Chapter 4

Monitoring Of Sunflower Using Microwave Remote Sensing For Pest Infestation
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4.1 Introduction:

Sunflower (*Helianthus annus* L.) has been traditionally cultivated in Karnataka, Maharashtra and Andhra Pradesh. In recent years, its cultivation was taken up in non-traditional states like Haryana, Punjab, Uttar Pradesh, Gujrat, Tamilnadu, Orissa, Madhya Pradesh, Chattisgarh and Rajasthan also. Karnataka accounts for nearly half the area under sunflower in the country. Sunflower is cultivated both as Kharif and Rabi crop in India. The Rabi output is much higher than the Kharif output. According to the trade, the domestic demand for sunflower oil in India is about 6 Lakh tonnes while the output is about 3 Lakh tonnes only. Refined sunflower oil is the most preferred oil of upper middle class people in India, because, it is the most flavorless and odorless oil and does not affect the flavour of vegetables and other dishes cooked in it (Agriculture 2003).

Crop yield information can provide important information for local governments in arranging agricultural activities. There is a long history of using remote sensing data to obtain information about crop growing conditions (Li 1994). In the early 1980s, much attention was paid to use microwave remote sensing for crop yield estimation all over the world. Remarkable achievements were obtained after many studies. Nevertheless, because of the limitation of the data acquisition for optical remote sensing, it is very difficult to carry out real-time monitoring of crop growth and estimate yield promptly based on these methods. Radar remote sensing is the obvious choice as the most appropriate data source for agricultural monitoring and crop yield estimation (Li 2003).

Measuring within field variability in grain yield is the most important information for precision farming. Although large within field variations in yield
are common due to soil, topography, moisture, rain fall and fertilizer inputs (Moran et al, 1997, Basso et al, 2001, Shanahan et al, 2001), effective management of the field requires that within field variability be reduced to a minimum. One of the main causes of reduction of crop yield is pest infestation in the field. Monitoring of pest infestation is also very essential by which timely preventive measures can be taken. It is very tedious and cumbersome to assess the level of damage of crop by ground truth management. In the era of technology revolution, it is necessary to estimate the crop damage with satellite data/ remote sensing.

The accuracy of canopy characteristics estimation from satellite data depends on the nature of the sensor i.e., sensor parameter. Numerous studies have thus investigated the potential of many instruments to extract canopy biophysical variables in the microwave region (Le Toan et al, Ulaby et al, Singh et al, 2002, 2003, 2004). These variables must be both strongly coupled with the radiative transfer in the canopy and pertinent with regards to process models describing ecosystem functioning and its relations to other components of the global system.

This chapter deals the analysis and algorithm development for assessment insect pest infestation in sunflower using microwave data.

4.2 Critical growth stages of crop:

i. 4-5 leaf stage: This stage lasts up to 40 Days after sowing. Number of leaves is not many and size remains moderately small.

ii. Flowering stage: This phase is the main growth phase at the end of it the plants are in full bloom. The plants grow in height and the size of the leaves becomes very large. This stage continues up to 80 days after sowing.
iii. Grain filling stage: During this stage flowers grow and the capitulum starts becoming heavy due to filling of grains (seeds). The crop matures in about 100-110 days.

4.3 Pest Infestation in Sunflower

Insect pests are often a major limiting factor in sunflower production. Of the 50 species of insects recorded on sunflower in world, about 15 are considered potentially major pests. The pests of crop sunflower can be grouped in accordance to the part of plant they infest.

a. Insect pests infesting head: Sunflower moth, Sunflower bud moth, Banded sunflower moth, Head clipper weevil, Sunflower seed weevils.
b. Insect pests infesting the stalk: Sunflower stem weevil, cocklebur weevil, Girdlers.
c. Insect pest infesting foliage: Sunflower beetle, Tistle Caterpillar, Beet armyworm, Grasshopper.
d. Insect pest infesting roots: Carrot beetle, sunflower root weevil.

During our study the grasshoppers was the major pest observed. It destroyed the foliage thus affected the chlorophyll content of plant. The presence of 11 or more grasshoppers per square yard in crop margin is likely to cause economic damage (Patrick, 2000).

Sunflower (CGL208) was seeded in the month of December 2000. In this study, the maturity period of crop sunflower was extended from 110 to 120 days. The readings were taken up to 80 days after sowing. An outdoor bed of 5m x 5m was prepared for the study. The crop was irrigated maintain soil moisture for normal development of plant. The soil had 2% gravel, 38% sand, 52% silt and 8% clay and it was silt clay loamy type of soil.
4.4 Field data analysis:

The observations of plant height (PH), Leaf Area Index (LAI), total chlorophyll (TC), Biomass (BIO), soil moisture (SM) and pest were observed at regular intervals from 14 days after sowing.

Figure 4.1 shows the variation of plant height with age of crop. The graph shows a continuous increase in height up to the age of 80 days after which grain filling period starts. The sharp increase in height is observed between 22 to 70 days after sowing. Variation of Total Chlorophyll with age of crop is shown in figure 4.2. It represents a continuous increase in total chlorophyll till the age of 52 days after that chlorophyll content decline sharply. Another parameter LAI with age of crop is shown in Figure 4.3. Sunflower being a broad leaf plant and the LAI increased sharply up to 80 days after sowing.

In figure 4.4, the variation in pest number is shown with the age of crop. It can be clearly seen that the increase in pest number is observed with the age of crop. It is may be due to the change in sunflower biophysical parameters.

The occurrence of pest infestation with sunflower chlorophyll is shown in fig. 4.5. The increase in pest number coincides with the decrease in chlorophyll by referring the fig. 4.5 and fig. 4.2. This can be due to feeding habits of grasshopper which feeds on leaves (i.e., chlorophyll). It leads into decrease in TC and slight decrease in biomass also.

An empirical relation has been developed between sunflower chlorophyll and occurrence of pest infestation (P) and found as

$$P = 0.0198 \times (TC)^2 - 0.6073 \times (TC) + 8.95501$$

(1)

The observed crop parameters PH, LAI, TC, BIO, and SM were individually correlated with pest occurred which is shown in Table 1. It is noticed that the dependence on pest on total chlorophyll is showing highest $r^2$ value, which infers that pest is highly correlated with sunflower chlorophyll rather than other plant parameters. This analysis extend the work to develop a model to
assess the sunflower chlorophyll with microwave data, which is done in the following part of the chapter

4.5 Description of Scatterometer data

For development of algorithm to assess the plant chlorophyll, microwave scatterometer analysis has been carried out at different stages of the sunflower. Microwave emission and microwave scattering has been observed that is discussed below

4.5.A. Temporal variation of scattering coefficient and emissivity of sunflower:

Figure 4.6 and 4.7 shows the temporal variation of scattering coefficient ($\sigma'$) of crop sunflower at 20°, 30°, 40°, 50°, 60° and 70° for HH-pol and VV-pol respectively. The average dynamic range of VV-pol is higher than overall dynamic range of HH-pol. The dynamic range is maximum (-20.7dB to -1.5dB) at 40° incidence angle for HH-pol, while for VV-pol, it is maximum at 50° incidence angle (-47.2dB to -9.1 dB). Thus the maximum sensitivity of $\sigma'$ on TC is obtained at higher incidence angles i.e. $\theta>40^\circ$ for both like polarizations. The variation of scattering clearly shows the polarization effect at all incidence angles. A good dynamic range in higher incidence angle is observed which indicates microwave scattering at X-band is quite sensitive with various changes in the crop. These typical characteristics are strengthening to develop a model to assess the crop sunflower parameters at X-band.

Figures 4.8 and 4.9 show the temporal variation of emissivity with age of crop at different incidence angles i.e., 20° to 70° at the interval of 10° for HH-pol and VV-pol respectively. The emissivity generally increases with the age of crop sunflower for both like polarizations. The peak value of emissivity is observed
between 70-80 days of sowing, this time TC was in its maximum value. The dynamic range varies from 0.065 to 0.362 for HH-pol and 0.025 to 0.111 for VV-pol. The dynamic range for VV-pol is more than HH-pol, which indicates that VV-pol is more sensitive than HH-pol to observe the sunflower parameters at X-band. These characteristics of emissivity can be well used for crop discrimination/identification and yield prediction.

Microwave interacts with various plant parameters. But, in this chapter, we are interested to assess the number of pest on sunflower, which is closely correlated with the sunflower TC. Therefore, the next step of study is to assess the TC of sunflower with microwave scattering/emission.

4.5.B. Chlorophyll assessment with microwave scattering:

Table 2 shows the linear regression results of scattering coefficient $\sigma^*$ with respect to total chlorophyll of sunflower at different incidence angle for both like polarization. It would provide the best incidence angle to observe the TC at X-band. The variation in is from 0.285 to 0.789 and from 0.0185 to 0.862 for HH-pol and VV-pol respectively. The maximum value of $r^2$ is observed at 40-degree incidence angle for HH-pol and 50 degree incidence angle for VV-pol. The angular variation of SE is also discussed in the same table. The SE varies from 0.1256 to 0.306 and from 0.0857 to 0.3207 for HH and VV-pol respectively. This analysis infers that the best suitable incidence angle for observing TC of sunflower is 40 degree and 50-degree incidence angle for HH- and VV-pol respectively. While VV-pol has better dependence on TC than HH-pol. This study will be helpful to pre-decide the sensor parameter for satellite or air-borne sensor.

The variation of scattering coefficient ($\sigma^*$) with the total chlorophyll of sunflower is shown in figure 4.10 at incidence angle 40 degree and 50 degree for HH- and VV-pol. The scattering coefficient increases with increase in
sunflower TC. Based on these results, an empirical relation has been developed between $\sigma^*$ and TC, which is as following

$$
\sigma^* = -0.2472 \text{ (TC)} + 1.689 \quad \text{at 40}, \text{ HH-pol} \quad \text{....(2)}
$$
$$
\sigma^* = 0.1782 \text{ (TC)} - 10.548 \quad \text{at 50}, \text{ VV-pol} \quad \text{....(3)}
$$

Inverting these equations provides the value of sunflower TC remotely. The inversion relations are as following

$$
\text{TC} = 6.87 - 4.04 \sigma^* \quad \text{at 40}, \text{ HH pol} \quad \text{.... (4)}
$$
$$
\text{TC} = 59.19 + 5.61 \sigma^* \quad \text{at 50}, \text{ HH pol} \quad \text{.... (5)}
$$

The TC is assessed by equation 5 for the best correlated polarization. The results are shown in figure 4.11. Significant results are obtained for the assessment of TC with microwave scattering.

4.5.C. Chlorophyll assessment with microwave emission:

A regression analysis has been carried out between TC and emissivity at different incidence angle and both like polarizations. The results are shown in table 3. It is observed that the slope is positive nearly at all incidence angles for both like polarizations, which infers that emissivity increases with increase in TC. In the same table coefficient of regression is also observed for various incidence angles for both polarizations. It is positive for both like polarizations. The range of $r$ is from 0.0428 to 0.3862 and from 0.1627 to 0.9068 for HH- and VV- polarizations respectively. The maximum value of $r$ is obtained at 60' incidence angle for both like polarizations.

The table 3 also shows the angular variation of coefficient of determination ($r^2$) for both like polarizations. The highest value of $r^2$ is 0.1491 for HH-pol and 0.8224 for VV-pol both at 60' incidence angle. The value of $r^2$ for VV- pol is higher than HH pol, which reveals that VV pol shows better
percentage of dependence on TC. Therefore, VV pol and 60° incidence angle is the best sensor parameter to observe the effect of TC on emissivity.

The variation of emissivity (e) with TC is shown in figure 4.12. It is observed that emissivity increases as TC increases at 60° incidence angle. The regression lines (solid for HH pol and dotted line for VV pol) are shown in figure 4.12 at 60° incidence angle and are written as

\[
\begin{align*}
\text{for HH pol: } & e = 0.0042 \times (\text{TC}) + 0.7649 \quad \text{at } 60° \\
\text{for VV pol: } & e = 0.0055 \times (\text{TC}) + 0.8035 \quad \text{at } 60°
\end{align*}
\]

The inversion of these equations for estimating TC is as following

\[
\begin{align*}
\text{for HH pol: } & \text{TC} = 2398.09 \times (e) - 182.12 \quad \text{at } 60° \\
\text{for VV pol: } & \text{TC} = 181.82 \times (e) - 146.1 \quad \text{at } 60°
\end{align*}
\]

It is observed after rigorous analysis that VV pol is better for observing sunflower TC, and with these equations 8 and 9, it also confirms that TC calculated with VV pol is closely matched with observed values of TC than HH pol. This gives an impact that using equation 9, TC can be estimated. The estimated chlorophyll and observed chlorophyll by equation 9 is shown in figure 4.12. A good agreement has been noticed between observed and estimated chlorophyll.

4.6 Pest Estimation with Remote Sensing Technique (i.e., with X-band Scatterometer)

4.6.A Interpretation of Pest infestation by microwave scattering:

The number of pest by scatterometer (or remote sensing techniques) has been assessed by developing an empirical relation, which is one of the main works of this chapter. The TC can be estimated by scatterometer through equation number 5 for VV pol. VV-pol has been considered because, it gives better precision than HH-pol for estimating sunflower TC at X-band. Using equation 1 and 5, the pest occurrence can be written as
\[ P = 0.623(\sigma^2) + 9.74(\sigma^o) + 42.372 \quad (10) \]

Using equation 10, pest infestation can be directly estimated by scatterometer or satellite/air-borne sensor data.

The observed number of pest and estimated number of pest (using equation 10) with microwave scattering has been shown in figure 4.13, where it is clearly indicated that the percentage of agreement between observed and estimated number of pest are good.

### 4.6.B Interpretation of Pest infestation by microwave emissivity

Using equation 1 and 9, the relationship between pest occurrence and emissivity can be written as

\[ P = 654.6(e)^2 - 1162.3(e) + 520.312 \quad (11) \]

Using equation 11, pest infestation can be directly estimated by microwave emissivity.

The observed number of pest and estimated number of pest (using equation 8) with microwave emission has been shown in figure 4.14, where it is clearly indicated that the percentage of agreement between observed and estimated number of pest are good.

### 4.7 Conclusions:

Remote sensing techniques can be applied to the estimation of pest infestation. This study uses these techniques to make preliminary estimates of sunflower TC as well the occurrence of pest infestation. The following main findings have been obtained in this chapter;

- Sunflower has maximum TC in the middle age in our field (i.e., 55 days approximately).
• The maximum pest infestation occurs (P) at the time of maximum TC in the sunflower and an empirical relation has been obtained between P and TC with good value of coefficient of determination.

• It was found that P mainly depends upon TC and other plant parameter dependence is less significant for occurrence of pest infestation.

• A strong correlation has been obtained between sunflower TC and microwave scattering/emission at X-band.

• VV-polarization has shown the better results than HH-pol. for observing the TC at X-band.

• Higher incidence angle has been obtained as the best suitable incidence angle for observing sunflower TC.

• The empirical relation obtained in between TC and pest occurrence has shown remarkable results for assessment of pest occurrence.

The study strengthen the possibility of estimation of occurrence of pest infestation by microwave scattering/emission.
**TABLE 1**

LINEAR REGRESSION RESULTS OF PEST WITH SM, PH, TC, LAI, BIO

<table>
<thead>
<tr>
<th></th>
<th>SM</th>
<th>PH</th>
<th>TC</th>
<th>LAI</th>
<th>BIO</th>
</tr>
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<tr>
<td>$R^2$ (Coefficient of Determination)</td>
<td>0.194</td>
<td>0.193</td>
<td>0.791</td>
<td>0.026</td>
<td>0.030</td>
</tr>
<tr>
<td>$R$ (Correlation Coefficient)</td>
<td>0.440</td>
<td>0.439</td>
<td>0.890</td>
<td>0.162</td>
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<tr>
<td>SE = SQRT(VarR)</td>
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<td>0.269</td>
<td>0.070</td>
<td>0.325</td>
<td>0.323</td>
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**TABLE 2**

Linear regression results of Scattering Coefficient ($\sigma'$) with total chlorophyll (TC) of Sunflower for different angle of incidence (θ) at X-Band (9.5GHz).

<table>
<thead>
<tr>
<th>Angle</th>
<th>Slope</th>
<th>Intercept</th>
<th>$r$</th>
<th>$r^2$</th>
<th>SE</th>
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<td>20</td>
<td>-0.2499</td>
<td>-2.0610</td>
<td>0.3361</td>
<td>0.1129</td>
<td>0.2957</td>
<td>HH</td>
</tr>
<tr>
<td>30</td>
<td>-0.2539</td>
<td>-0.5143</td>
<td>0.4464</td>
<td>0.1993</td>
<td>0.2669</td>
<td>HH</td>
</tr>
<tr>
<td>40</td>
<td>-0.2472</td>
<td>1.6890</td>
<td>0.7893</td>
<td>0.6231</td>
<td>0.1256</td>
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</tr>
<tr>
<td>50</td>
<td>-0.3559</td>
<td>-0.8623</td>
<td>0.4242</td>
<td>0.1800</td>
<td>0.2733</td>
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<tr>
<td>60</td>
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<td>0.2828</td>
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<tr>
<td>70</td>
<td>-0.3133</td>
<td>-4.0760</td>
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<td>0.3062</td>
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</tr>
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<td>20</td>
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Linear regression results of Emissivity (e) with total chlorophyll (TC) of Sunflower for different angle of incidence (θ) at X-Band (9.5GHz).

<table>
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<tr>
<th>Angle</th>
<th>Slope</th>
<th>Intercept</th>
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<th>r²</th>
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Fig 4.1: Variation of plant height with age of crop

Fig 4.2: Variation of total chlorophyll with age of the plant
Fig 4.3: Variation of Leaf Area Index with age of crop

Fig 4.4: Variation of pest number with age of crop
Fig 4.5: Variation of pest number with Total chlorophyll
Fig 4.6: Temporal variation of scattering coefficient with age of sunflower for HH pol at 9.5 GHz for different incidence angles.

Fig 4.7: Temporal variation of scattering coefficient with age of sunflower for VV pol at 9.5 GHz for different incidence angles.
Fig 4.8: Temporal variation of emissivity with age of sunflower for HH pol at 9.5 GHz for different incidence angles.

Fig 4.9: Temporal variation of emissivity with age of sunflower for VV pol at 9.5 GHz for different incidence angles.
Fig 4.10: Variation of scattering coefficient with total chlorophyll (TC) of sunflower for both like polarizations.

Fig 4.11: Observed vs. calculated total chlorophyll with Scattering Coefficient.
Fig 4.12: Variation of emissivity with total chlorophyll (TC) of sunflower for both like polarizations

Fig 4.13: Observed vs. calculated total chlorophyll with emissivity
Fig 4.14: Observed vs. calculated pest number with TC calculated using scattering coefficient

Fig 4.15: Observed vs. calculated pest number with TC calculated using emissivity