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Article

Multi-Temporal Land-Cover Classification of Agricultural Areas in Two European Regions with High Resolution Spotlight TerraSAR-X Data

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Abstract: Functioning ecosystems offer multiple services for human well-being (e.g., food, freshwater, fiber). Agriculture provides several of these services but also can cause negative impacts. Thus, it is essential to derive up-to-date information about agricultural land use and its change. This paper describes the multi-temporal classification of agricultural land use based on high resolution spotlight TerraSAR-X images. A stack of 14 dual-polarized radar images taken during the vegetation season have been used for two different study areas (North of Germany and Southeast Poland). They represent extremely diverse regions with regard to their population density, agricultural management, as well as geological and geomorphological conditions. Thereby, the transferability of the classification method for different regions is tested. The Maximum Likelihood classification is based on a high amount of ground truth samples. Classification accuracies differ in both regions. Overall accuracy for all classes for the German area is 61.78% and 39.25% for the Polish region. Accuracies improved notably for both regions (about 90%) when single vegetation classes were merged into groups of classes. Such regular land use classifications, applicable for different European agricultural sites, can serve as basis for monitoring systems for agricultural land use and its related ecosystems.

Keywords: agriculture; land use; radar; multi-temporal classification

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1. Introduction

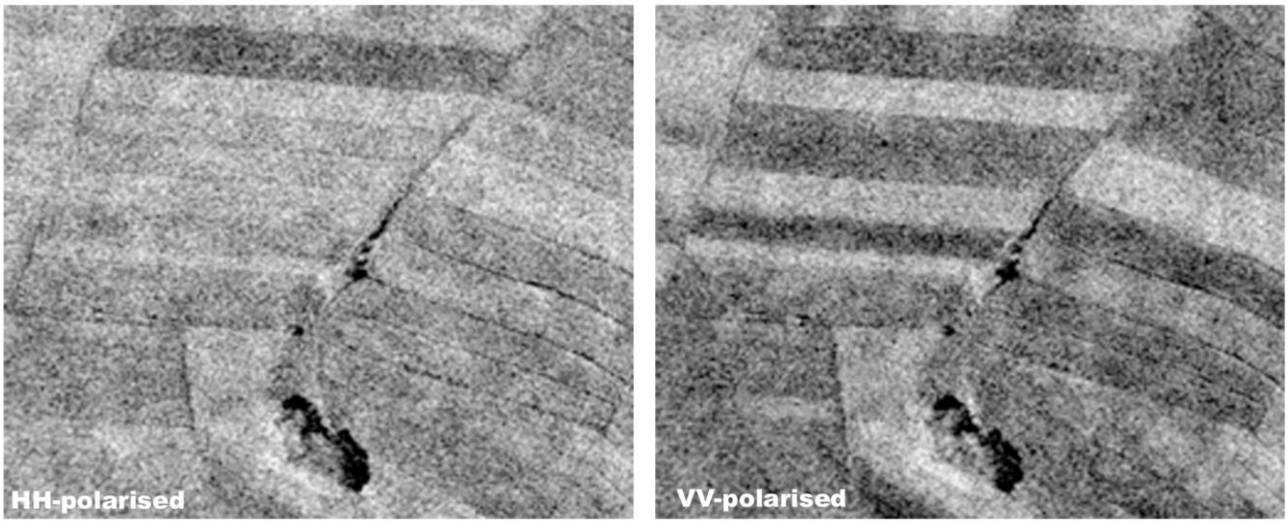
Human land use causes transformations of the earth surface. Humans profit from land use because different goods are provided from ecosystems, e.g., food, freshwater, timber and fiber [1-4]. The intensity of human land use increased rapidly in the twentieth century [1,5]. This refers especially to forest-covered and agricultural areas [2]. Today, most area in Europe is occupied by agriculture [4]. These areas are beneficial for crop production and simultaneously provide various other important ecosystem functions like e.g., water purification or habitat conservation for different species [4,6]. Although land use practices are important for human well-being and closely linked to functioning civilizations, they also can lead to negative impacts. For example, the expansion of croplands and their intensification allow for higher yields in food production, but also cause rapid and irreversible changes in landscape structure, biodiversity, and soil- and water quality [3-5,7].

Up-to-date information about land use and its change is essential to assess status and development of land use and to explore the resulting effects [1,8]. Satellite-based remote sensing is well-suited for land cover and change detection because of its regular revisit intervals, a wide regional coverage, and a high availability [8]. There are numerous examples for land use classifications based on satellite-image data on global, regional and local scale. Prior systems with lower ground resolution like the LANDSAT series, SPOT 1–3 or ENVISAT were used for classifications on large scale with coarse resolution as the Global Land Cover 2000 or the CORINE project that generated land use information for world-wide scale and for the European continent [9,10]. In recent years new satellite-based multi-spectral scanners enabled a higher ground resolution. Land use classification derived from these satellite data allows for a better spatial and substantial distinction between different land use classes. This is shown in different studies, where land use classification derived from e.g., QuickBird or IKONOS-2 data is used for different applications, e.g., agricultural, environmental or soil erosion topics [11-13]. Nevertheless, multi-spectral scanners are restricted by lower data availability due to haze or clouds, especially when based on a satellite system. This fact is documented in many studies where lower classification accuracies result from insufficient input data [14-17].

Since 2008, new satellite based radar images acquired by e.g., RADARSAT-2 or TerraSAR-X are available to generate multi-polarized radar images with a high ground resolution (Figure 1) [18,19]. Since, in contrary to passive systems, synthetic aperture radar (SAR) systems are not dependent on atmospheric influences or weather conditions, they are especially suitable for multi-temporal classification approaches. The basic idea of this approach is to use a stack of radar images within a vegetation period to classify time series. The phenology of different crop types and other agricultural vegetation structures leads to different conditions of their appearance and thus provides a higher content of information. Studies with previous systems like ERS-2 or ENVISAT-ASAR in general demonstrate the feasibility of this approach [20-23]. The results can improve, when decision tree based classifiers are used [24] or when a mix of optical and SAR data is applied [25]. Although there are various investigations with older SAR-apertures, there is lack of knowledge about possibilities of land use classifications with the new high resolution radar systems.

The objective of this study is to test possibilities for multi-temporal land use classification in European agricultural areas on small scale with high resolution TerraSAR-X radar data. Because agricultural areas can vary strongly in different regions, two highly differentiated study areas have been chosen for investigations.

Figure 1. TerraSAR-X High Resolution Spotlight Image in HH and VV polarization. (© German Aerospace Center (DLR) 2009).



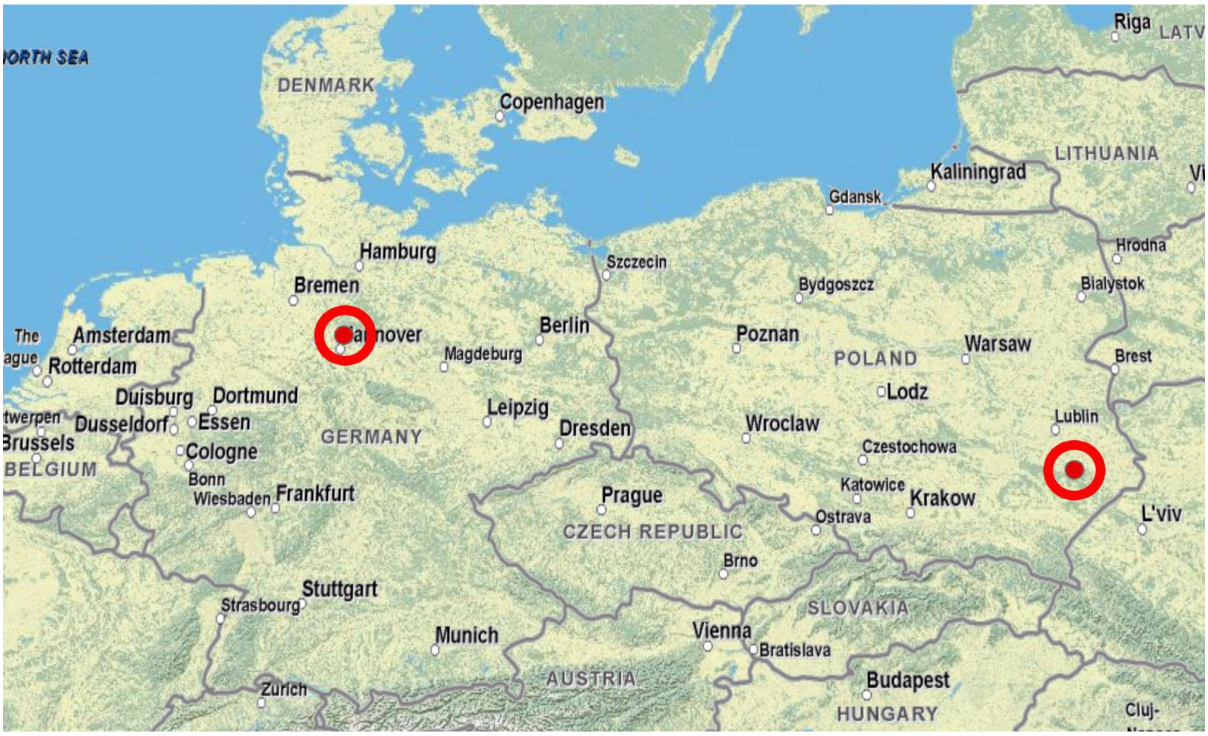
2. Methodology

2.1. Study Areas

Two European study areas have been chosen for land use classification, one in Germany and one in Poland. The German area (Fuhrberger Feld) is situated in North Germany close to Hanover (52.56°N, 9.84°E). The Polish area (Gorajec) is located in the very Southeast of Poland (50.68°N, 22.85°E) (Figure 2). Agriculture is the dominating land use in both regions but they differ strongly in their social, ecological, economic, and geomorphological conditions. The German area is characterized by intensive agriculture and modern production methods. Large fields with a low rate of field margin strips, hedgerows and other habitat structures dominate. Furthermore the terrain is flat. As a water protection area, it provides ground water as drinking water for the region of Hanover.

The Polish study area belongs to one of the least developed regions in Europe [26]. Here traditional production methods are applied and the technical and agrochemical equipment standard is low. According to this, the landscape structure is dominated by a mosaic of habitat structures, and the size of fields is exceptionally small. The Gorajec area is prone to soil erosion due to steep slopes and loess soils [27]. The two regions are chosen to test the robustness and transferability of the classification method under varying conditions.

Figure 2. Location of study areas. (© ESRI online resources [28]).



2.2. Data Sets

During the growing season of the year 2009 (March to October) TerraSAR-X images for both study areas were acquired in High Resolution Spotlight Mode (HS) (Table 1). The images were taken in dual polarization VV and HH and delivered as ground range products (MGD or EEC) with equidistant pixel spacing in azimuth and ground range direction [29]. Eight images are available for the Gorajec area. For the Fuhrberger Feld region no images could be ordered in August and September, thus only six images are available. The incidence angles varied (*cf.* Table 1). Ground range resolution for Fuhrberg site is 2.1 m (3.4 m for May) and 2.3 m (2.0 m) for Gorajec. Resolution in azimuth direction is 2.9 m for May in Fuhrberg area and 2.4 m for all other acquisitions. The extent of the scenes is 5 km in azimuth and 10 km in ground range according to the HS-Mode.

Table 1. Availability and incidence angle of TerraSAR-X images in the year 2009.

Study area	Day of acquisition	Incidence angle [°]	Resolution	
			ground range [m]	azimuth [m]
Fuhrberg	11 March 2009	34,75	2,1	2,4
Gorajec	14 March 2009	31,72	2,3	2,4
Fuhrberg	13 April 2009	34,75	2,1	2,4
Gorajec	27 April 2009	31,72	2,3	2,4
Fuhrberg	22 May 2009	43,65	3,4	2,9
Gorajec	13 May 2009	21	2	2,4
Fuhrberg	18 June 2009	34,75	2,1	2,4
Gorajec	10 June 2009	31,72	2,3	2,4

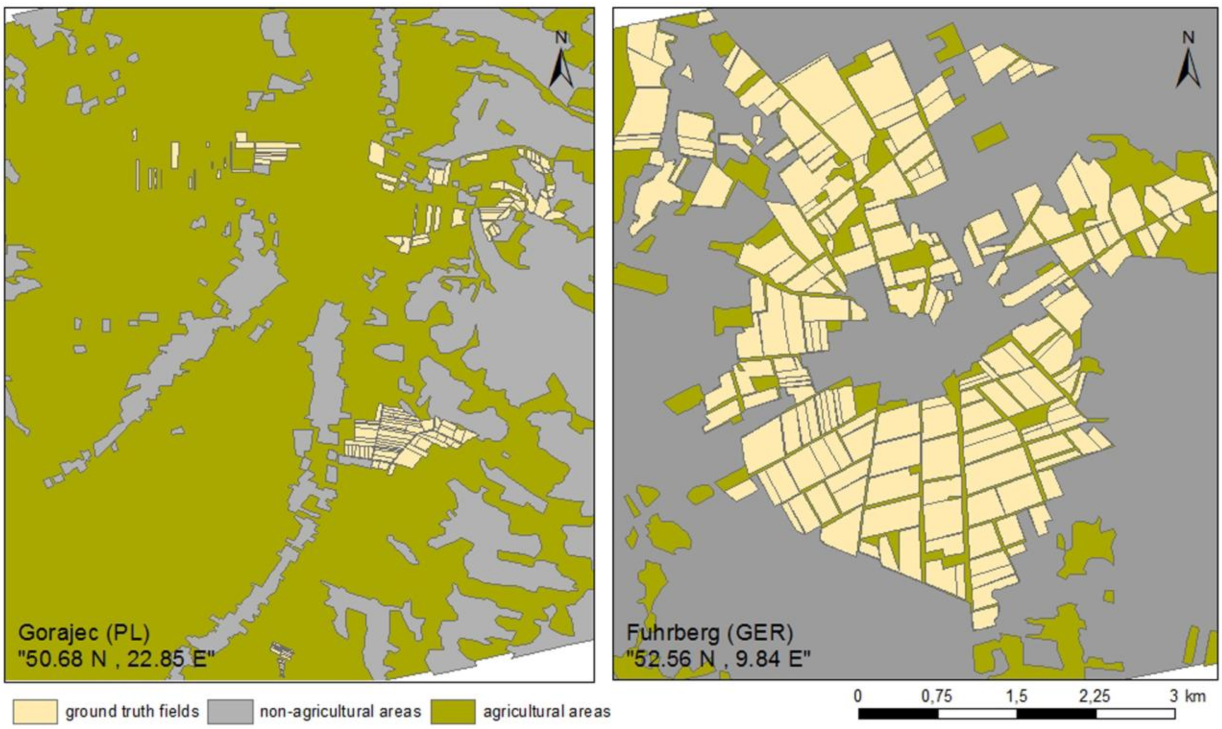
Table 1. *Cont.*

Study area	Day of acquisition	Incidence angle [°]	Resolution	
			ground range [m]	azimuth [m]
Fuhrberg	10 July 2009	34,75	2,1	2,4
Gorajec	13 July 2009	31,72	2,3	2,4
Fuhrberg	no data for August 2009			
Gorajec	04 August 2009	31,72	2,3	2,4
Fuhrberg	no data for September 2009			
Gorajec	06 September 2009	31,72	2,3	2,4
Fuhrberg	17 October 2009	34,75	2,1	2,4
Gorajec	9 October 2009	31,72	2,3	2,4

2.3. Ground Truth

In 2009, vegetation mapping (arable land, grasslands) was conducted to generate ground-truth information (Figure 3). In the Fuhrberg region, vegetation mapping was conducted simultaneously to the image date; 152 fields were visited regularly on each acquisition date and 46 fields once in July. This results in a total number of 198 test fields for the Fuhrberg region.

Figure 3. Location of ground truth areas collected in 2009.



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

The size of the investigated fields differs considerably between both study areas. The mean size of the fields in the Fuhrberg region is 5.27 ha, the maximum area is 24.36 ha and the smallest field has a size of 0.37 ha. The fields average size in the Gorajec is 0.70 ha (max. size 3.12 ha, min size 0.03 ha).

As listed in Table 2, 15 different crop types were sampled in each study area. The differences of both study areas lead to different characteristics of crops with regard to cultivation practices and different cultivars. This is reflected by the comparison of the ground truth results.

Table 2. Land cover type and number of plots in the study areas.

Fuhrberg (Germany)		**Gorajec (Poland)**	
Crop type	**No. of fields**	**Crop type**	**No. of fields**
grasslands	43	grasslands	4
oat	4	Oat	7
rye	33	Rye	12
barley	20	Barley	24
maize	13	Maize	5
spelt *	1	grain mixture	21
wheat	9	wheat	25
winter rape	8	turnip rape *	2
sugar beets	18	sugar beets *	3
potatoes	24	Potatoes	6
fallow land	2	fallow land	4
strawberries *	3	black currant	5
asparagus*	12	Tobacco	13
beans*	1	beans *	4
Lolium perenne (ryegras)	4	Trefoil	4

* crops excluded from classification (see Section 2.5).

In the Fuhrberg area, the presence of weeds is low in most fields because of inputs of fertilizer and pesticides. In Gorajec crops are less developed and the amount of weeds is higher than in Fuhrberg. Most fields contain different kinds of weeds or suffer from a disease—a hint to a possibly low pesticide input. There is also a huge number of fields with a mixture of different types of grains (barley, wheat and oat; wheat and rye) in the Gorajec area. This is not found in the Fuhrberg area.

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 [30];
- Cultivation practices;
- Other relevant observations (e.g., weed content, crop residues).

Additionally, GPS-referenced pictures of all ground truth areas were taken and the local weather conditions and moisture of surface area (caused by haze or rain) were recorded for each acquisition date.

In addition to this, during the year 2010 ground truth of hedges, ruderal sites and grasslands were taken in both study areas. This vegetation does not change considerably within a time period of two years; we assumed that the 2010 ground truth data were also valid for 2009.

In the Fuhrberg area, a total number of 115 hedges with an area of 27.9 ha and 18 ruderal areas (2.5 ha) were mapped. Moreover, ground truth information and the position of 21 hedges with an overall area of 5.5 ha were taken in the Gorajec area. Additive information about grassland and ruderal vegetation was gained from squares with a size of 8 × 8 m (72 for grasslands and 40 for ruderal areas).

2.4. Image Pre-Processing

Images which were ordered as MGD products were georeferenced by use of EEC product types. After co-registration of the images, the multi-temporal DeGrandi filter was applied for data sets of both areas. The described procedures were performed with ENVI SARSCAPE Software.

For radiometric calibration a procedure was written in IDL (Interactive Data Language) by use of a formula according to INFOTERRA [31]:

$$\sigma^0_{[dB]} = 10\log_{10}(\text{CalFact DN}^2) + 10\log_{10}(\text{Sin}\theta_{loc}) \quad (1)$$

where: σ^0_{dB} = Calibrated pixel value in decibel

CalFact = Calibration and processor scaling factor

DN = Pixel intensity value

θ_{loc} = Local incident angle (angle between the radar beam and the normal to reflecting surface).

2.5. Image Classification

For image classification the Maximum-Likelihood Classifier (ML) is chosen which represents a common classification approach. Its feasibility for land use classification with multiple datasets is described in different studies [25,32]. About 50% of ground truth fields per class have been chosen randomly to train the classifier and the rest is used to test exterior accuracies of classification results.

For the Fuhrberg region 12 vegetation classes are selected. Four vegetation classes (fallow land, strawberries, beans, spelt) are excluded due to a too limited amount of ground truth. Asparagus is masked out because of strong inhomogenity in the measured signal due to a strong impact of plants' row direction and height. In the Gorajec area, 14 vegetation classes are identified. In this region the quantity of ground truth areas for sugar beet, turnip rape and beans is not sufficient to create own crop-classes. Urban regions and forests are also masked to be excluded from the classification process. The ML-classifications are realized using all available images, but separately for HH, VV and both (HH and VV) polarizations.

2.6. Assessment of Accuracies

Accuracy assessment was done by comparing the mean backscatter signal values per class. They showed a difference in backscatter for broad- and fine-leaved vegetation types. Crops with broad leaves cause a high backscatter of radar signal after full development of canopy structure, whereas those with fine leaves show low backscatter values (Figure 4) [33]. Furthermore there is a characteristic low backscatter signal during spring time for fine-leaved vegetation that is not ploughed during the year, e.g., grasslands and hedges, while ploughed soils and winter grain generally cause higher backscatter (Figure 5) [33].

Figure 4. Mean backscatter values per field in June 2009 for VV polarization in the Fuhrberg area.

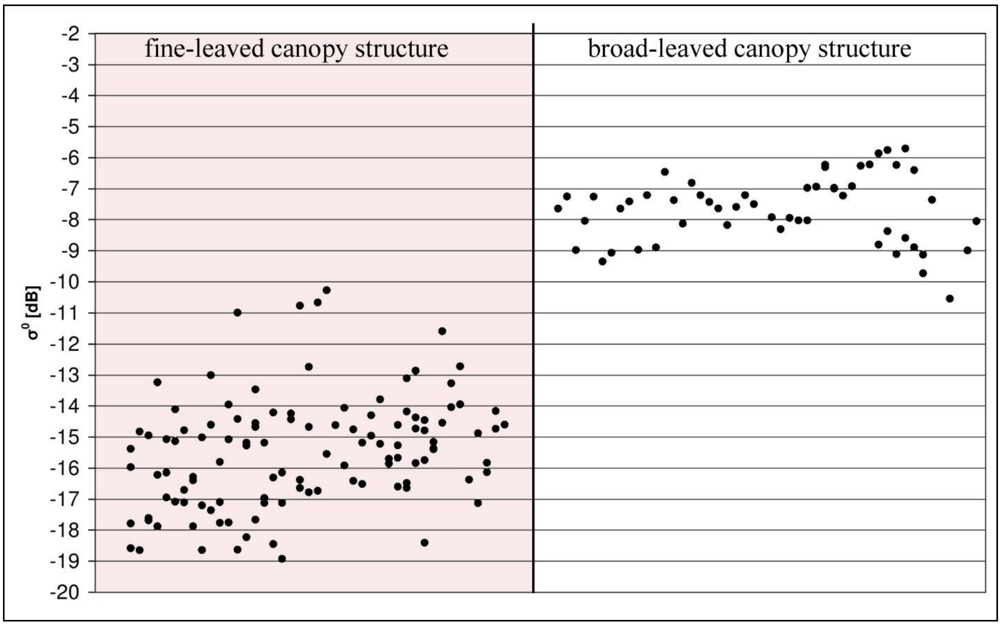
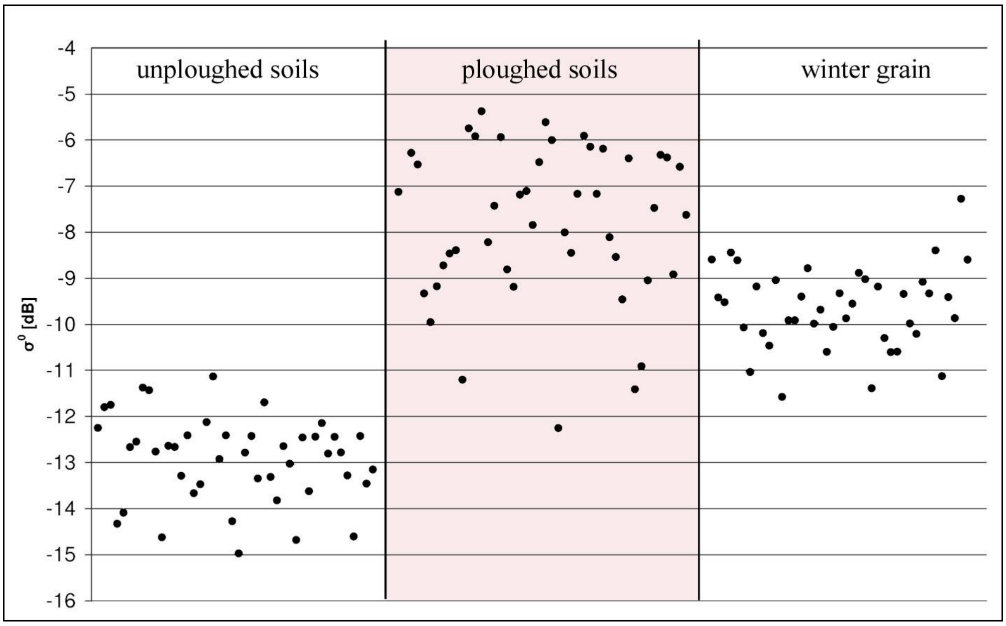


Figure 5. Mean backscatter values per field in March 2009 for VV polarization in the Fuhrberg area.



The different backscatter characteristics of broad and fine-leaved canopy structures and between ploughed and unploughed soils promise high classification accuracies for these groups of vegetation types (class groups). According to this knowledge, the accuracies of classification results were tested for the class groups and additionally for spring and winter grain (Figure 6). The advantage of this approach is a significant improvement of land use information accuracy for aggregated land use classes. Thus, after calculation of the accuracies for each single class, the ability of distinction between the two class groups 'broad-leaved' and 'fine-leaved' was tested in a second accuracy assessment. In a third working step, the group of fine-leaved classes was tested for the accuracies between ploughed and whole year cover vegetation classes (unploughed). This is equivalent to a differentiation between grain and no grain because grain is the only crop group within this class-group which needs ploughed soil. In the last step, the differentiation between winter and spring grain within the grain class was checked.

Figure 6. Definition of class groups for accuracy assessment (schematically).

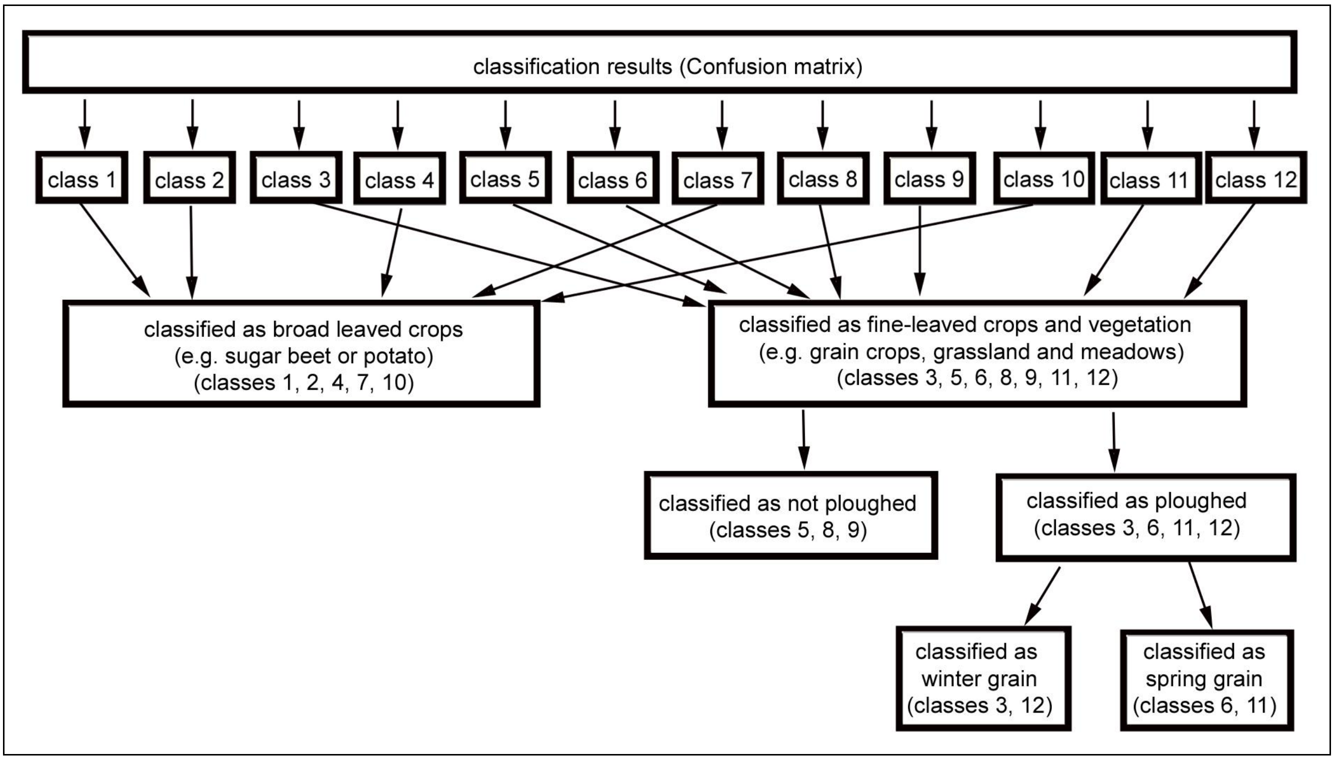


Table 3 assigns the crop types (single classes) of the study areas to the class groups. Crops that create a homogeneous horizontally closed canopy of broad leaves (e.g., potatoes, sugar beet or rape) are clumped into the broad-leaved class group. Vegetation types with mainly fine leave canopy structure like grain or grasslands belong to the fine-leaved group. Ruderal areas and hedges, which mainly contain fine-leaved plants or bushes, are also part of the fine-leaved class group. This is also true for blackcurrant bushes in the Polish area where the ground is covered by dense grass and weed. Rye is cultivated as winter grain in both study areas; and in the Polish area some of the wheat fields are cultivated with winter wheat. All other cultivated grain in both areas are drilled in spring (spring grain).

Table 3. Distribution of single classes within class groups.

Class group	Fuhrberg	Gorajec
broad-leaved	maize; potato; rape; sugar beets	maize; potato; tobacco
fine-leaved	grasslands; ruderal; hedges; Lolium perenne (ryegras); oat; barley; wheat; rye	grasslands; ruderal; hedges; black currant; trefoil; oat; barley; spring wheat; winter wheat; rye; grain mixture
no grain (unploughed)	grasslands; ruderal; hedges; Lolium perenne (ryegras)	grasslands; ruderal; hedges; black currant; trefoil
grain (ploughed)	oat; barley; wheat; rye	oat; barley; spring wheat; winter wheat; rye; grain mixture
winter grain	rye	rye; winter wheat
spring grain	oat; barley; wheat;	oat; barley; spring wheat; grain mixture

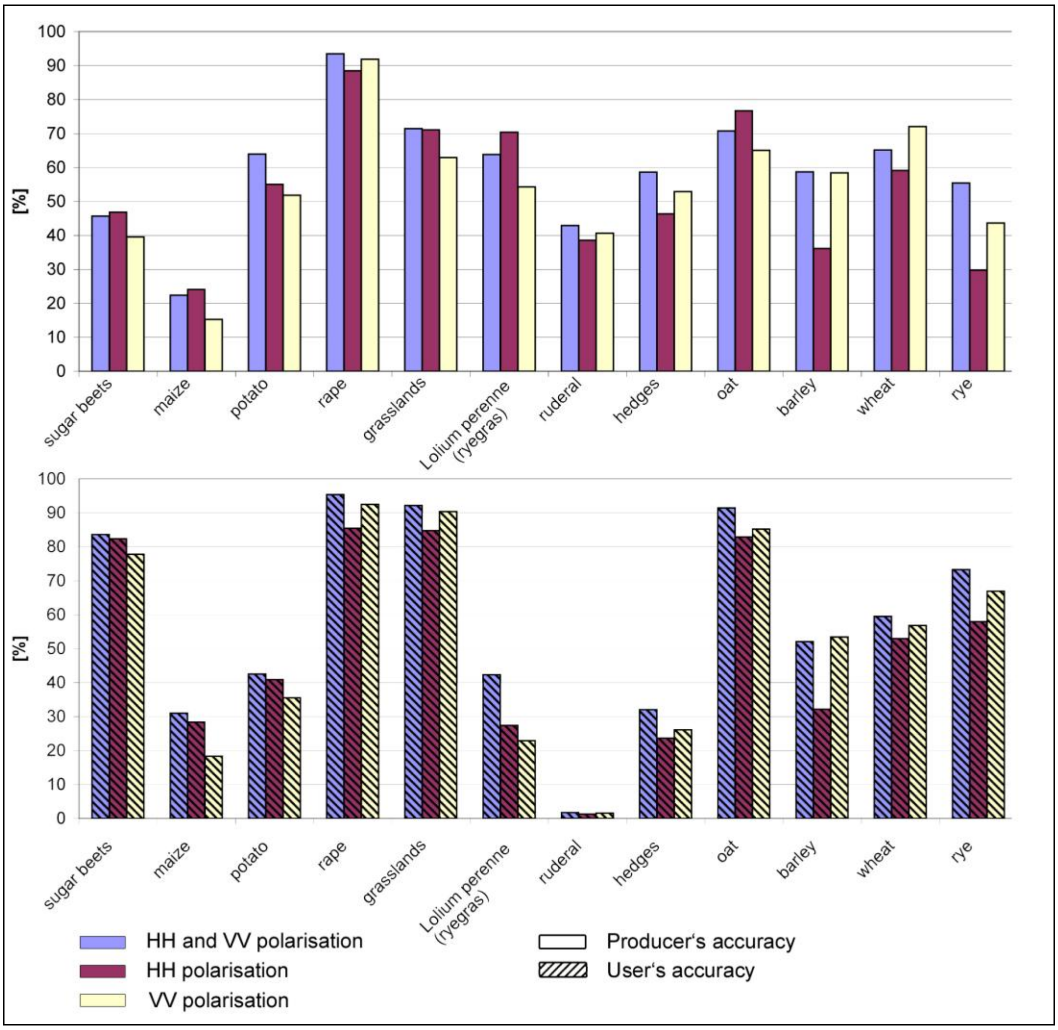
3. Accuracies of Classification Results

3.1. Classification Accuracies for Fuhrberg Area

Overall classification accuracy for all classes is highest (61.78%) when both polarizations were considered. It is lower when only one polarization (HH 52.9% or VV 55.48%) is used for classification process. Accordingly, the Kappa coefficient is highest for both polarizations with 0.57 (0.48 for HH and 0.5 for VV).

The trend of highest accuracies for classification with both polarization is also recognizable regarding producer’s and user’s accuracies for each of the 12 vegetation classes (Figure 7). Very few classes show slightly higher accuracies for just one polarization, e.g., the producer’s accuracy for oat and wheat. But for most classes producer’s or user’s accuracies of at least one polarization are very close to the ones of both polarizations and in some cases even higher. Therefore in some cases it is feasible to use one polarization to achieve better results. Rape crops have highest accuracies of above 90% whether viewed from the user’s or from the producer’s perspective. Oat and grasslands also achieve user’s accuracies of above 90% but have lower producer’s accuracies of about 70%. Most of the other classes have producer’s accuracies of above 50% for at least one polarization state. The user’s accuracies show higher values for sugar beets and rye when compared to producer’s accuracies, but most classes have decisively lower user’s accuracies. It is remarkable that there is a very low user’s accuracy rate for ruderal areas. This is due to the fact that test areas of the classes ‘grasslands’ and ‘hedges’ have been misclassified as ruderal at a high quota. A very similar effect can be observed for hedges, where many pixels are misclassified as ruderal.

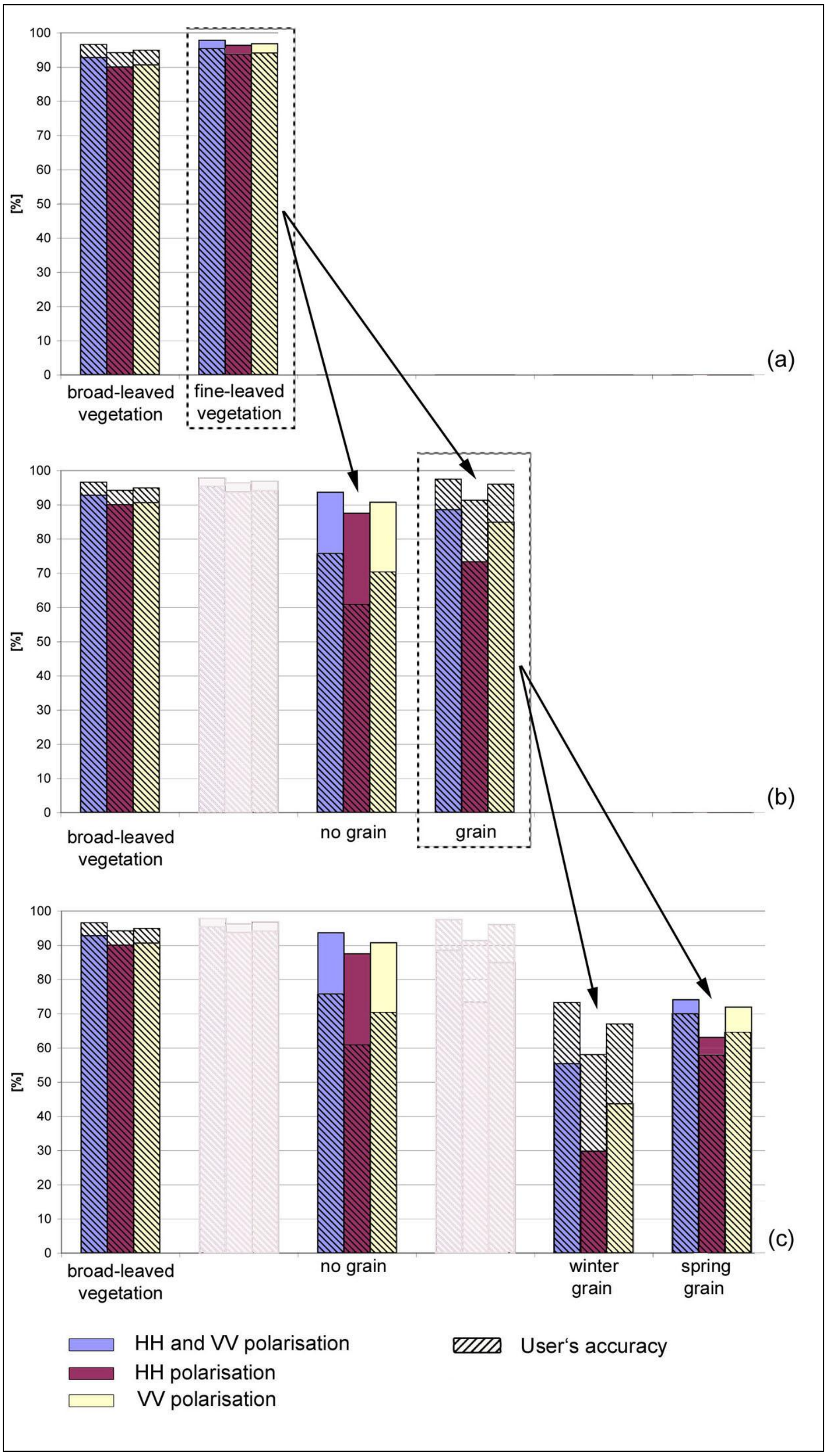
Figure 7. Producer's and user's accuracies for single classes in the Fuhrberg region.



There is a significantly higher accuracy for the classification of class groups in comparison to single classes (Figure 8). The differentiation between broad-leaved and fine-leaved vegetation is possible at a very high overall accuracy rate of 95.87% (Kappa coefficient 0.92) for both polarizations and has similar high values for classification with use of just one polarization. The achieved producer's accuracies for the broad-leaved class group are above 90%. The fine-leaved class group is classified by producer's accuracies higher than 95%. The user's accuracies for both class groups are similarly high with rounded 94/95%.

The overall accuracy of discrimination between grain and no grain (for unploughed, see Section 2.6) within the fine-leaved group and the broad-leaved is 91.36% for both polarizations (Kappa coefficient 0.88). The values for VV polarization are similar (88.46%, 0.84) and lower for HH polarization (82.99%, 0.78). Producer's accuracies reach values nearly or above 90% except of the HH polarization results for both groups (grain and no grain). User's accuracy is very high for grain with 97.49% accuracy for both polarizations (91.3% for HH and 95.99 for VV). The class group of "fine-leaved but no grain" is characterized by lower user's accuracies of 75.73% for both polarization (60.88% HH, 70.33 % VV). This is due to a relatively high misclassification quota of the classes 'ryegrass' (Lolium perenne) and 'hedges' as 'rye'. This fact is also responsible for the lower producer's accuracy of the rye class.

Figure 8. Classification accuracies for class groups in the Fuhrberg study area **(a)** Overall accuracy for HH + VV polarization is 95.87% (Kappa coefficient is 0.92). For HH polarization values are 93.89% (0.89) and for VV polarization 94.41% (0.89). **(b)** HH + VV: 91.36% (0.88), HH: 82.99% (0.78), VV 88.46% (0.89) **(c)** HH + VV: 82.06% (0.77), HH: 72.5% (0.66), VV: 77.89% (0.73).



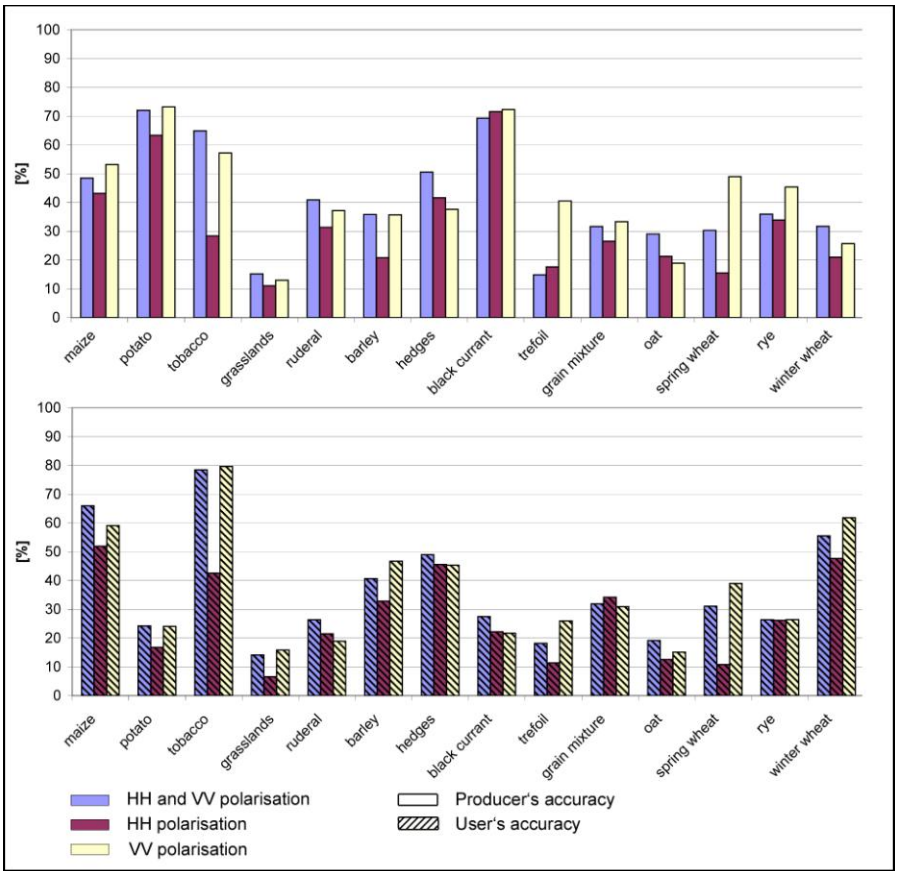
An additional differentiation of winter and spring grain enables overall accuracies of 82.06% with a Kappa coefficient of 0.77 with both polarizations and distinction of the class groups broad-leaved, no grain, winter grain and spring grain. Values for VV polarization are slightly lower (77.89%, 0.73) and about 10% (Kappa 0.66) lower for HH polarization. Regarding the producer's and user's accuracy, it is recognizable that accuracy values are 70% and more for both polarizations, with exception of producer's accuracy for winter grain (55.42%). That is because a high quota of test areas for rye has been classified as spring grain. The VV and especially HH polarization show lower accuracies in all cases.

3.2. Classification Accuracies for Gorajec Area

Overall accuracy for all classes and polarizations is very low (39.25%, Kappa coefficient 0.32). Accuracy for VV polarization classification is almost equal (38.44%) but lower at above 10% for HH polarization (28.59%, 0.21).

Accuracies of VV and HH+VV are also very similar with regard to producer's and user's accuracies (Figure 9). VV classified producer's accuracies are clearly higher for trefoil, spring wheat and rye. The ones of both polarizations are higher for hedges. That is the only class where producer's accuracies of HH are higher than for VV. Maize and tobacco exhibit high accuracies from user's and producer's view, whereas potatoes and blackcurrant have high producer's but lower user's accuracies. Winter wheat is the only grain with user's accuracies of above 50% but producer's accuracies are lower. Compared to accuracies of classification for Fuhrberg region, results for the class grasslands are obviously less reliable for Gorajec.

Figure 9. Producer's and user's accuracies for single classes in the Gorajec region.



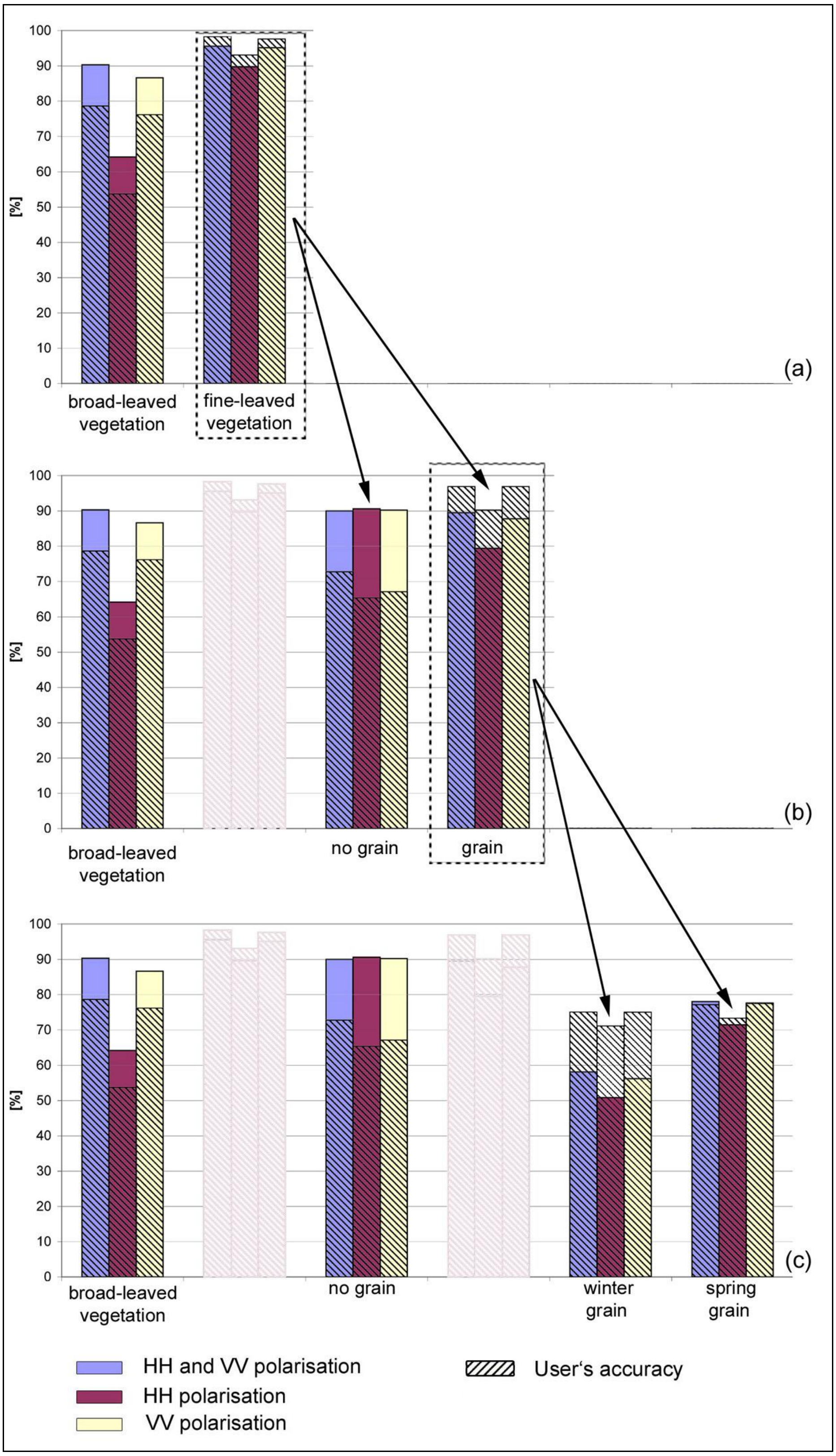
Overall accuracies rise up to 94.77% with a Kappa coefficient of 0.84 (HH + VV) for classification of the class groups broad-leaved and fine-leaved (Figure 10). The values remain on a high level when just VV polarization is considered for classification (93.87%, 0.81) and show lower accuracies for HH polarization (85.7%, 0.66). Producer's accuracy for both class groups is above 90% when both polarizations are considered and slightly lower for VV polarization. Classification with only HH polarization results in clearly lower accuracy values for broad-leaved. While user accuracies remain on a high level for fine-leaved, there is a decline for the broad-leaved group user's accuracy. A similar effect is recognizable for the group of not ploughed fine-leaved whereas user's accuracies are lower than producer's. This effect can be explained by the fact that there is a much higher quota of test fields for grain. Nevertheless, producer's accuracies exhibit high values for the class of no grain and broad-leaved. A classification for the class groups broad-leaved, fine-leaved, not ploughed (fine-leaved), spring grain and winter grain results in an overall accuracy of 76.22% and a Kappa coefficient of 0.71 (for HH 67.7%, 0.62, for VV 74.95%, 0.7). Classification of the same class groups is close to the accuracies for the Fuhrberg area (HH + VV 82.06%, 0.77) although the overall accuracies for single classes are clearly lower in Gorajec.

4. Discussion

We proved in this study the capability of high resolution TerraSAR-X data for classification of agricultural land use class groups in two different regions. The classification results are validated against a great quantity of ground truth data regularly collected on numerous fields (198 for Fuhrberg and 135 for Gorajec). The spatial resolution of the system is sufficient to classify also narrow and small land use patterns. This is shown especially by the results of the Polish test area. The robustness of classification is also remarkable since accuracies of class groups are comparable for both study areas.
The presented results show that classification accuracies become clearly better when single classes are merged into class groups. Thus the reliability of land use information becomes significantly higher but with a coarser class differentiation. McNairn *et al.* [25] already remarked that merging of single grain classes after classification produced higher accuracies for one single grain class than the use of merged grain for classification process. The results of our study approved this statement. Merging of classes after classification increased the accuracies for both study areas to a comparable high level despite very different conditions in both regions. On the contrary, classification results for single classes vary strongly between the study areas and are lower than for the merged class groups in general. Accuracies for single classes in Fuhrberg area are clearly higher than for Gorajec where most classes have accuracies lower than 50%. Nevertheless, in Fuhrberg most classes do not exceed an accuracy rate of 70% with the exception of rape which is correctly classified by over 90%.

It is noticeable that some classes have highest accuracies in Fuhrberg but lowest in Gorajec. For example grasslands have third highest producer's accuracy of all Fuhrberg classes but lowest in Gorajec. This effect is caused by different agricultural practices in both regions which is a good example of the dependency of classification quality on political, social and economic conditions on regional scale resulting in differences in agricultural land use. Grasslands in Fuhrberg are intensively used on a large scale with a regular swathe to get highest yields. Gorajec is known for extensive land use [26]. Grasslands are sprinkled in small patterns with different intensity of use or abandonment.

Figure 10. Classification accuracies for class groups in the Gorajec study area. **(a)** Overall accuracy for HH + VV polarization is 94.77% (Kappa coefficient is 0.84). For HH polarization values are 85.7% (0.66) and for VV polarization 93.87%, (0.81). **(b)** HH + VV: 89.69% (0.82), HH: 78.57% (0.68), VV: 87.93% (0.79) **(c)** HH + VV: 76.22% (0.71), HH: 67.7% (0.62), VV: 74.95% (0.7).



A more subtle differentiation within the class groups would increase classification quality. This can be realized by different approaches that will be tested in a next step. In preliminary classification tests, the accuracies for grasslands in the Gorajec region could be improved by a factor of 3. That was possible when no grain class group was classified a second time based on two selected images at specific dates. This is because single classes exhibit high variations in backscatter signal at certain dates of acquisition. The selection of these dates is not possible when all classes are considered but much easier for the few classes within a class group. Another approach to improve results is to use object based classification for the group of fine-leaved but not ploughed (no grain). By this, linear structures at the crops edges (e.g., hedges, field margins) can be determined by their characteristic linear shapes.

As the described classifications for VV polarized images show better results than the one of HH-polarized images, and the acquisition of data with just one polarization increases ground resolution [29], the use of VV polarized data might improve classification in fine structured regions. Furthermore, a combination with optical data might be powerful for higher classification accuracies [25].

Land use classification with TerraSAR-X data as presented in this study opens numerous possibilities to derive knowledge about impacts caused by agricultural land use and its change. The intensity of land use strongly affects ecosystem and causes e.g., soil erosion, loss of biodiversity or water pollution [4,34]. The applicability of remote sensing land use data for the assessment of soil erosion is attested in different studies [13,35,36]. The high accuracy of land use classification as presented in this study is able to improve results for soil erosion assessments or other applications based on accurate land cover classification. With regard to biodiversity, knowledge about field sizes, the quantity of crop edge structures (e.g., hedges, field margin strips and other ruderal vegetation structures) and the amount of weeds within crops is essential. As mentioned, these parameters vary strongly between both study areas and thus our classification results are well suited to demonstrate assessment and monitoring of different indices in agricultural regions.

5. Conclusions

Results of this study underline the robustness of multi-temporal classification approach with high resolution TerraSAR-X spotlight data. It is not only robust in availability of data, independent of atmospheric conditions, but also in its applicability for strongly diverse regions in terms of agricultural management and geology. That allows for automatic and consistent land use classifications with accuracies of about 90% for defined class groups. The approach offers possibilities to generate important basic land use information for monitoring of different agriculture related systems and ecosystems that serve for human well-being. In the future, further investigations will focus on object based approaches or Random Forest classifiers for better classification results of single classes instead of class groups.

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