beets show backscatter values between -8 and -10dB in June. From July to September sugar beet fields remain on a high value (>-8 dB). Compared to sugar beets in Fuhrberg area, backscatter rises during summer month

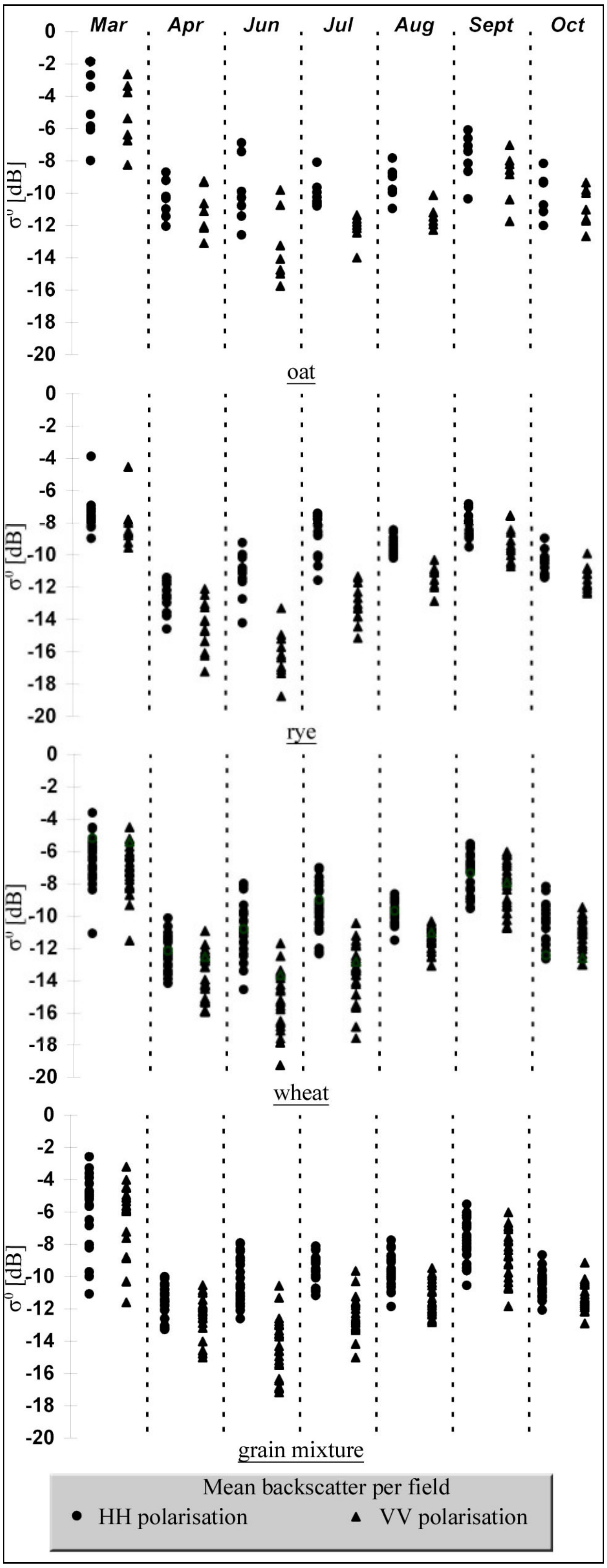

Figure 4: Backscatter distribution for grains in the Gorajec area

but does not likewise cross the line of -6 dB. Potatoes have highest backscatter during the July and August acquisitions (>-9.2 dB and > -8.2 dB). In June and September they differ within huge ranges. This is very similar to potato fields in Fuhrberg with exception of June where the values of Gorajec seem randomly distributed. Backscatter values for both maize fields increase constantly from April to July. They remain on a level of >-10 dB until a significant decrease in October. In comparison, Fuhrberg backscatter values for maize fields increase to a higher level in June and July. Tobacco, which is also a broad-leaved crop, increases from April to July to a high level of above -7.3 dB. After reaching this peak, it turns to lower level but remains above -10 dB until harvest in October. The VV polarised backscatter value for broad-leaved crops decreases with a lower rate compared to the one of HH polarised signal. This is very similar to the results for Fuhrberg. The backscatter of broad-leaved crops is comparable to the one of Fuhrberg site, although they do not reach such high values.

Grains: Grain crops mainly exhibit high backscatter values in March (Fig. 4). In April values are significantly lower. HH polarised backscatter increase within a wide range from April to July. In August, before harvest started, most values decrease to <-10dB. This is especially recognizable for wheat and rye. After the harvest the values increase in September and than decrease in October to <-8 dB. Compared to the grain crops in Fuhrberg area, grain fields in Gorajec vary within a wider range. An increment for grain crops in July can be observed likewise, but not as clearly as in Fuhrberg. Furthermore, there is an explicit difference between both June acquisitions with wide distributed values in Gorajec and low backscattering in Fuhrberg. There is a clear difference between VV and HH backscatter during the summer month. VV values are significantly lower. In June and July a strong decrease of backscatter values can be found. In June the mean decline is between 5.1 dB for rye and 3.2 dB for barley. In July the mean decrease ranges from 4.1 dB for rye and 2.2 dB for oat. In August decrease is less with mean declines from 1.2 dB (barley) to 2.1 dB (oat). VV backscatter during the summer month decreases stronger than for grains in Fuhrberg area.

Grasslands and meadows: Measured backscatter for grasslands and meadows shows a constant value of <-10 dB. The only exceptions are two fields in March with clearly higher backscatter of >-10 dB and one measurement in June with -9.5 dB. Although grasslands do not reach values as low as the ones in Fuhrberg, they remain on a relatively low value compared to other crop types in the Gorajec region. An increment of values in July, similar to the one in Fuhrberg, cannot be found. The same effect as in Fuhrberg is observable in March, when most values are lower then grain crops or bare soils. The VV polarisation backscatter is lower during all month (average 1 dB). But during the summer month the decrease is stronger with about 2 dB. This is comparable to the Fuhrberg results for VV backscatter in grasslands and meadows.

4. CONCLUSIONS

The results of backscatter measurements for the different crops are very promising because individual backscattering patterns for the different crops can be found by using time series of images. As the images are available all over the year independent from the weather conditions, the phenological development of the plants during the year can be detected. This allows not only for a clear separation of broad-leaved crops from small leaved crops, but also for discrimination within the group of broad leaved crops (e.g. sugar beets and maize). The separation between the different grains still has some problems, with the exception of oats. But, due to its very specific reflection, especially in April, grasslands can be differentiated from all grains very clearly. This is not given for applications with optical data, when differentiation is often not available (Gonzalez-Sanpedro et al., 2008).

The high resolution of the radar images allow for a fine grained description of the inhomogeneities of the soil and/or plant structure. This is clearly visible from the different results of the German and Polish fields. These differences can be explained with the highly diverse conditions in both study areas (higher weed content, lower agricultural production standard, undulating terrain with resulting differences in local incidence angles for the radar signal, and smaller fields in Poland). This can be a disadvantage because it results in additional scatterers distorting the crop reflection. On the other hand, it might be used to derive e.g. the weed content if fields with the same crop are compared. Further investigations are necessary to come to conclusions.

These first results about the characteristic backscatter properties for different crop types which are comparable for both research areas already show the high potential for multi-temporal land-use classification with high resolution, satellite based synthetic aperture radar. Especially, the possibilities for detecting the different crop types provide a first important precondition for the derivation of soil erosion risk: crops with a high risk for erosion can be separated from those with a lower risk. This information can be mapped for the respective regions and provides input data for the C factor, an important parameter for the calculation of soil erosion with the Universal Soil Loss Equation (USLE). The provision of exact information about crops and their phonological development during the year is a central issue for the quality of erosion risk calculation (Meusburger et al., 2010).

The high resolution of the radar data allows also for the detection of smaller structures like hedgerows and field margins. It will be the next step to collect respective ground truth to compare the backscatter values of these biotope structures.

Further on, enhanced classification approaches have to be tested which make use of the information from the time series and the polarisations to derive the best classification results. An extent of the developed classification method on more subtle habitat structures within agricultural areas, e.g. woody landscape elements or field margin strips, will follow. Afterwards the suitability of the classification results for the assessment of biodiversity and soil erosion changes will be evaluated. Thus effects of land use and its changes on the selected ecosystem services will be elaborated.

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