Assessing the Value of Monotemporal SPOT-1 Imagery for Forestry Applications Under Flemish Conditions

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ABSTRACT: The value of SPOT-1 monotemporal data for tree species identification has been assessed. The test area is characterized by highly dispersed forests and individual stands of restricted area. The performance of conventional digital classification techniques has been compared to the visual interpretation of digitally enhanced images, by testing the results statistically. The results show that the enhancement procedure for visual interpretation is of minor importance when compared to the acquisition date. For both visual interpretation and digital classification techniques, the images recorded during the early period of the growing season are most suited. For Euclidean distance classification, at least the infrared and one of the visible bands should be used. If the optimal acquisition period is selected, visual interpretation would be the preferential technique for the differentiation of global land-use classes. The advantage of visual analysis is lost if detailed levels of forest information are required. However, if images acquired during less favorable registration periods are used, visual analysis is the preferred technique whenever detailed forest information is to be extracted.

INTRODUCTION

IN FLANDERS, THE NORTHERN REGION OF Belgium, satellite imagery has not been used operationally yet as far as forest management is concerned. The forest inventory method used until 1980 was based on decadal questionnaires. Since 1982, mapping and inventory of the forest resources has been based upon 1:30,000-scale color infrared (CIR) aerial photography. Through visual interpretation and field checks, base maps with high planimetric accuracy have been produced and a forest management data base has been created (Coppin *et al.*, 1986).

Satellite imagery is recognized as a useful tool for forest mapping and inventory. Due to the coarse 80-m spatial resolution, operational use of Landsat MSS images in the context of small scale forestry in Belgium is unlikely to succeed. It can be expected that the use of higher spatial resolution Landsat TM and SPOT-1 data would yield significant improvements.

The aim of this study is to assess and compare objectively the performance of conventional digital classification techniques and visual interpretation of digitally enhanced monotemporal SPOT images for the identification of tree species in the Flanders. Various channel combinations and transformations are evaluated on their suitability for classification. The effect of enhancement procedure and of recording date is examined. The performances of visual and digital classification are compared through a statistically based test.

LITERATURE REVIEW

This review deals with reports describing the ability of monotemporal SPOT imagery to classify tree species and forest stands. Published research results confirm those reported in earlier SPOT simulation studies. The low dynamic range of data acquired over forested areas is the main factor prohibiting satisfactory classification results (Guyon *et al.*, 1987; Jaakkola *et al.*, 1984). The high correlation between SPOT-1 bands XS1 and XS2 further reduces discrimination power significantly (Jaskolla, 1984; Wooding, 1984; Aurelio, 1984; Stibig, 1986; Haeme, 1986). Inclusion of a mid-infrared channel as planned for SPOT-4 would contribute significantly to classification accuracy on level III (individual species) (Degloria, 1987; Stibig, 1986). Jaakkola (1986, 1987), Boureau (1987), Guyon (1987), and Aboussouan (1987) indicated the along-track striping caused by cross-talk between the two HRV sensors as a disturbing factor for digital classification. The detection of parcel boundaries, even in the case of small scale land use (Wooding *et al.*, 1984; Kirchof, 1985), turned out to be satisfactory due to the high spatial resolution. The integration of PA and XS images, followed by several filter procedures, allowed visual detection of 71 percent of the parcel boundaries indicated on the forest map (Jaakkola, 1987).

Classification results of level I (forest) and II (coniferous, deciduous, mixed) forest classes by visual interpretation of digitally enhanced SPOT images are comparable to those obtained with Landsat TM imagery (Seuthé, 1987). Jaskolla (1984) and Roebig (1984) observed that visual interpretation of integrated simulated SPOT panchromatic and multispectral products allowed classification up to level II forest classes. Buchheim (1984) even indicated the ability to discriminate level III classes (species) for coniferous forest on standard SPOT products, although other studies have contradicted this (Seuthé, 1987). Forests differ by texture and context from other land-use forms. This is neglected in per-point classifiers but captured in the visual interpretation. Irons (1985) stated that per-point classifiers do not use the potential of higher spatial resolution. As long as digital texture classifiers are not operational, visual interpretation of SPOT products will gain importance in operational applications for forest mapping and inventory (Degloria, 1984; Jaakkola, 1987). Although the higher spatial resolution facilitates visual interpretation, the spectral overlap between level III forest classes is not eliminated.

METHODS

STUDY SITE DESCRIPTION

The forested area of Flanders (115,000 ha) is highly dispersed. Individual stands are mostly 1 ha or smaller. Sixty-one percent of the productive forest area is coniferous, *Pinus nigra* ARN. var. Calabrica SCHN. and *Pinus sylvestris* L. being the most

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important species, occurring mainly as homogeneous stands. *Pseudotsuga* sp., *Larix* spp., *Picea* spp., *Thuya* spp., and *Tsuga* spp. are less common, though they form scattered stands in most state-owned forests. *Quercus* spp. and *Fagus sylvatica L.* are the dominant deciduous species, usually occurring in mixed stands. Mixed deciduous/coniferous stands are also common in Flanders.

The state owned Ravels forest (810.94 ha) was selected as the study site (Figure 1). It is located between 51°21'N and 51°24'N latitude and 4°59'E and 5°04'E longitude. The relief is flat and ranges between 30m and 35m above sea level. As well as being representative of the average forest unit size in the region, homogeneous stands (54.2 percent) dominate in Ravels. *Pinus nigra* ARN. var. Calabrica SCHM. (Corsican pine) and *Pinus sylvestris* L. (Scots pine) are the most important species, constituting 75 percent of the coniferous stands. The majority of the Scots pine stands are nearly mature. They show natural variations in canopy closure and most stands are characterized by an open canopy. Hence, the spectral signature is strongly influenced by the understory vegetation, which consists of grass, black cherry (*Prunus serotina* EHRH), or a mixture of both. Mixed deciduous/coniferous stands occupy 18.5% of the area. Deciduous forest with *Quercus borealis* MICHX (Red Oak), *Quercus robur* L. (pedunculate oak), and *Fagus sylvatica* L. (beech) covers 12.5 percent of the forest area. The western part of the study site (zone A, Figure 1) is in a reconversion phase and is characterized by a very complex stand structure. The eastern part (zone B, Figure 1) originally privately owned, consists mainly of scattered forest mixed with small parcels of agricultural and bare land.

Image Characteristics

To evaluate the effect of the acquisition date, four multispectral (XS) scenes were selected from different dates corresponding to distinct phenological stages. In addition, a panchromatic (PA) scene was selected to test the contribution of 10m by 10m spatial resolution to visual interpretation. The selected SPOT scenes are listed in Table 1. It should be noted that the PA and XS images are of different imaging date, because images of the same registration date were not available. Conclusions concerning integration of PA and XS mode will have to consider both spatial and multitemporal effects. All XS images displayed an along-track striping, which appeared particularly strong over the forested region in channels 1 and 2. This striping problem is accentuated by the low dynamic range of the data in these channels, producing a poor signal-to-noise ratio. Two haze bands were perceptible above the forested zone on the XS September image. Due to cloud cover, the XS May image was incomplete: only zone A could be used in the study. All images were geometrically co-registered by means of control points and resampling by cubic convolution.

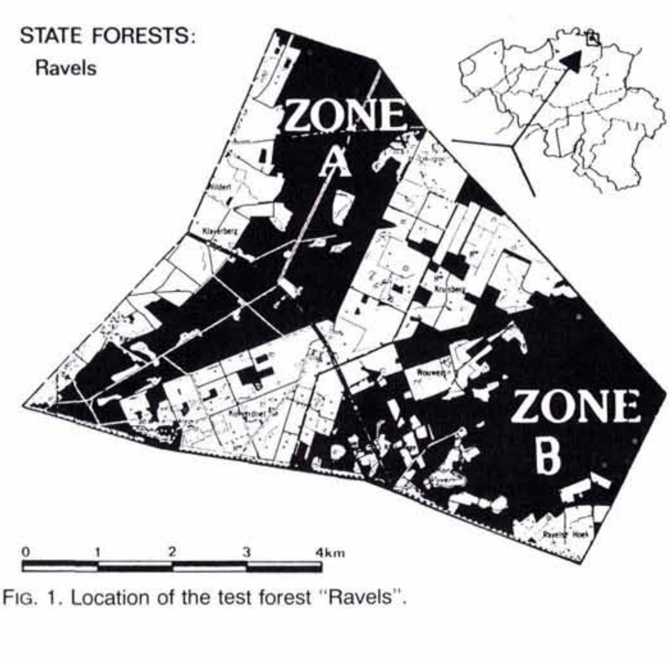

FIG. 1. Location of the test forest "Ravels".

Cover Types

The choice of the cover types was determined by the finest level possible for automatic feature discrimination i.e. tree species. Table 2 lists the cover types distinguished in visual interpretation as well as in digital classification. To reduce interpretation time, only four cover types (forest, clearcut, water, and agricultural lands) were considered for zone B.

VISUAL INTERPRETATION OF DIGITALLY ENHANCED SPOT IMAGES

Enhancement

Five enhancement procedures were selected to prepare XS SPOT images for visual interpretation (Table 3). All procedures were conducted using the I²S S600 software system.*

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TABLE 1. CHARACTERISTICS OF THE SPOT IMAGES USED IN THE STUDY.

Frame	Recording Date	Mode
K42/J246	27 May 86	XS
K43/J246	27 Jun 86	XS
K42/J246	28 Sep 86	XS
K43/J246	30 Oct 86	XS
K43/J246	01 Feb 87	PA

TABLE 2. COVER TYPES DISTINGUISHED IN THE DIGITAL CLASSIFICATION AND THE VISUAL INTERPRETATION.

Cover type
1. Corsican pine
2. Scots pine
3. Other coniferous
4. Mixed coniferous/deciduous
5. Beech
6. Oak
7. Clearcut
8. Water
9. Agricultural lands

TABLE 3. TECHNIQUES USED FOR ENHANCEMENT OF THE XS SPOT IMAGES.

Procedure	Applied Enhancement Techniques	Label
1	Logarithmic transformation; Edge enhancement; Linear scaling	LOG
2	Linear transformation; Edge enhancement	MAT
3	Logarithmic transformation; Edge enhancement; Linear transformation as described by National Television Systems Committee (Ref. 4); linear scaling	YIQ
4	Linear transformation on a 3 band image composed of the original IR-band and the sums of PA with band 1 and 2; Linear scaling	XS+PA
5	Selection of first three principal components of the (XS1, XS2, XS3, PA) image; Edge enhancement; Linear scaling	KL

As forest zones in general, and coniferous forest in particular, appear as dark features, a logarithmic transformation was used in the enhancement procedures LOG and YIQ. In the latter procedure, the logarithmic transformation was followed by a YIQ transformation. The YIQ representation (Table 3) is known as the tristimulus representation, prescribed by the NTSC (National Television Systems Committee). The Y value represents the luminosity of the object, while the I and Q values are crominance values and linearly independent of the luminosity vector (Haydn, 1982). The YIQ transformation takes account of the sensitivity of the human eye for the three basic colors.

Applying a 3 by 3 transformation matrix on the original XS image results in a set of brightness values, which are a linear combination of the original digital numbers (DN). The most appropriate matrix for within forest discrimination was selected interactively (Table 3: MAT , XSPA). This matrix was different for each recording date and for the MAT and XSPA procedure.

Integration of the PA and XS modes has been accomplished by means of two techniques. In the XSPA technique, the high frequency components of the PA image are considered to be correlated positively with those of the first two SPOT XS channels. Consequently, the 10 percent high pass filtered PA image was summed with each of the first two SPOT XS channels. Weights for PA and XS were defined interactively. In the Karhunen-Loëve procedure (Table 3 : KL) the three first components of the Karhunen-Loëve transformed 4-band image (XS1, XS2, XS3, PA) were selected. Although the PA channel had little effect on these components, the KL procedure is considered to be another technique for combining PA and XS images. Plate 1 shows a part of the test forest, selected from the KL enhanced June image.

All selected procedures were applied on the imagery of the four registration dates. After enlargement, the enhanced images were plotted using a thermal color plotter, at a scale of approximately 1:35,000; four sets of 20 different images were available for visual interpretation.

VISUAL INTERPRETATION

The thermal color plots were provided with an overlay and a selective interpretation key. For each cover type, one or two training locations were shown on the overlay by means of a pointing arrow. Fifty interpreters (students), divided into three groups, were asked to delineate the boundaries of all homogeneous areas and to identify them. A first group of 20 students got one set of the 20 different images. A second group, again of 20 interpreters, got two sets while a third group of 10 students got the last set of 20 images. Hence, the latter two groups had to execute two interpretations. For the second interpretation, each student was supplied with an image of different recording date and enhancement procedure than that of the first image they had to interpret. The time gap between two interpretations made by one person was long enough to eliminate the *habit effect*. As such, four repetitions for each available combination of enhancement technique and imaging date were available.

DIGITAL CLASSIFICATION

A supervised per-point classification was selected. Before deciding on which classification algorithm to use, the distribution of the intensity values was checked. For each cover type distinguished, a set of random pixels, proportional to the area of the cover type, was sampled. By calculating for each spectral band and recording period the standardized values of the skewness and kurtosis coefficients of the samples, the distribution of the intensity values can be checked (Dagnelie, 1975). When the values for the standardized coefficients are outside the range -2.0 to 2.0, the data may depart significantly from a normal distribution. Significant deviations from the normal distribution were detected for the cover types *Corsican pine* and *Oak*. Because no normality assumptions are required for the Euclidean distance classification, this algorithm was preferred over the maximum likelihood algorithm.

For each cover type, two or three randomly selected training (TR) samples were retained. Only the XS images were classified. The same TR sample locations were used for the four images. Single channels, the ratio of the infrared (XS3) and red (XS2) channel, as well as the first principal component and all possible channel combinations (green + red, green + infrared, red + infrared, and green + red + infrared) were tested on their suitability for classification.

ACCURACY ASSESSMENT

To evaluate the accuracy of classification and interpretation, results were compared with cover type maps using a statistical approach. These maps were obtained by interpretation of color infrared photography (scale: 1:10,000; date: 05 Sep 86). A stratified random sampling scheme was used to select the control points. The most appropriate sample size for each cover type was determined by using the binomial probability density function, (Van Genderen, 1978). The population accuracy, Q, was postulated as the accuracy required for forest management (Table 4). Because the cover types *other coniferous* and *mixed deciduous/coniferous* are economically of minor importance and are not abundant in the test region, a lower accuracy was postu-

PLATE 1. Part of the test forest selected from the KL enhanced June image.

TABLE 4. THE ACCURACY Q FOR EACH COVER TYPE AND GROUPED COVER TYPES AS REQUIRED FOR FOREST MANAGEMENT PURPOSES.

Cover Type	Q(%)	Cover Type	Q(%)
Corsican pine	85	Coniferous	95
Scots Pine	85		
Other coniferous	60	Deciduous	95
Water	95		
Beech	85	Forest	95
Oak	85	Non forest	95
Clearcut	95	Agricultural lands	95
Mixed	60		

lated. The minimum sample size (n) is obtained when the probability of making no errors for the postulated accuracy, Q, reaches a value less than 0.05. To this minimum sample size supplementary pixels were added, proportional to the area of the cover types concerned.

Zones A and B were sampled separately, resulting in a test area covering 1.5 percent of the forest surface. Due to their restricted appearance, the minimum sample size (n) was not obtained for the classes *water*, *clearcut*, and *beech*. Hence, it is more probable that the classification accuracy is lower than the estimated accuracy for those classes.

The accuracy for the Ravels zone A classification was examined for several levels of detail (Table 5). Level A corresponds to the cover types distinguished in visual and digital classification. Because significant confusion occurred between the classes *other coniferous*, *mixed coniferous/deciduous*, and *scots pine*, they were merged for level B. Deciduous species were also merged in level C, while level D corresponds to the global land-use classes as discriminated in the Ravels zone B classification. Producer's and user's accuracies, error estimators for omission and commission, respectively, were calculated for individual and grouped cover types as well as for the total matrix (Story, 1986). The error matrices were compared using discrete multivariate analysis (DMA). A statistical measure called KHAT was computed along with the large sample variance (Bishop, 1975; Hudson, 1987). The KHAT statistic corrects for change agreement, accounts for errors of both omission and commission, and is used to calculate the Z-statistic (Rosenfield, 1986). The latter measure may be used to conduct pairwise tests of significance. Values larger than 1.96 indicate a difference significant at the 5 percent level of confidence (Congalton, 1986).

ANALYSIS OF VARIANCE

The results of the visual interpretation were analyzed to assess the effect of recording date and enhancement procedure on interpretation accuracies. Two methods were used : DMA and analysis of variance. Accuracies were transformed using arcsin $\sqrt{p}$ to increase homogeneity of variance (Dixon, 1983). A two-way analysis of variance was run separately on the transformed accuracies for the individual cover types and on the average accuracies. When interaction between recording date and enhancement procedure was found to be significant ($\alpha = 0.05$), the Duncan multiple range test was used to assess which enhancement procedure was optimal for each registration date. When recording date and/or enhancement procedure were found to have a significant effect on accuracy, the Duncan multiple range test was used again to assess which registration dates and/or which enhancement procedures were significantly better ($\alpha = 0.05$).

TABLE 5. LEVELS OF DETAIL CONSIDERED FOR ACCURACY ASSESSMENT OF THE RAVELS ZONE A CLASSIFICATION

Level A	Level B	Level C	Level D
1. Corsican pine			
2. Scots pine			
3. Other coniferous			
4. Mixed coniferous/ deciduous			
5. Beech			
6. Oak			
7. Clearcut			
8. Water			
9. Agricultural lands			

RESULTS AND DISCUSSION

VISUAL ANALYSIS

No statistical difference in interpretation results was observed between experienced and unexperienced interpreters. The Z-statistic indicates significant differences in accuracy between repetitions for the interpretation levels A, B, and C. For level D, however, those differences are seldom significant. Hence, visual interpretation is probably not likely to provide reliable detailed forest information, but can give satisfactory results for discrimination of global land-use classes.

Two methods can be used to assess the effect of enhancement procedure and registration date on interpretation accuracy. Either the sum error matrix of the four available repetitions (method 1) or only the matrix corresponding to the most accurate interpretation is considered (method 2). The results indicate that method 2 is less sensitive to differences in interpretation accuracy and, although the resulting conclusions are different, those from the second method are more general. Degloria (1985) states that for operational applications the best interpreter will always be selected and uses method two to evaluate interpretation tests.

By using this method, the effect of enhancement procedure proved to be insignificant, independent of the considered level of detail. If the effect of enhancement procedure was evaluated for each acquisition date instead of averaged over all acquisition dates, the results were similar. However, for interpretation levels A and B, and averaged over all techniques, the differences in interpretation accuracy resulting from using different acquisition dates are highly significant. If those differences are also evaluated for each technique, then only for interpretation level D, no significant difference can be detected. Hence, for interpretation level D, neither enhancement procedure nor acquisition date significantly influences the interpretation accuracy. For all other levels of detail, the applied enhancement procedure is of minor importance compared to the registration period. The highest interpretation accuracy can be obtained using an image from the end of June, and this positive effect is stronger as interpretation detail increases.

Using the KHAT-value, the variability between interpreters is not taken into account. To incorporate and isolate this variability which is considerably high, the technique of analysis of variance is used. Table 6 summarizes the results of the analysis of variance. From these results, it can be concluded that the acquisition date has a significant effect on nearly all interpretation accuracies, except for the classes *water* and *mixed coniferous/deciduous*. The images dating from either May and/or June yield significantly higher interpretation accuracies. Identification of broadleaved forest however forms an exception; in this case interpretation of the September image seems to be most suitable. The classes *mixed coniferous/deciduous; scots pine*, and *other coniferous* can not be discriminated satisfactorily. One of the major causes for this confusion might be the presence of black cherry (*Prunus serotina* EHRH) which invades incompletely closed stands.

The effect of enhancement procedure is less significant. The choice of enhancement technique seems to be important only for the discrimination between forest and non-forest. The XSPA procedure yields significantly better results, independent from the considered acquisition date. The superiority of this technique for forest/non-forest discrimination may be attributed to the integration of the 10-m resolution mode which resulted in a better delineation of clearcut and small agricultural fields located within the forest complex. However, for the other cover types, the finer spatial resolution does not result in higher interpretation accuracies.

Interaction between recording date and enhancement technique was in general not significant, the only important inter-

TABLE 6. THIS TABLE SUMMARIZES THE RESULTS OF THE ANALYSIS OF VARIANCE. IN PART I A CODE (▼,●,■) INDICATES THE OCCURRENCE OF (I) A SIGNIFICANT INTERACTION BETWEEN THE FACTORS ACQUISITION DATE AND ENHANCEMENT PROCEDURE (▼), (II) SIGNIFICANT DIFFERENCES BETWEEN ACQUISITION DATES (●), AND/OR (III) SIGNIFICANT DIFFERENCE BETWEEN ENHANCEMENT TECHNIQUES (■). ACQUISITION DATE(S) AND/OR ENHANCEMENT PROCEDURE(S) ARE NOTED IN BRACKETS WHEN THE TESTED DIFFERENCES WERE FOUND SIGNIFICANT. THE INDICATED ACCURACY VALUE IS A MEAN VALUE, AVERAGED EITHER OVER ALL ENHANCEMENT TECHNIQUES AND THE SIGNIFICANT BEST ACQUISITION DATE(S), OVER ALL ACQUISITION DATES AND THE SIGNIFICANT BEST ENHANCEMENT PROCEDURE(S), OR OVER THE SIGNIFICANT BEST ACQUISITION DATE(S) COMBINED WITH THE SIGNIFICANT BEST TECHNIQUE(S). PART II OF THE TABLES INDICATES THE ACQUISITION DATE/ENHANCEMENT TECHNIQUE COMBINATION WHICH RESULTS IN THE HIGHEST ACCURACY, AVERAGED OVER THE FOUR REPETITIONS.
M; J; S; O INDICATE, RESPECTIVELY, THE XS IMAGES DATING FROM 27 MAY 86; 27 JUN 86; 28 SEP 86; 30 OCT 86.
LOG; MAT; YIQ; XS+PA; KL INDICATE THE APPLIED ENHANCEMENT TECHNIQUES (TABLE 3).

			User's (%)		Producer's (%)
			Overall accuracy		
I	Level A	●	59.05 (J;M)	●	55.16 (J;M)
	Level B	●	71.13 (J;M)	●	67.79 (J;M)
	Level C	●	75.27 (J;M)	●	69.84 (J;M)
	Level D	●	84.71 (J)	●	70.92 (J)
II.	Level A		64.49 (J;XSPA)		58.83 (J;MAT)
	Level B		75.82 (J;MAT)		72.46 (J;MAT)
	Level C		78.61 (J;MAT)		74.33 (J;MAT)
	Level D		85.56 (J;MAT)		74.45 (J;LOG)
			Accuracy for the merged forest class		
I.	Zone A	●	93.49 (J;S)	●,■,▼	97.60 (M;J;XSPA;MAT;KL)
	Zone B		77.33 (J;S;O)	■	94.13 (XSPA;KL)
	Zone A + B		87.20 (J;S;O)	■	94.99 (XSPA;MAT;YIQ)
II.	Zone A		94.71 (J;MAT)		98.17 (S;XSPA)
	Zone B		82.00 (S;LOG)		97.58 (J;XSPA)
	Zone A + B		90.00 (S;XSPA)		97.38 (J;XSPA)
			Accuracy for the merged non-forest class		
I.	Zone A	●,■,▼	95.25 (M;J;XSPA;MAT;KL)	●	87.93 (J;S)
	Zone B	●,■	97.67 (J;XSPA)		79.15
	Zone A + B	●,■,▼	96.21 (J;XSPA)		82.35
II.	Zone A		96.39 (S;XSPA)		90.14 (M;MAT)
	Zone B		97.67 (J;XSPA)		86.20 (S;XSPA)
	Zone A + B		96.21 (J;XSPA)		86.38 (S;XSPA)
			Accuracy for the individual and merged forest classes		
I.	Coniferous	●	83.00 (J;M)		75.30
	Deciduous	●	73.81 (S)	●	60.36 (J;M)
	Corsican pine	●	64.12 (O;M;J)	●,▼	75.48 (J;M;S)
	Mixed/Scots pine/ Other coniferous	●,▼	71.43 (J;M;MAT;XSPA;KL;LOG)		69.73
	Beech	■,▼	65.37 (MAT;XSPA;KL;LOG)	■	85.84 (XSPA;MAT)
	Oak	●	39.93 (J;M)	●	37.83 (J;M)
II.	Coniferous		89.54 (M;LOG)		84.12 (M;KL)
	Deciduous		84.10 (S;XSPA)		73.01 (J;LOG)
	Corsican pine		74.70 (O;YIQ)		90.32 (S;XSPA)
	Mixed/Scots pine/ Other coniferous		75.79 (M;LOG)		85.39 (O;LOG)
	Beech		92.06 (J;XSPA)		96.67 (M;XSPA)
	Oak		66.90 (J;LOG)		47.56 (J;LOG)

action noticed being for the forest class beech. Combination of the acquisition dates May or June with the XSPA enhancement procedure results in a significantly higher interpretation accuracy. Here the multitemporal aspect has undoubtedly contributed to the better performance of the XSPA procedure for identification of the deciduous tree species beech. The interaction between enhancement procedure and acquisition date for *corsican pine* is much weaker and no conclusion can be formulated. A considerable increase in interpretation accuracy is noticed if for the available September image the XSPA enhancement procedure is applied (Tables 6, 7, and 8). This can be due to the masking of the haze bands in the September image by adding the first two XS channels with the PA channel. This masking however is not a typical contribution of the PA mode, but can be obtained by integration of any haze free band.

DIGITAL ANALYSIS

The optimal channel combination for ED-classification of forest features varies with the registration period. At least the infrared and one of the visible bands should be incorporated. XS3/XS2 ratio as well as the first principal component are *not* suitable for tree species discrimination. Classification accuracies obtained by using the infrared channel only were comparable. This is probably due to the low dynamic range of the visual channels. As for visual interpretation, the Z-statistic indicates the significant importance of the image registration period. Only for classification

As for visual interpretation, the Z-statistic indicates the significant importance of the image registration period. Only for classification level D do no significant differences exist when selecting the optimal channel combination for each acquisition date. As the classification becomes more detailed (levels C,B,A) the image dating from the end of the growing period (30 Oct 86) yields considerably lower accuracies. The images from May and June seem most suited, although they do not yield accuracies which are significantly higher than those of the September image classification. Table 7 indicates for each acquisition date the most appropriate channel combination together with the obtained accuracy (zone A only) for the considered cover types.

Comparison of Digital Classification and Visual Interpretation of Digitally Enhanced Images

The comparison was made for zone A only. Although the application of different enhancement procedures did not result in significant differences in average interpretation accuracy, the MAT procedure ranged first for *user* as well as for *producer* in the Duncan multiple range test. Hence, for each acquisition date, the best interpretation (V.1. method 2) of the MAT enhanced image was selected for comparison. It was noticed that some of the information available in the enhanced display images disappeared during the color plotting process. Hence, results of the visual interpretation test probably underestimate the real potential of the visual interpretation technique.

Selecting the optimal acquisition date (27 June 86), no significant difference in accuracy could be detected for levels A, B, and C (Table 8). Because the non-forest classes (Table 5) are more reliably distinguished, visual interpretation yields significantly better results for discrimination of global land-use classes. Many bare or sparsely vegetated agricultural lands are digitally classified as clearcut. Although these cover types are almost identical spectrally, they are visually distinguishable by their location within or outside the forest complex (context information). The advantage of the visual interpretation seems to be lost if interpretation becomes more detailed. Although the KHAT-value remains higher for visual interpretation, the accuracy differences with digital classification are not significant. Accuracy differences between both methods are noticed again as the acquisition date becomes less suitable for discrimination of vegetation classes. Visual interpretation is to be preferred whenever more detailed information is to be extracted from images dating from less favorable acquisition periods. The cover types, which are difficult to distinguish by visual interpretation, remain poorly discriminated by digital classification. Again, the class *mixed coniferous/deciduous*, as well as the classes *Scots pine* and *other coniferous*, are difficult to differentiate from each other. Moreover, the class *oak* cannot be isolated satisfactorily. The confusion with the other deciduous class (*beech*) is rather low, but large omission and commission errors occur with the class *mixed coniferous/deciduous*. However, this kind of discrimination problem is to be expected whenever transitional classes (such as *mixed deciduous/coniferous*) are utilized (Buchheim *et al*., 1984).

CONCLUSIONS

Research results reviewed in literature are mainly based on test sites with forest characteristics dissimilar to those in Flanders. The main goal of the research presented in this paper was to evaluate the value of monotemporal SPOT images for forestry applications under typical Flemish conditions. The performances of visual and digital classification were compared through a statistically based test. In a first approach, only standard image (pre)processing techniques have been applied.

The obtained classification accuracies are mainly dependent upon the recording date of the available images and the level of information detail required. The enhancement technique for visual interpretation is of minor importance compared to the acquisition date. Hence, a simple enhancement technique (e.g., piecewise linear stretching) is acceptable for interpretation purposes.

The optimal channel combination for Euclidean distance classification varies with the registration period. At least the infrared and one of the visible bands should be incorporated.

Table 7. Producer's (P) and User's (U) Accuracies for the most Accurate Classification (Classification with the Highest KHAT Value) Obtained Using the Monotemporal Images Dating from 27 May 86, 27 Jun 86, 28 Sep 86, and 30 Oct 86.

Acquisition date	27 May 86	27 Jun 86	28 Sep 86	30 Oct 86
Channel combination	XS1;XS3	XS2;XS3	XS2;XS3	XS1;XS2;XS3
Accuracy	P(%)/U(%)	P(%)/U(%)	P(%)/U(%)	P(%)/U)(%)
Overall level A	59/58	62/65	49/62	41/39
Overall level B	74/74	72/74	61/72	53/53
Overall level C	72/75	71/74	62/74	54/56
Overall level D	78/82	75/80	70/88	77/79
Forest	97/94	100/95	91/91	96/96
Non forest	88/94	89/99	79/97	91/91
Coniferous	83/83	88/86	95/74	83/72
Deciduous	67/57	78/65	69/71	33/50
Mixed/Scots pine/other coniferous	75/74	83/76	91/65	86/56
Beech	100/83	93/82	87/62	60/82
Oak	50/43	67/54	33/44	10/16
Coriscan pine	78/84	63/81	33/72	0/0

Table 8. Z-Statistic, Resulting from the Comparison of the Most Accurate Visual Interpretation and Digital Classification, Obtained Using the Monotemporal Images Dating from 27 May 86, 27 Jun 86, 28 Sep 86, and 30 Oct 86.

Acquisition date	27 May 86	27 Jun 86	28 Sep 86	30 Oct 86
Level of detail A	0.79	1.36	2.17 *(V>D)	4.52 (V>D)*
Level of detail B	1.16	1.03	0.43	3.41 (V>D)*
Level of detail C	0.80	1.51	0.52	3.32 (V>D)*
Level of detail D	1.21	3.25 *(V>D)	1.20	1.12

* (V>D): The visual interpretation is significantly more accurate than the digital classification at the 95 percent confidence level.

For visual interpretation as well as for digital classification, the images recorded during the first period of the growing season are most suited. The importance of the optimal registration period increases as more detailed forest information is to be extracted. If the optimal acquisition period is selected (27 Jun 86), visual interpretation is preferable for the differentiation of global land-use classes. For the discrimination of detailed forest classes, digital classification and visual interpretation perform equally well. Because of its objectivity and speed, apart from the training phase, the high degree of automation in digital classification is preferable here, especially if large areas are to be classified. However, if images dating from a less favorable registration period are available, visual analysis is the better technique whenever detailed information is required. Neither visual nor digital classification using a monotemporal approach produces satisfactory results at the forest management level for Flanders. However, acceptable results can be obtained for general purpose mapping, e.g., forest area updating. The results obtained by this research will serve as reference for further studies on the gain in accuracy by using a multitemporal approach and diverse segmentation techniques. Experimental results obtained by using a layered multitemporal procedure show a significant increase in accuracy (Borry *et al.*, 1988).

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