SOIL MOISTURE ESTIMATION FROM RADARSAT -1, ASAR AND PALSAR DATA IN AGRICULTURAL FIELDS OF MENEMEN PLANE OF WESTERN TURKEY

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ABSTRACT:

Due to the accelerating global warming, droughts which cause severe damages especially in the agriculture became a very recurrent phenomenon in all over the world. Monitoring the characteristics of soil moisture is very important in Turkey because the major impact of the global warming on our country appears to be climate changes. In this respect, drought has become a serious threat for the country where the agriculture is one of the major income sources. Therefore, monitoring of draughts has the highest priority among the other strategies. Although the sensitivity of microwaves towards the soil moisture is well understood, retrieving soil moisture with Synthetic Aperture radar (SAR) measurements still has difficulties due to the major impact of soil texture, surface roughness and vegetation cover. In this study, SAR data gathered by different sensors for the same area in closer dates were used to estimate the relative soil moisture. The relation between the ground soil moisture and the sigma nought/backscatter values of SAR images were investigated. Sigma nought values of C band HH polarized Radarsat Fine Beam image and C Band VV polarized ENVISAT (ASAR) images as well as backscatter values of an L band HH polarized ALOS (PALSAR) satellite images were used. RADARSAT, ASAR and PALSAR images were gathered on the 28th of May, 8th of June, and 10th of June in 2006 respectively for the alluvial lands of Menemen Town, Izmir. Ground soil moisture measurements taken using gravimetric methods showed a good agreement with the backscatter values of the images obtained from different types of SAR data. A comparison among the spatial distribution of retrieved soil moisture changes from SAR images was done. The correlations between the soil moisture content and backscattering of ASAR, RADARSAT-1 and PALSAR images were found 76%, 81% and 86 % respectively. Although the resolution of RADARSAT-1 fine beam image (6.25m × 6.25m) is closer to the resolution of PALSAR image (6.25m × 6.25m), PALSAR gives better correlation than RADARSAT-1 image. Although the resolution of RADARSAT-1 and PALSAR images is far more higher than that of the ASAR image (30m × 30m), the significance of the results produced is almost similar in such flat areas.

1. INTRODUCTION

Soils represent an important part of natural resources of Turkey. Soil management is an important element of sustainable agricultural development. The protection of soils has significance not only in the economy of the country but also in environment protection. Monitoring the characteristics of spatially and temporally distributed soil moisture is important due to the fact that the soil moisture controls the plant growth, the hydrological behaviour of the soil, and the ability of the soil to resist erosion, etc. Since Turkey has been located in the relatively drier parts of the earth, especially agricultural areas show vulnerability to reduced soil moisture. Parallel to the variations in the earth climate, the climate of our country also marks changes. Thus the precautions must be taken to decrease the effects of possible future droughts.

The major difficulties in retrieving the soil moisture with SAR images are due to soil texture, surface roughness and vegetation cover. The amount of moisture stored in the upper soil layer changes the dielectric constant of the material and thus affects the SAR return. Because the dielectric constant for water is at least 10 times bigger than that of the dry soil, the presence of water in top few centimetres of bare soil can be detected in SAR imagery (Lillesand and Kiefer, 2000). The large difference between the dielectric constant of water and of dry soil at microwave frequencies is the main factor for soil moisture estimation using microwaves (Wang, 1980). Since the 1960s the radar remote sensing has been used operationally. Radar sensors transmit microwave energy to the earth surface and record backscatters reflected by the objects on the ground. The wavelengths of the energy used by these active remote sensing systems vary with frequencies between 0.3 GHz to 300 GHz roughly corresponding to wavelengths between 1mm and 1m, with wavelengths between 0.5 and 50cm being widely utilized (Skidmore, A., 2003). For instance, the X-band within the range of 2.4-3.75 cm wavelength is usually reflected by the surfaces of the objects. The C-band falling into the wavelength range of 3.75-7.5 cm could only reach to the parts near to the surface of the objects. The L-band which has the wavelength range of 15-

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30 cm could penetrate through the plants (foliage etc.) and reach to the objects underneath such as ground, and etc. Because the soil moisture normally limits the penetration of waves to the depths of a few centimetres, the surface wetness conditions become apparent at longer wavelengths. The penetration of L-band radar to the several meters provides the observation of the moisture content under extremely dry soil conditions. However in many studies, the potential of SAR data for the retrieval of surface soil moisture was investigated not only with longer wave lengths but also with shorter wave lengths as C-band radars, and the microwave measurements have shown their sensitivity to surface soil moisture (Ulaby et al.1978, Dobson and Ulaby, 1986, Dubois et al. 1995, Shi et al. 1997).

Following the evolution of SAR satellite technologies, researchers have been investigated the effect of dielectric features on backscattering. For instance, Peplinski et al. (1995) investigated dielectric properties of different soil types and their effects on backscattering. They discovered that soil texture and volumetric moist content had an effect on the dielectric coefficient. In addition, these researchers emphasized that dielectric coefficients of soils vary with respect to clay types, and as the clay specific surface area becomes wider dielectric conductivities increase linearly. Romshoo et al. (2002) tried to forecast soil moisture in Sukhothai area, using a time series of space-borne ERS-2 SAR satellite data for the temporal monitoring. In their study, it has been discovered that in the study area, the backscatter coefficient of SAR data was sensitive to volumetric soil moistures of 0-5 cm in depth. Shao et al. (2003) have empirically investigated the variations in dielectric features of moist and saline soils, the samples of which were taken from a salt lake, and they observed an increase in the backscatter as the saline content increased. Yang et al (2006) demonstrated a technique to estimate the retrieval of soil moisture change by using multi-temporal Radarsat ScanSAR data. Their study had two parts. First part focused on minimizing the effects of surface roughness by using two microwave radar measurements with different incidence angles. Second part dealt with to reduce the effects of vegetation cover on radar measurements by using semi-empirical vegetation model and measurements obtained from the sensors as Landsat TM and AVHRR. Throughout the surveys in more than one decade, it has been detected that there is a strong relation between the backscatter coefficient and the soil moisture. The researchers whether used data from only one sensor type (such as ERS 1/2, RADRASAT-1, ENVISAT) to analyze the sensitivity of SAR data to soil surface parameters at various polarisations or incidence angles or they used two different sensor data to make the comparisons (such as ERS 1/2 versus RADARSAT-1 or ENVISAT versus RADARSAT-1) over fields with different characteristics. (Baghdadi et al., 2002; Baghdadi et al., 2006; Boisvert et al., 1997; Beaudoin et al., 1990; Alvarez-Mazos et al., 2005; Holah et al., 2005; Kelly et al., 2003; Oldak et al., 2003; Siegert and Ruecker, 2000; Sahebi et al., 2003; Srivastava et al., 2003; Weimann et al, 1998; Zribi et al., 2005a, 2005b). Researchers indicate that, the major difficulties in retrieving soil moisture with SAR measurements are due to the effects of surface roughness and vegetation cover.

The objective of the present study is to investigate the behaviour of RADARSAT, ASAR and PALSAR images to retrieve soil moistures for bare and just seeded soil. Besides, tests have been carried out to obtain the cross correlation not only between the different bands (C/ L) but also between the different polarizations (VV/HH). This work will enable us to perceive which sensor has the best potential for extracting soil moisture in such an agricultural plain areas including the latest satellite ALOS-PALSAR data.

2. IMPORTANCE OF SOIL CHARACTERISTICS IN ACTIVE AND PASSIVE REMOTE SENSING APPLICATIONS

In both passive microwave and active remote sensing, it is important to know the soil characteristics. The soil is constituted from 25 % air, 25% water, 45% and 5% inorganic and organic substances respectively. Organic and inorganic substances that are the solid parts of the soil form the structure of the soil. Inorganic solid matter of soil is composed of various rock decompositions and minerals in different sizes and composition as well as rock pieces (Altinbas et al. 2004). The texture of the soil is formed from various ratios of sand, silt, and clay which are called inorganic substances. It is known that diameters of particles range between 2 and 0,02 mm, of silt particles between 0,02 and 0,002, and of clay particles which have diameters smaller than 0,002 mm. In interpreting soil reflection values for remote sensing applications, size of surface soil particles, volume of the pores, ratio of the size of a pore, and amount of water stored in these pores is very important. The pores in sandy soil texture are called macrospores and the pores in clay texture are called microspores. Although the size of pores in sandy soil is large, total volume of pores is smaller than that of clayey soil. In addition, reflection of electromagnetic radiation from the surface of soil is dependent on some features such as slope of the terrain, surface relief, structure of the soil, organic matter content, size distribution of the particles constituting the soil, stoniness, saltiness, iron oxide content, and etc. Dielectric contents of the soil play important role in microwave back scattering. Soil structure and moisture are the main characteristics that determine the dielectric contents of soils. For instance, while increased amount of sand in soil enables the soil to become less absorbent and to have low water holding capacity, increased amount of clay in soil causes the soil to become more absorbent and to have more water holding capacity. Increase in the amount of water causes the dielectric content to be increased. Spectral characteristics of the soil are mainly influenced by the organic matter content and the moisture content (Stoner et al. 1980).

3. STUDY AREA

The study area is in the lands of Menemen (Izmir) Plain to the west of Gediz Basin, and covers about 400 square km. The Aegean Sea lies to the west of the study area, and Manisa Province lies on the East. The area is also bordered by Bakircay Basin on the North, and Izmir Bay on the South (Figure 1).

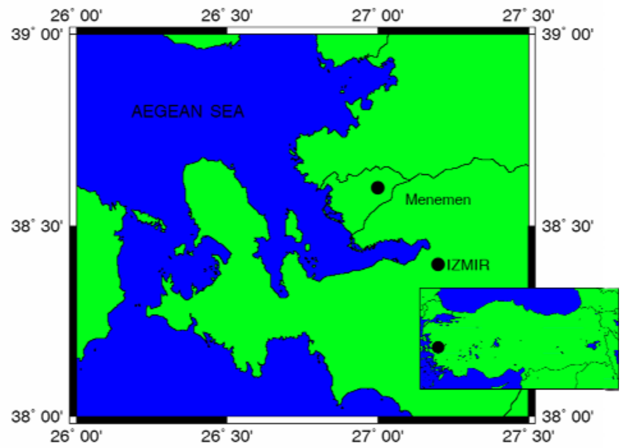

Figure 1. Location map of the study area

In the Menemen Plain, semi-dry and less humid mesothermal climate is dominant and the rain (which is 616 mm / m2) falls in the winter season. Thus, the summer season is drier. There is excessive sun light and evaporation in summer seasons. Relative humidity is around 50%. Although all crop types can be grown in the plain, the main products are cotton, corn, and cereals. Viniculture is also common in the area. The land use types of the areas nearby the sea, which have become very salty due to improper drainage practices, are pastures. Texture of the plain soil is deep and composite. The Gediz River floodings have created plain fields, levees and depression geomorphologic formations in its surroundings (see Figure 1). Soil texture and distribution of the soil moisture in Menemen Plain is coherent with these geomorphological formations. While clay texture is dominant in depression fields, levee lands are sandy and over flow mantle plains have a loamy texture. The area has a micro relief however the slope in general is 1%. In a larger part of the study area, the fields were prepared for cotton and corn farming before the seeding at the beginning of May 2006. The roughness of the unplanted study area was similar to that of the other fields in the study area. In this season, usually cotton is planted. Since the area has not received enough rain until the beginning of May, the soil moisture levels varied usually relating to their water holding capacities. Irrigation was started on the dates of the data acquisition. Therefore, estimated soil moisture is not the only natural soil moisture; there is also the moisture content of irrigated soils.

4. MATERIAL S AND METHOD S USED

4.1 Materials

In order to validate the above concept, the image data used in this study were acquired by the ENVISAT-ASAR, ALOS-PALSAR and RADARSAT-1. RADARSAT-1 satellite image of 28 May 2006, ENVISAT-ASAR satellite image of 8 June 2006 and ALOS-PALSAR satellite image of 10 June 2006 that include agricultural fields of Menemen Plain were used. The RADARSAT-1 operates at C band (5.332 GHz) with HH polarisation. It operates under 8 different beam modes (Fine, Standard, Wide, ScanSAR, Extanded Low, Extended High) with varying spatial and radiometric resolutions at various incidence angles between 20° and 49° (RSI 2000). Fine beam mode image with 6.25m x 6.25m resolution was selected from the 8 different beam modes. The ASAR (Advanced Synthetic Aperture Radar) operates in the C band. It can acquire images in both single and dual polarisations as HH, HV, and VV. The incidence angles vary between 15 ° and 45° (Baghdadi et al., 2006). For this study a VV polarised image with the resolution of 12.5 m x 12.5m was selected. The PALSAR (Phased Array L-band Synthetic Aperture Radar) operates in L band and acquires images in five observation modes (Fine Beam Single (FBS), Fine Beam Dual (FBD), Direct Transmission (DT), ScanSAR and Polarimetry). The incidence angles range between 18° to 55°. It can acquire data in four polarisations (Rosenqvist et al., 2004). Fine beam mode with 6.25m x 6.25m resolution was selected from the five different beam modes. The detailed description of the SAR data used is given in (Table 1).

	RADARSAT-1	ASAR	PALSAR
Date	28/05/2006	08/06/200 6	10/06/2006
Sensor	SAR Fine 1	ASAR/IM	PALSAR/FBS
Pixel Spacing	6.25 m.	12.5m.	6.25 m.
Orbit	55139	22112	2010
Flight direction	Ascending	Ascending	Ascending
Processing	SGF	PRI	L1.5
Polarization	H/H	V/V	H/H
Swath	50 km	ISI-105	80 km
Incidence Angle	37-40	15-22.9	41.5

Cadastral maps in 1/5000 scale and topographic maps in 1/25000 scale were used for the rectification as the ancillary data. An orthorectified SPOT image and SRTM data were used for the orthorectification of the SAR data.

Table 1. Properties of the SAR data

4.2 Methods

For the geometric correction of SAR images, topographic maps, cadastral maps, and an orthorectified SPOT image were used. Geometric correction of SPOT-2 satellite images was implemented by map to image rectification by using cadastral maps in 1/5000 scale and topographic maps in 1/25000 scale. Sufficient number of spatially homogeneous ground control points was used, and the rectification accuracy was within acceptable limits. RMS error was smaller than 1 pixel (< 20 m). The RADARSAT, ASAR and PALSAR images were geometrically corrected by using both image-to-image and map to image rectification processes. Around the number of 40 control points which were evenly distributed was selected per each SAR data from the rectified SPOT-2 image and from the topographic maps with a pixel RMS error less than 6.25 m, 12.5m and 6.25 m for RADARSAT-1, ASAR and PALSAR images respectively. All images were registered to a UTM Zone 35 ED50 datum.

Field works were carried out for a ground truth data collection in synchronization to the RADARSAT-1 and ASAR and PALSAR passes. Sample points were chosen arbitrarily which were evenly distributed across the Menemen Plain in order to determine the soil characteristics. It has been noted that on the dates that the satellite images were taken, the area that included around 80 sampling points per each SAR image date was not covered by plants (i.e. the area was ready for summer planting or just seeded). The coordinates of the sample points were measured with a hand held GPS and added to georeferenced SAR images as an attribute (Figure 2). Samples were collected before or just after the seeding. In some fields cases it was noticed that the farmers increased the density of the surface soil by flattening with force in order to prevent soil moisture loss before the planting season.

Soil samples were gathered using 100 cm3 metal cylinders, and soil moisture levels were detected using a gravimetric method in the laboratories (Black, 1965). Soil texture analyses were made using the Hydrometer Method in order to correlate reflection values with the soil moisture in collected soil samples (Bouyoucous, 1951 and Soil Survey Staff, 1993). Fresh of soil samples were weighed and noted. Then soil samples were oven dried for 24 hours at 105°C temperature. Dried samples were weighed once again for the dry weight. Gravimetric soil moisture values were calculated for the 240 sample points (i.e. 72 points for PALSAR, 74 for ASAR and 94 for RADARSAT) with the help of fresh weight and dry weight samples. Also clay and sand contents of each sample were calculated. During the field works the characteristics of the soil such as stoniness, roughness and surface relief were noted carefully.

Sigma nought values for RADARSAT and ASAR images were calculated using PCI Geomatica software. Sigma nought values were taking the local incidence angle at that pixel position in the range direction. Backscatter values for the PALSAR image were used.

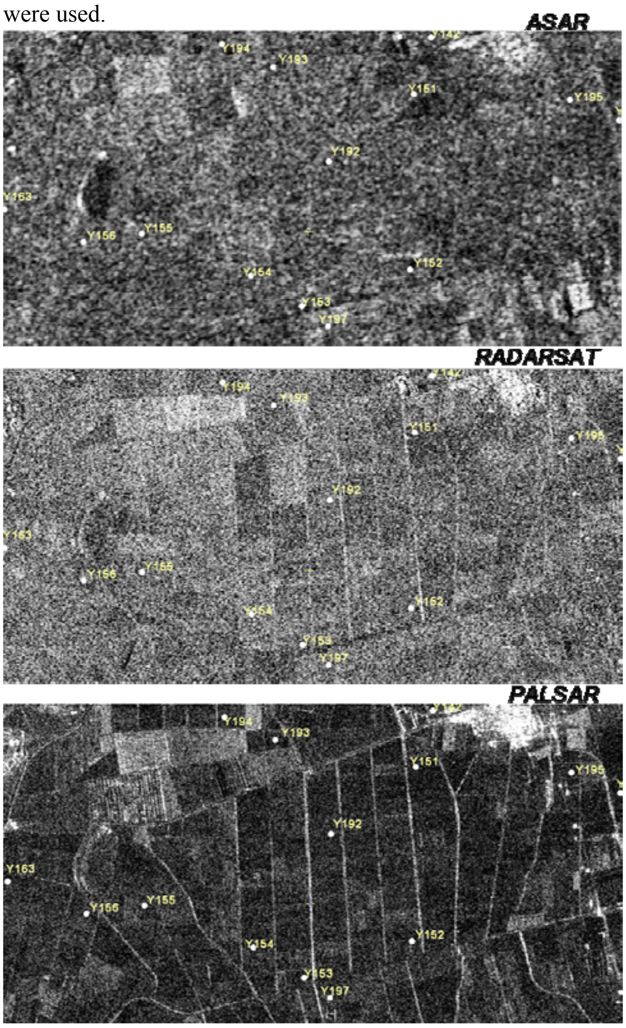

Figure 2. Georeferenced SAR images and the locations of the sample points

The relation between the bare soil moisture and each type of SAR data was investigated by calculating correlation coefficients. For each sample point, instead of using the corresponding pixel value of the actual ground point coordinate, a 9 x 9 kernel window was used to calculate the average backscattering value in dB (σ°) or in DN.

5. RESULTS AND DISCUSSIONS

In this work, the areas showing similar roughness characteristics, i.e. the plains, were chosen as the study area. The contribution of SAR images to detection of soil moisture was investigated by taking into account the interaction of SAR images with surface relief. The stoniness did not exist in the study area, which was basically constituted of plain grounds that might affect the backscattering. It was assumed that only the soil texture and the soil moisture could affect backscattering.

After analyzing the 240 soil samples from the study area, the relation between moisture content (which was believed affecting backscattering directly) and ratios of clay, silt, and sand in soil was investigated. Although theoretically it is known that clay texture has higher water holding capacity we still have made an attempt to check the real situation in the research area, (i.e. correlation calculations were performed in order to check the coherence between the real situation in the study area and the findings given in the literature). The correlation studies indicated that the clay content was correlated with the moisture at 0,72 level whereas the sand content was anti-correlated with the soil moisture at a level of 0,70. It was also noticed that the amount of the silt was not correlated with the moisture (Figure 3).

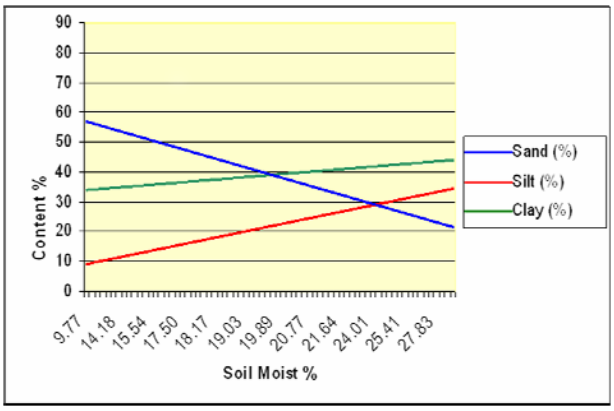

Figure 3. The relations of soil moisture with the ratios of clay, silt, and sand in soil samples

It is known that the moisture content of the soil varies depending on the inorganic material and the clay content of the soil. In the study area, the organic material content of the soil is very low and homogeneous. The flat and nearly flat areas form the physiological suture of the study area. In the area, clay content of the soil is not homogenous. Thus soil moisture content of the study area changes depending merely on the clay content and the micro relief of the soil. In this study the relation between the soil moisture and RADARSAT-1 backscattering, soil moisture and ASAR backscattering, and soil moisture and PALSAR backscattering is compared. While processing the SAR data, the resolution of the images was resampled to 8 m for RADARSAT-1 and PALSAR data and to 30m for ASAR data. SAR data has different resolutions. The resolution of RADARSAT-1 and PALSAR data is three times better than the ASAR data. There is a pretty high correlation (R^2 = 0.86) between the soil moisture content and the PALSAR backscattering, which is the best among all the SAR images (Figure 4a). RADARSAT-1 gives better result (R^2 = 0.81) than ASAR (Figure 4b). ASAR is the worse (R^2 = 0.76) among the all (Figure 4c). This result is related not only with soil moisture content but also with soil texture. In addition, due to the fact that PALSAR has the biggest wavelength causing to penetrate deeper, gives higher correlation with the moisture content of the soil. The significance of linear association was tested for all SAR backscattering results from different satellites using Fisher's F test for α = 0.05 significance level, and all were found significant (for the PALSAR F=431,5706952 and significance F=2,09369E-31, for the RADARSAT F=380,7293985 , significance F=2,81845E-34, for the ASAR F=244,5656022, significance F=1,07252E-24).

In investigating the soil moisture change, the spatial resolutions of the each C band SAR data affect the average soil moisture value of the represented area. However, the polarisation does not affect the result significantly since both RADARAT-1 (HH polarised) and ASAR (VV polarised) give a good (i.e. acceptable) correlation with the soil moisture. With regard to the band difference; despite the resolutions of both images were the same, PALSAR (L) band gave better correlations than that of RADARSAT-1 (C band) for the same soil characters. Comparing the graphs, linear association from PALSAR analysis is about 5 % better than RADARSAT-1 analysis. It is also better than ENVISAT analysis by about 10 %.

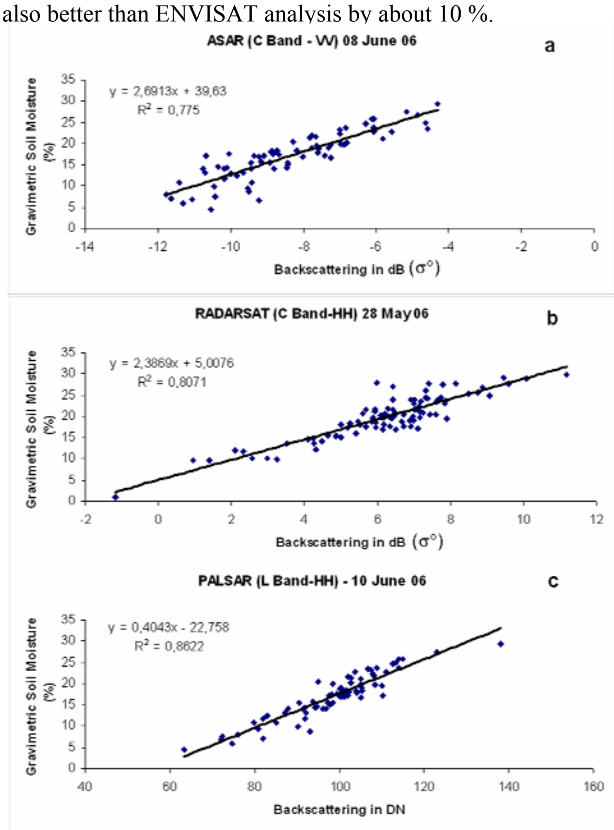

Figure 4. Variation of backscattering coefficient with gravimetric soil moisture a) for ASAR b) for RADARSAT-1 and c) for PALSAR

6. CONCLUSIONS

In this study the potential of RADARSAT, ASAR, and PALSAR data was investigated for estimating soil moistures over bare soils in Menemen Plane of Western Turkey. RADARSAT, ASAR and PALSAR images are collected on 28 May 2006, 8 June 2006 and 10 May 2006 respectively. In most of the studies comparisons were made between the multi polarisations or multi incidence angles of the same sensor or comparisons made between the ASRAR and RADARSAT-1 data. In this study, the estimates of soil moisture obtained from the SAR data of three different satellites for HH and VV polarisations and for C and L bands are compared to find the best sensor for measuring the bare soil moisture in agricultural areas as in Menemen Plain.

It has been found out that for the bare soils having a relief of less than 1% and having no stoniness, the correlations between the soil moisture content and backscattering of ASAR, RADARSAT-1,and PALSAR images were 76%, 81% and 86% respectively. The RADARSAT-1 Fine Beam image has the same resolution (6.25m $\times$ 6.25m) with the resolution of PALSAR image (6.25m $\times$ 6.25m). Although they both were resampled to 8m, PALSAR gave better correlation than RADARSAT-1 image. Although the resolution of RADARSAT-1 and PALSAR images is far higher than that of the ASAR image (30m$\times$30m), the significance of the results produced is almost similar in such a flat area. Despite the spatial resolution difference and polarization differences of RADARSAT-1 and ASAR images (8m-HH versus 30m-VV), the estimated soil moistures show high correlation with backscatter values for the both image types. From the point of view of monitoring and mapping the soil moisture content of agricultural fields; for the areas having larger fields, both SAR images can be utilized almost equivalently whereas for the areas having smaller fields RADARSAT-1 image gives better results. Regarding to the band difference, RADARSAT-1 (C band) and PALSAR (L band) images having the same resolution are compared, and as expected PALSAR data gave % 5 better estimation than the RADARSAT-1 data. This means L band resulted in the best correlation between the ground soil moisture and the estimated soil moisture.

Baghdadi et al. (2006) found out in their study that ASAR sensor does not seem to offer any advantage compared to the mono- polarization and multi incidence RADARSAT -1 sensors. They studied HH and HV polarizations for different incidence angles and recommended to study VV polarisation to see the potential of ASAR versus RADARSAT in estimating soil moisture. In this study it has been revealed that VV polarisation of ASAR sensor does not prove any better to RADARSAT-1 sensor. If the price differences per scene are taken in to account, one should consider purchasing ASAR (VV) for the vast acreages. In this sense, 5% difference in R^2 values of ASAR and RADARSAT-1 correlations do not show any significance.

Among all the sensors, the PALSAR is the most cost effective data and gives the best moisture estimation in bare soil. For the soils having the same characteristics as with the Menemen Plain, PALSAR images can be preferred for moisture estimations. This study revealed that the PALSAR which is designed to achieve high performance and flexibility and the L-band data continuity of JERS-1 can be used successfully for monitoring the soil moisture.

Fieldworks have revealed that the soil cultivating technique, e.g. compaction of the soil to prevent the moisture loss was another factor that affected the backscattering. Increases in backscatter values in all SAR images have been observed in fields that were levelled by applying compaction by force. The next phase of our research includes investigation of the changes in backscattering from SAR images with soil texture, pore volumes, pore sizes, moisture content, and soil cultivation techniques.

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