The Monsoon and Its Variability
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Lecture - 36
Monsoon Variability and Agriculture-Part 2

Today, I am going to continue to talk about monsoon variability and agriculture as I mentioned last time a very, very important topic and we were talking about a study region, which is a semi-arid region, semi-arid part of the Indian peninsula over which groundnut is now grown extensively and we said this was not always sow, the traditional cropping pattern was very complex.

Now, how did the transition occur from the traditional to the current cropping pattern, which compresses primarily groundnut and a little bit of other crops as well. Now, the traditional crops largely provided food grains for local consumption. That is what agriculture was for in the olden days. The development programs of the government of India undertook after freedom from colonial rule such as road construction and electrification, led to the spread of a market economy in this region.

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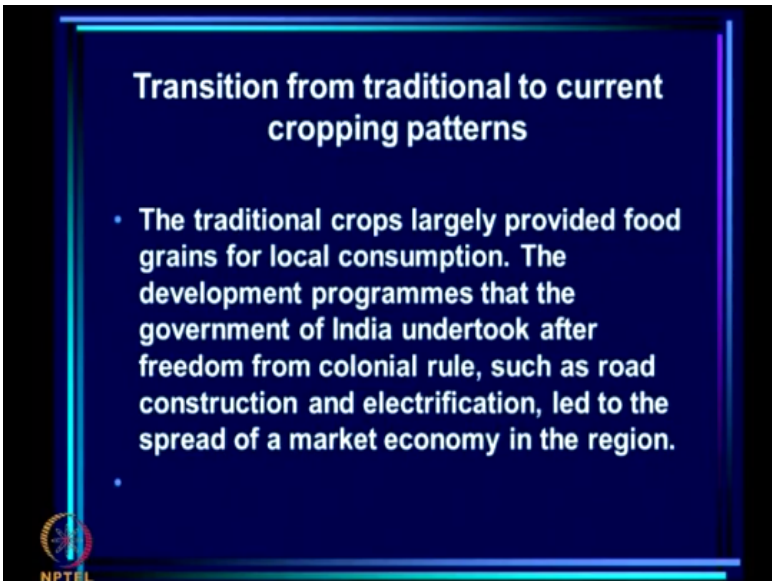

At the same time, food grains became available at rates subsidized by the government, this is in ration shops and hence the need for cultivation of food crops for home consumption decreased. Now, with the setting up of oil mills, the price for groundnut increased and it

became profitable for the farmers to change over a groundnut based cropping system and this is what they did.

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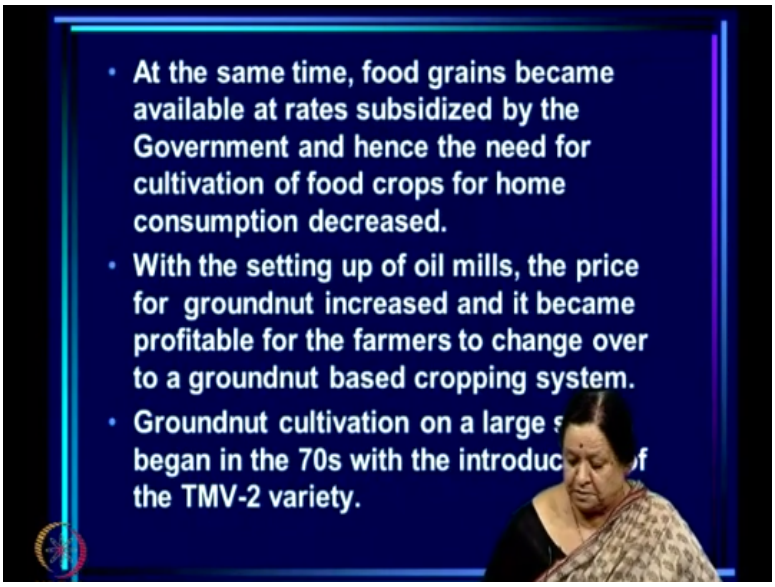

So, groundnut cultivation on a large scale began in this region in the 70s with the introduction of TMV-2 variety, which is grown even today in that region. Now, I mentioned last time that is it is extremely important to progress in this area to have an interdisciplinary group of which a farmer is a very, very important member. So, farmers, agricultural scientist, and meteorologist were the 3 kinds of people who had to participate in this interdisciplinary interaction.

Now, first of all let us consider, what the perceptions of the farmers are? Now, many people have a doubt, how much do the farmers know? In fact, in order to understand the level of knowledge and approach of the farmers, it is important to note that rainfed agriculture has been practiced for a very long time in India. The strong links between climate variability and agricultural production of the Indian region are very well known.

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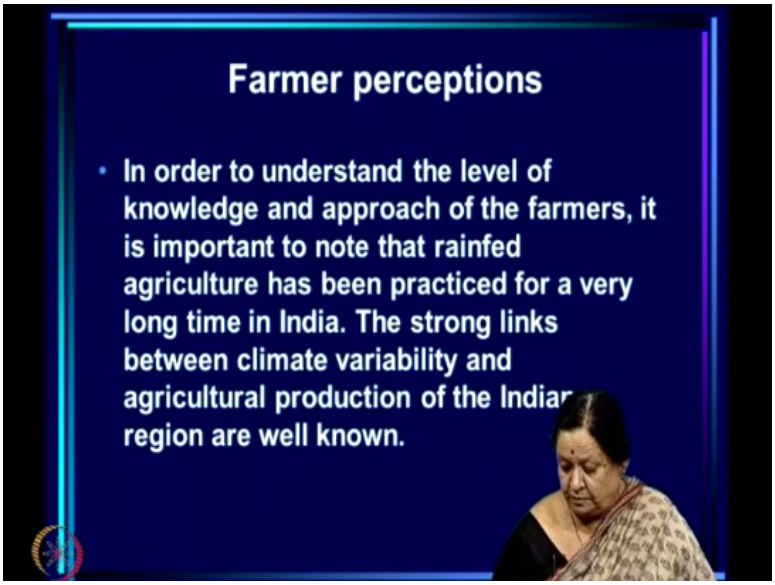

In fact, over 2000 years ago, Kautilya, you know who wrote Kautilya's Arthashastra, who is believed to be a contemporary of Aristotle stated that for agriculture and he was referring primarily to the Indo-Gangetic plains, the optimum distribution of rainfall during the summer monsoon that is June to September is 1 with 1/3 of the rainfall in the first and fourth month and 2/3 in the middle 2 months.

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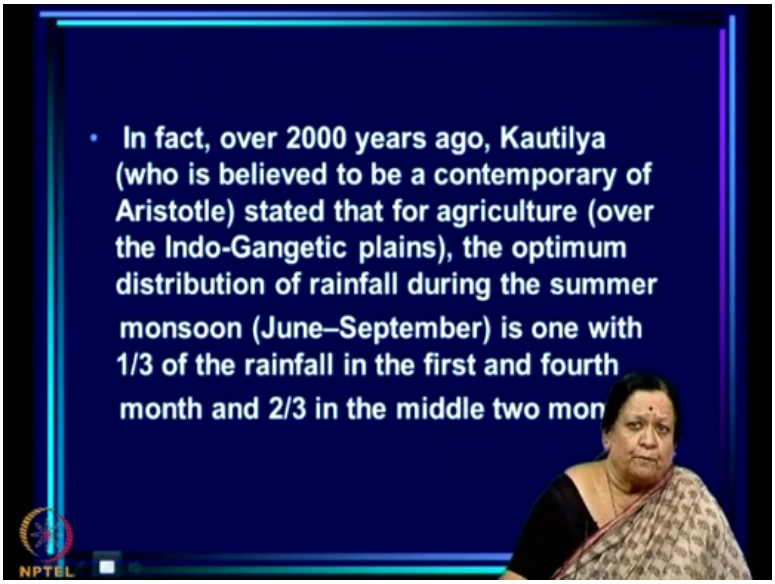

This was Kautilya's perception of what is the optimum, "what is happening? It is going back instead of front, sorry, okay." Some of the crops grown today such as sorghum and pigeonpea have been cultivated in India for over 2000 years. Even relatively recently introduced groundnut crop has been cultivated for more than 100 years. Not surprisingly, farmers have considerable knowledge of the nature of the impact of the rainfall variability in their region on traditional crops.

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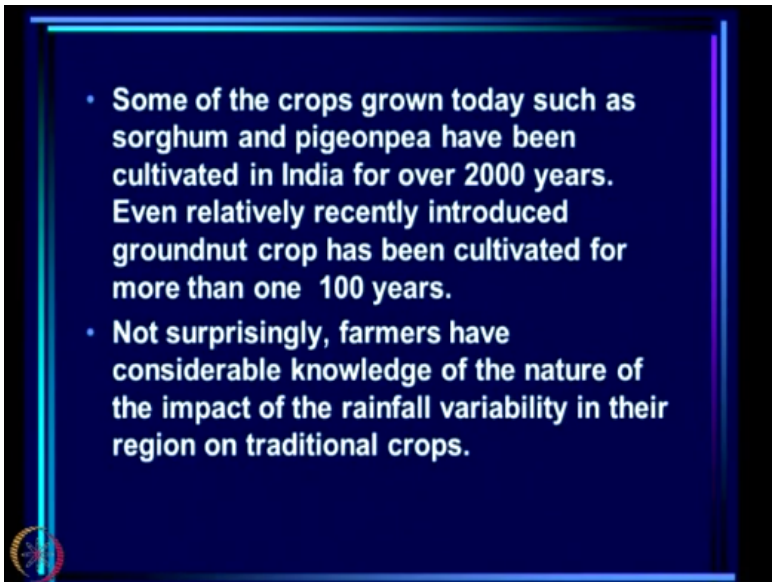

This knowledge is reflected in several proverbs such as the following from our study region: Uttara chusi, yattara gampa. Wait for the Uttara rain that is the rainfall during 13 to 26 September, if it fails, leave the place. So, if the Uttara rain on 13 to 26 September period rain fails, then it is much better to simply leave the place and not worry about the groundnut in the field or the following from the Indo-Gangetic plains, where Kautilya resided:

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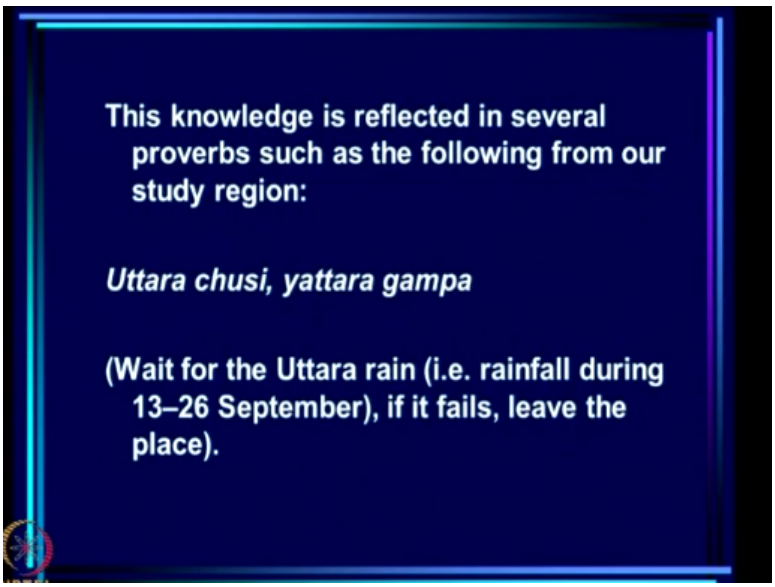

Awat adar nahi diyo, Jat no diyo hasta Bina Khane dona gaye Pahuna aur Grihasta. So, during the coming monsoon, if there is no rain in one of the nakshatra's and while going during hasta, there is no rain, then both the host and guest will have to go without food. See, Ardra is the 22nd June to 5th July, so this is when the onset occurs, onset of the monsoon occurs over the Indo-Gangetic plain.

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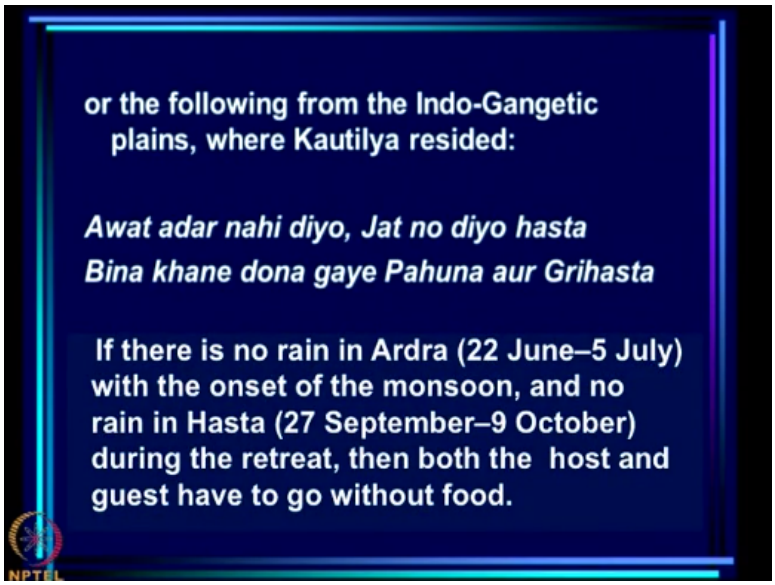

So, he is saying that if there is no rain during the onset phase that is 22nd June to 5th July and no rain in the phase when it retreats from this region, 27 September to 9th October, then both the host and guest will have to go without food, in other words, the crops will fail. So, these people had considerable knowledge of the impact of the variation of rainfall on the crops and in particular which were the sensitive periods in which rain is very important and without rain you would get crop failure.

Now, noticed that the time units used by the farmers Ardra, Punarvasu or Uttara and so on, all over India are not weeks or months, but 13 to 14 day periods called nakshatras based on the solar calendar. It is very important to remember that what they used are nakshatras based on the solar calendar, which I show here and it begins with of course beginning of the year is Ashwini 13th April to 26th April, it goes on to Bharani, Krittika, Rohini and so on.

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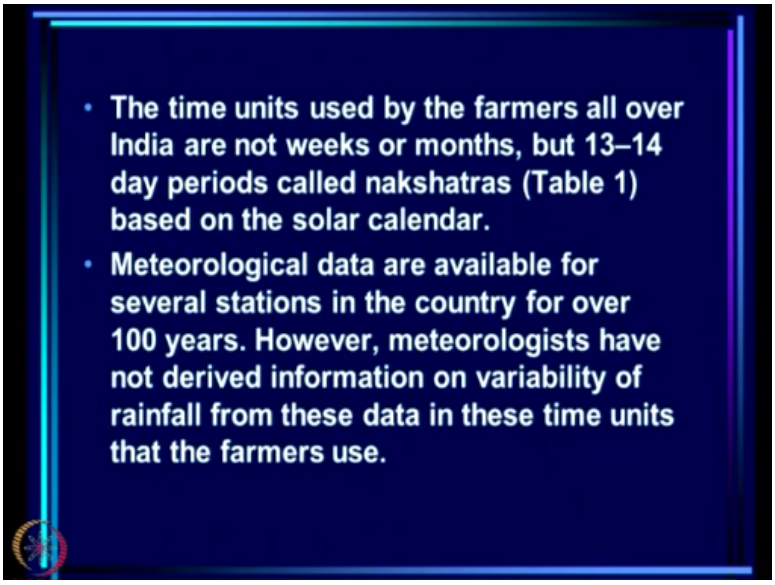

Then, we come to Punarvasu, which is 6th July to 19th July, which is the time after which people start sowing in our region. In fact, they start sowing during Punarvasu itself in ground. So, Punarvasu, Pushya and so on and so far and you heard the name Uttara I mentioned, Uttara is 13th to 26th September and Hasta is 27th September to 9th October. So, knowledge of the impact of variability of rain during associated with these nakshatra.

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Table 1
Time units (*nakshatras*) that Indian farmers use for planning

Nakshatra	Period*	*Nakshatra**	Period*
Ashwini	13 April–26 April	*Swathi*	24 October–5 November
Bharani	27 April–10 May	*Vishakha*	6 November–18 November
Krittika	11 May–24 May	*Anuradha*	19 November–2 December
Rohini	25 May–7 June	*Jyeshtha*	3 December–15 December
Mrigashira	8 June–21 June	*Moola*	16 December–28 December
Ardra	22 June–5 July	*Purvashadha*	29 December–10 January
Punarvasu	6 July–19 July	*Uttarashadha*	11 January–23 January
Pushya	20 July–2 August	*Sravana*	24 January–5 February
Aslesha	3 August–16 August	*Dhanishtha*	6 February–18 February
Makha	17 August–30 August	*Shatabhisha*	19 February–3 March
Pubbha	31 August–12 September	*Poorvabhadra*	4 March–17 March
Uttara	13 September–26 Sep	*Uttarabhadra*	18 March–30 March
Hasta	27 September–9 October	*Revati*	31 March–12 April
Chitta	10 October–23 October		

*After India Meteorological Department 1999.

During these periods, the impact on crops is very well known and in fact, the proverbs that you looked at just now or a result of this knowledge or a reflection of this knowledge. So, now meteorological data are available for several stations in the country for over 100 years. But, equivalent to a (()) (07:26), meteorologists have not derived information on variability of rainfall from this data in these time units that the farmers use.

Now, I just want to emphasize one more point, because the work nakshatra in India is used also for lunar nakshatras and these are the nakshatras the people refer to as the star under which one is born and so on and horoscopes involve these nakshatras, but what the farmers use are solar nakshatras. So, they are by and large fix by calendar date with a day or 2, this way or that way and not much more.

So, they are really equivalent to using the biweekly or 2 week periods instead of weekly or monthly rainfall, for which we generally make climatological averages. So, it is not at all difficult given the data that we have to make average rainfall or decide on what is the likelihood of a certain spell in the nakshatra and so on for each nakshatra. But, these had not been done earlier.

Now, I want to talk a little bit about impact of rainfall variability on the present cropping system. So, although farmers have considerable knowledge of the impact of the local climate and its variability on traditional crops, they have not cultivated the present cropping pattern sufficiently long to provide these insights for the newer crops. So, for the crops that they are cultivating, they do not have as many insights as they had for the traditional crops.

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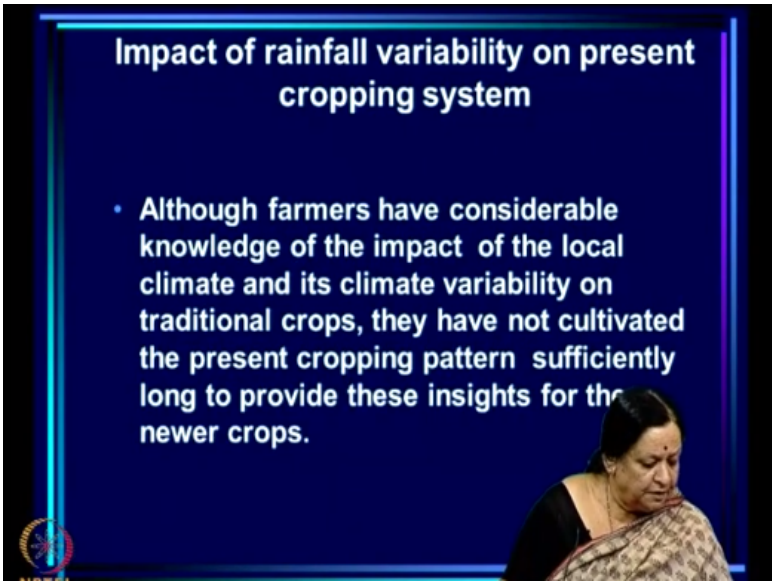

In fact, our collaboration on monsoon variability and agriculture began when one day in early October, Seshagiri Rao, who was a student in the Center of Ecological Sciences at our Institute, who is also a farmer in the Pavagada/Anantapur region, asked me why it rains so often during the harvest season nowadays? This was his question. Why is it nowadays it is raining so often during the harvest season of groundnut?

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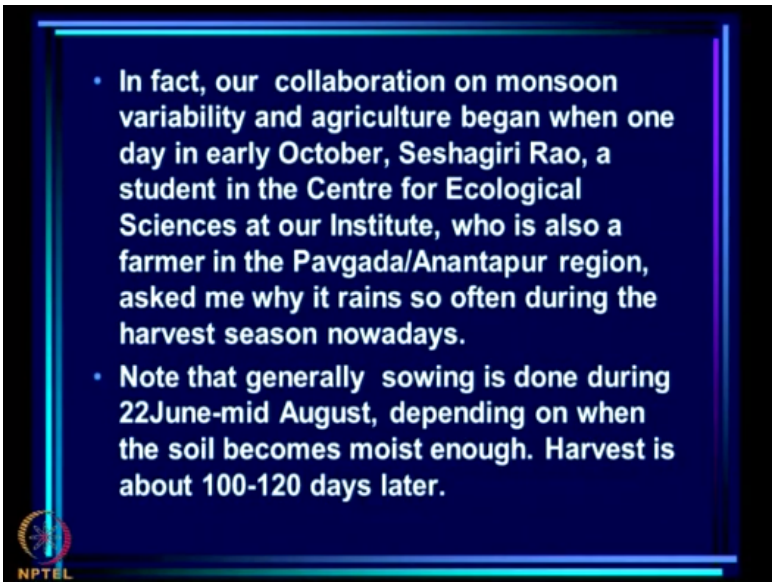

Now, just to tell you when the harvest season generally occurs, generally sowing is done during 22nd June to mid-August, depending on when the soil becomes moist enough. Now, harvest is about 100 to 120 days later. This implies that if the sowing is done early in the sowing window that is to around 22nd June, harvest has to be done in early October, counting 110 days, okay. Whereas, if it done in early August then the harvest is in mid-November.

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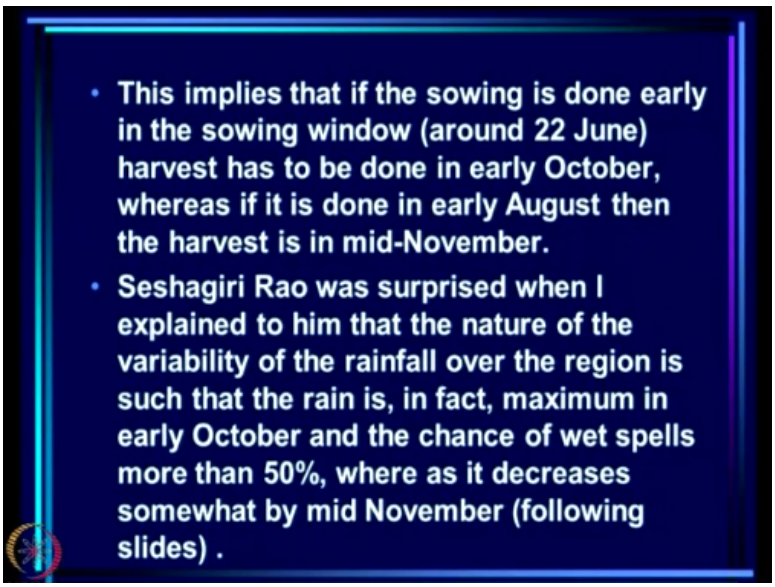

Now, Seshagiri Rao was very surprised when I told him that the nature of the variability of the rainfall over the region is such that the rain is, in fact, maximum in early October, which is when harvest time would come, if one had sown very early that is around 22nd June. So, the rain, in fact, is maximum in early October and the chance of wet spells more than 50%, whereas it decreases somewhat by mid-November.

And in fact, in the next few slides, I will tell you what we can derive from data for daily rainfall at Anantapur for about 90 years, okay. For first of all, we have to note that the rainfall does vary a great deal from year-to year, so it is important to look at daily rainfall and what you see is just a rainfall within the rainy season for 3 years and you can see how different it is. This is the year in which it is reasonably well distributed with one dry spell here.

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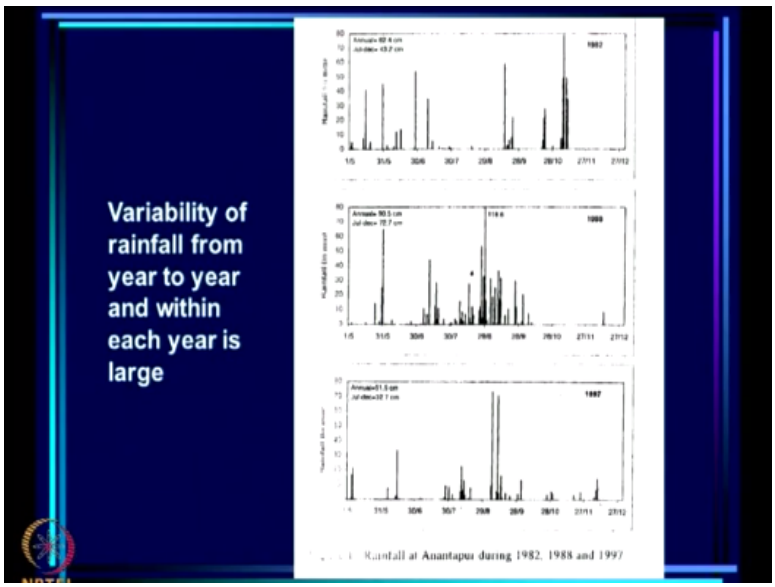

Then, in this year most of the rain came here and very early withdrawal if you like or cessation of rains. Whereas, here there is only one genuine wet spell and small, small wet spells several of them occurred throughout the year, this is 1997, 1988, and 1982. So, the total rainfall also varies from year-to year, but within the season also, we get considerable variation between dry spells which can be long, like this one or this one and wet spells.

So, there is considerable variability of rainfall from year-to year in this region, but one can still see talk of the averages and this is actually the weekly rainfall. Now, what you see here this is the mean rainfall. Mean rainfall, weekly rainfall at Anantapur and what you find is that in fact the maximum is occurring in late September and early October, this is the maximum rainfall after which it decreases.

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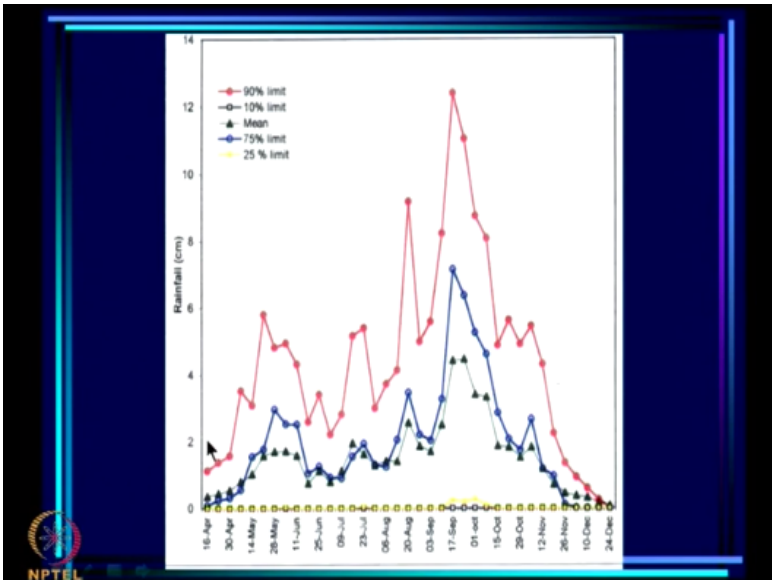

There is a small peak towards the end of May and early June, but the major peak is this one and this is the 90% limit; in other words, that 5% of the years have rainfall more than this and 5% of the years have rainfall less than this. So, this is that have rainfall less than this, this is the 10% limit. So, 80% actually of the years have rainfall between these 2 ranges the red line and the blue line and the blue line is the 75% and 25% is generally just 0.

So, quarter of the years will have 0 rainfall irrespective of the nakshatra. This is 75% and this is 90% of the mean, okay. Now, what is the weekly rainfall? Probability of wet spells, again the same thing at Anantapur, this is the probability of wet spells > 1 cm, this is wet spell greater 2 cm in that week. So, weekly rainfall > 1 cm this is the probability and this is the probability for 2 and you can see again, end of September, early October, you get highest probability of wet spells and correspondingly, lowest probability of dry spells.

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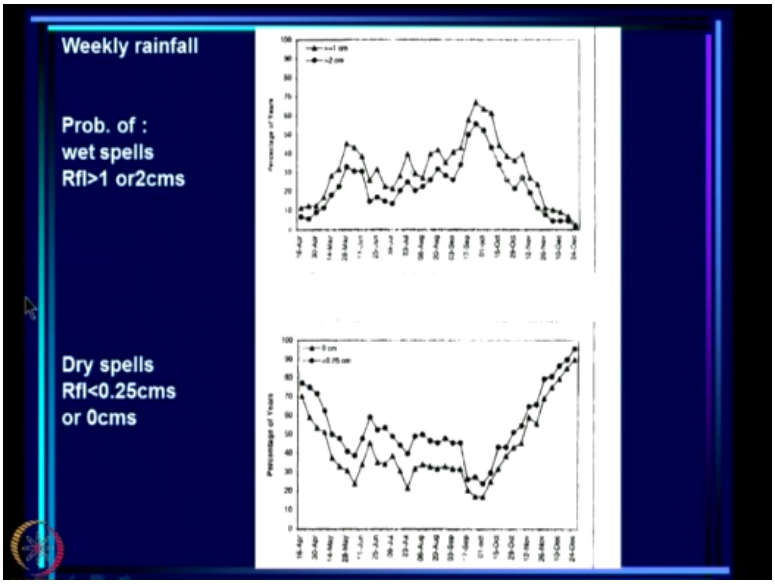

These are dry spells with rainfall < 0.25 or 0 range. This is actually probability of 0 range and this is probability of 0.25 range. So, you that this period about which Seshagiri Rao was complaining is the period with highest chance of wet spells and lowest chance of dry spells and this we derived, because we have data for so many years for Anantapur, so the farmers were not aware of this important facet of the climatology of rainfall over the region.

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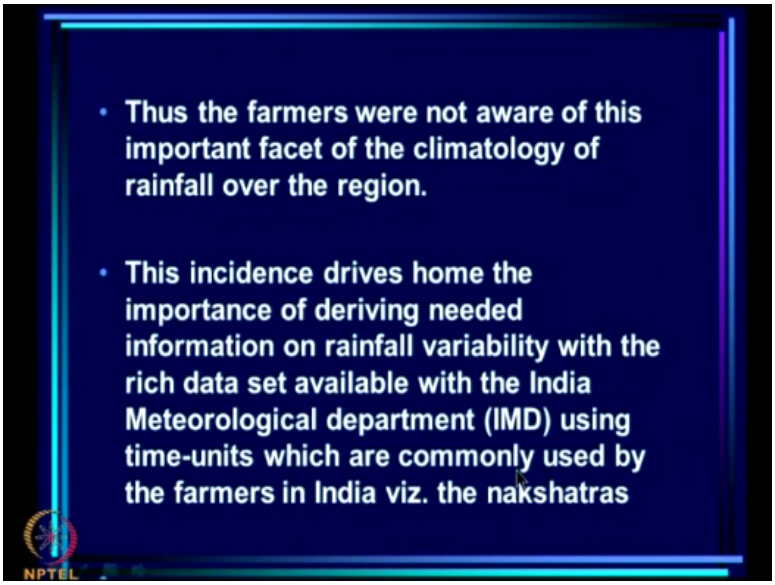

When we say climatology, we mean average behavior. So, this is the very important facet of the average rainfall for the region. Let it is at peak in late September and early October and the farmers were not aware of it, this is why Seshagiri Rao, asked me that question. Now, these incidents drive home the importance of deriving needed information on rainfall variability with the rich data set already available at India Met Department using time-units which are commonly used by the farmers in India namely nakshatras.

See, this climatology is derived for monthly and weekly rainfall on a regular basis, but this drives on the point that since farmers used nakshatras as time unit. It would be a good idea to generate information on rainfall variability with these time units. So, we have actually done this. So, RAINFO-for farmers, we have used daily rainfall data for 100 years at 170 stations. These are all taluk headquarters in the state, derived basic information on rainfall variability.

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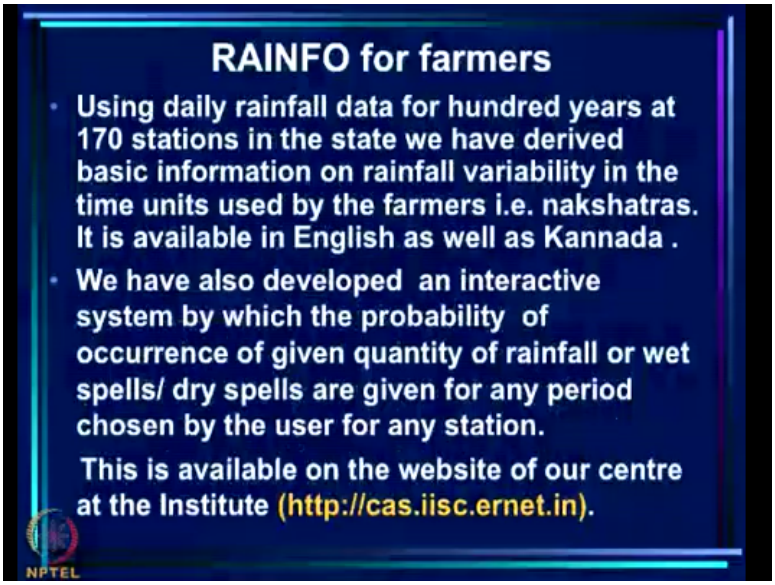

In the time units, used by the farmers that is nakshatras and this information is available both in English as well as in the local language Kannada. We have also developed an interactive system by which the probability of occurrence of given quantity of rainfall or wet spells or dry spells are given for any period chosen by the user for any station. This is available on the website of our center at the institute.

This is the rainfall variability at Pavgada now from May to November. Pavgada is very close to Anantapur and this is where the form of Seshagiri Rao and this gives the mean rainfall for each nakshatra for Pavgada and 2 neighboring stations, 3 neighboring stations in fact and what you see is, what you saw earlier that there is a peak in Uttara nakshatra that is why the proverb said that if it does not rain in Uttara, time has come to pick up your basket and leave.

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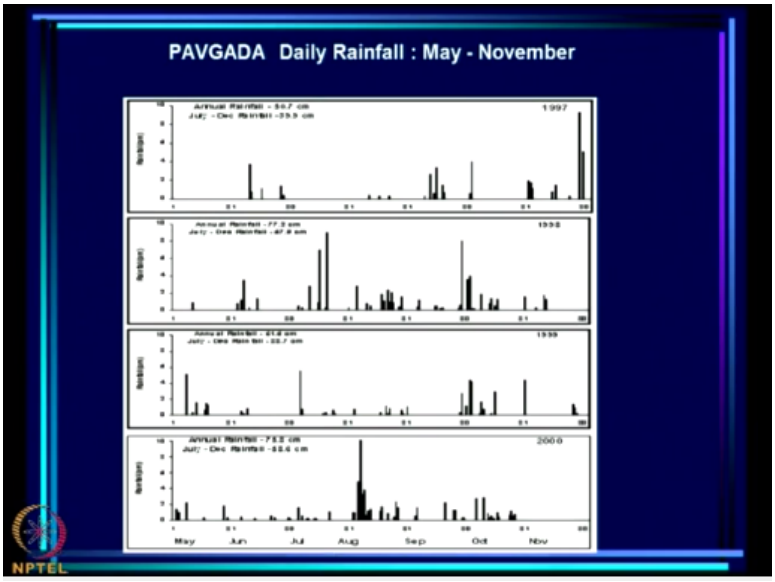

Because, the mean rainfall in Uttara is very high and continues to be high in Hasta as well. So, this is the nature of the mean rainfall, but what is needed is not just the mean, but probability of various events and this for Pavgada is the probability of rain of different quantum of rainfall in centimeters here. During a specific nakshatra, Punarvasu which is 6 to 19 July and what you see is that probability of absolutely no rain is very small.

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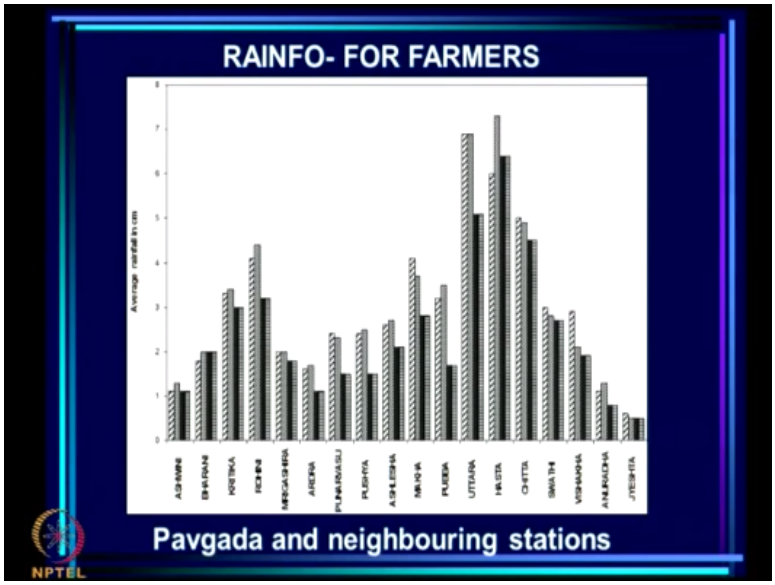

But, probability of very little rain is very high in Punarvasu and then, there is a long tail which smaller and smaller chance, much smaller than 10% chance of some rain, say 3 cm, 5 cm, 6 cm, and so on so forth during this 14-day period. On the other hand, you see Uttara, which is the one where you have assured rainfall, you see that the probability of 0 rain is actually < 10%. It tends to rain quite a bit up to about 10 cm during these nakshatra.

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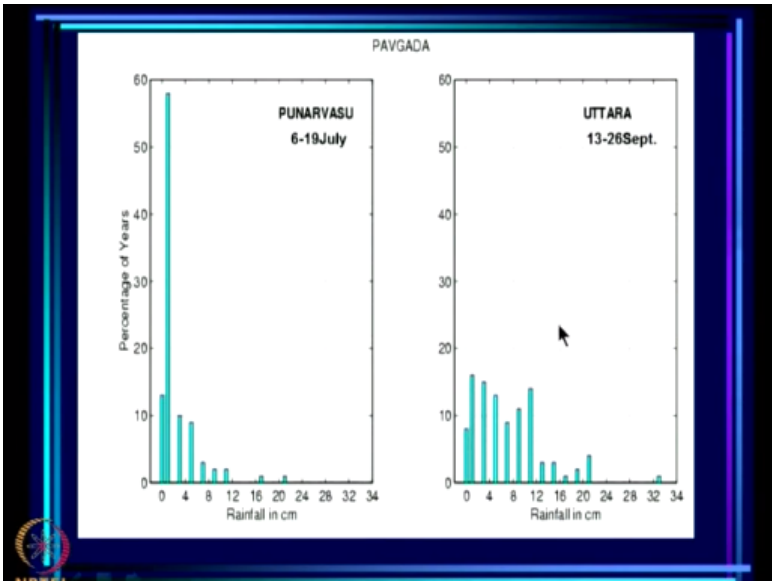

After that the probability somewhat lower for rainfall higher than 10 cm. So, information like this has been generated for every nakshatra for every station. You can also ask the question, what are the probabilities of seasonal rainfall in different ranges? So far, Pavgada for example, we have seasonal rainfall between 31 and 40 cm, 50% of the years have that. Between 41 and 50, 26% have that. 51 and 60, 16.7, and 61 and 70, 8.3, okay.

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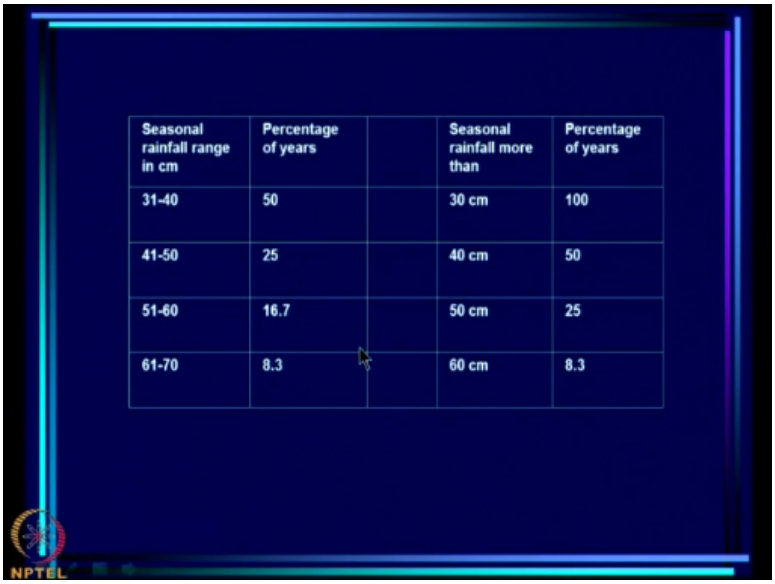

Seasonal rainfall range in cm	Percentage of years		Seasonal rainfall more than	Percentage of years
31-40	50		30 cm	100
41-50	25		40 cm	50
51-60	16.7		50 cm	25
61-70	8.3		60 cm	8.3

Now, we can also ask the question for some of the strategies we may need to know, what is the chance of rainfall more than 30 cm? 100%, because all the years in the recorded history, have had rainfall more than 30 cm. What is the chance of rainfall more than 40 cm? We are now talking of total seasonal rainfall, well it is 50%, 50% of the years have rainfall < 40. Rainfall more than 50 cm likely only in 25% of the year and rainfall more than 60 cm is very, very small. It is only 8%.

So, when one has to plan various strategies, this variability has to be taken into account. Now, as I mentioned before there are wet spells and dry spells and these have major impacts on the growth of the plant as well as on pests and diseases, because they can trigger pests and diseases in the area. So, what we have done also is to calculate the probabilities of say 3 to 4 days of wet spell once or twice, okay.

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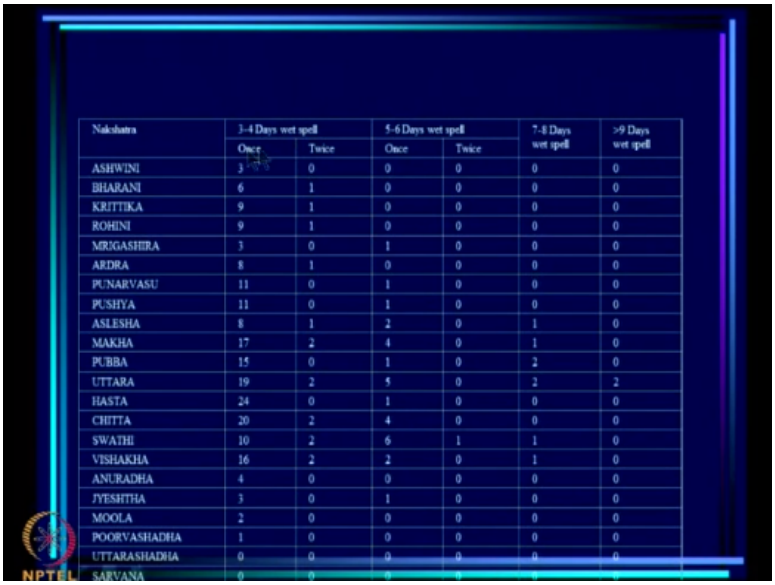

Nakshatra	3-4 Days wet spell		5-6 Days wet spell		7-8 Days wet spell	>9 Days wet spell
	Once	Twice	Once	Twice		
ASHWINI	3	0	0	0	0	0
BHARANI	6	1	0	0	0	0
KRITTIKA	9	1	0	0	0	0
ROHINI	9	1	0	0	0	0
MRIGASHIRA	3	0	1	0	0	0
ARDRA	8	1	0	0	0	0
PUNARVASU	11	0	1	0	0	0
PUSHYA	11	0	1	0	0	0
ASLESHA	8	1	2	0	1	0
MAKHA	17	2	4	0	1	0
PUBBA	15	0	1	0	2	0
UTTARA	19	2	5	0	2	2
HASTA	24	0	1	0	0	0
CHITTA	20	2	4	0	0	0
SWATHI	10	2	6	1	1	0
VISHAKHA	16	2	2	0	1	0
ANURADHA	4	0	0	0	0	0
JYESHTHA	3	0	1	0	0	0
MOOLA	2	0	0	0	0	0
POORVASHADHA	1	0	0	0	0	0
UTTARASHADHA	0	0	0	0	0	0
SARVANA	0	0	0	0	0	0

5 to 6 days wet spell once twice, 7 to 8 days wet spell and then 9 days wet spell, larger than 9 days wet spell, which is actually never occurs, 7 to 8 days does occur during some of the nakshatras, this is Ashlesha, Makha, Pubba and Uttara. (()) (19:41) Uttara, the chance is very high, altogether 3 to 4 days spell also is maximum in Uttara, chance is 19, then such spells occurring twice, chance is 2 and 5 to 6 days, once chance is 5 and 7 to 8 days, 2 and more than 9 days 2 and so on.

So, all these things have been calculated, so that we can know the climatology. Similarly, for dry spells also and for dry spells, you can see that again chances of 3 to 4 days of dry spells, also very large in Uttara, Hasta, Chitta and so on and then there are of course, longer dry spells possible, which come before the peak and after the peak here. So, this kind of information is available.

So, this kind of information that we have about you know how much it is likely to rain during the total season. How many dry spells you are likely to get it within the nakshatra and so on, can be used by intelligent farmers in different types of decision making even on the basis of

the experience of 2 to 3 decades in cultivation. So, I consider now so this is as far as giving information or making information on rainfall variability available to farmer.

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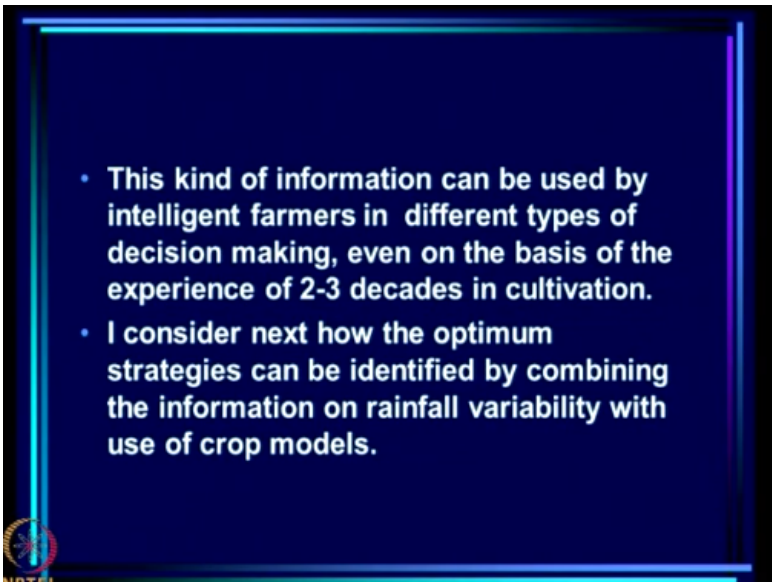

So that, given the knowledge crop they are cultivating, they can make some informed decisions about various farming strategies. Now, we will consider how the optimum strategies can be identified by combining these kind of detailed information on rainfall variability with the use of crop models and this as I said is a very powerful tool we have now in our hand, which has been validated over several regions for several crops.

So, strategies for enhancement of yields in the face of variable climate, this is what we are looking for. Now, most of the farm-level decisions such as enhancement of the seed rate that is how many seeds you plant, how many seeds you sow per acre or per unit area or application of fertilizers or pesticides involve additional costs. Now, it is important to remember that in rainfed region such as this, there are high levels of risk and low levels of production and the resources available for such inputs are very meagre.

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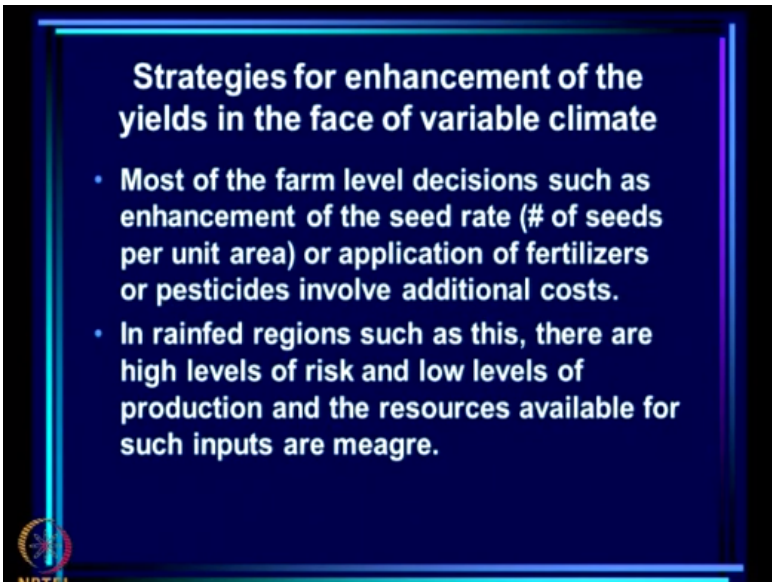

We have already seen how the yield fluctuates from year-to year and so, the profit margins are low even when there is no loss and there are years in which there is crop failure as well. So, resources available to the farmers are not large and therefore, farmers tend to avoid investments in such things. This is also because the benefit of such investment itself depends on the rainfall.

For example, if the rainfall is very poor, no matter how much fertilizer you have added, you will not get enhancement of yields.

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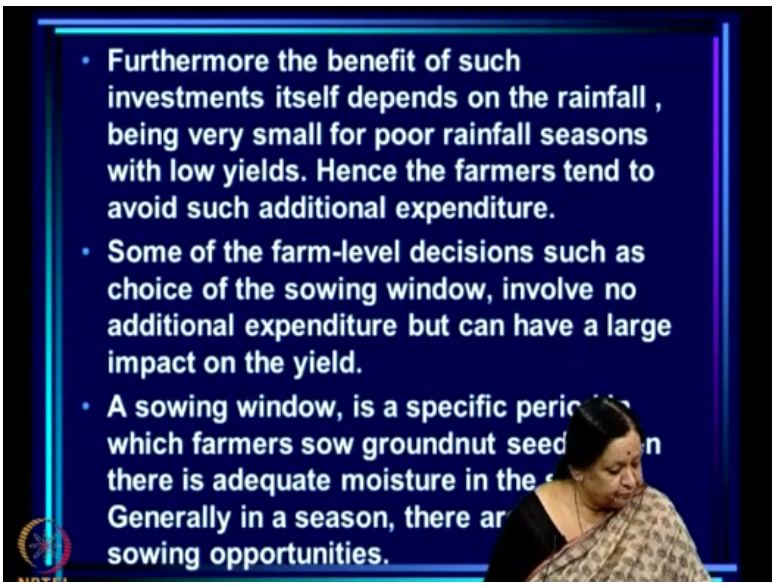

The yield will be low because the rainfall is very low. So, the farmers are not quite sure of how much enhanced yield they would get by addition of fertilizers in this situation when rainfall varies from 1 year to the (()) (23:10) they do not know which a poor monsoon year is

going to be. So, the farmers tend to avoid such additional expenditure, but there are some farm-level decisions such as choice of the sowing window, which involve no additional expenditure but can have a very large impact on the yield.

This has been documented and in fact you may ask the question, what is the sowing window? So, sowing window is a specific period, in which farmers sow groundnut seeds when there is adequate moisture in the soil. So, when there is an opportunity to sow that is to say when the soil is moist enough and the date is within the accepted sowing window such and such of date in June to such and such date in August for example, then that is called a sowing window, okay.

Now, in the package of recommendations developed by agricultural scientists sowing in May-June is recommended, okay. For this groundnut, it is suggested that in the absence of sowing opportunities in May and June, which means if it did not rain enough in May or June, so that the soil was never moist enough for sowing to be done, then they say it's all right, then you can do sowing in July, if it rains adequate in July, so that the soil moisture is adequate.

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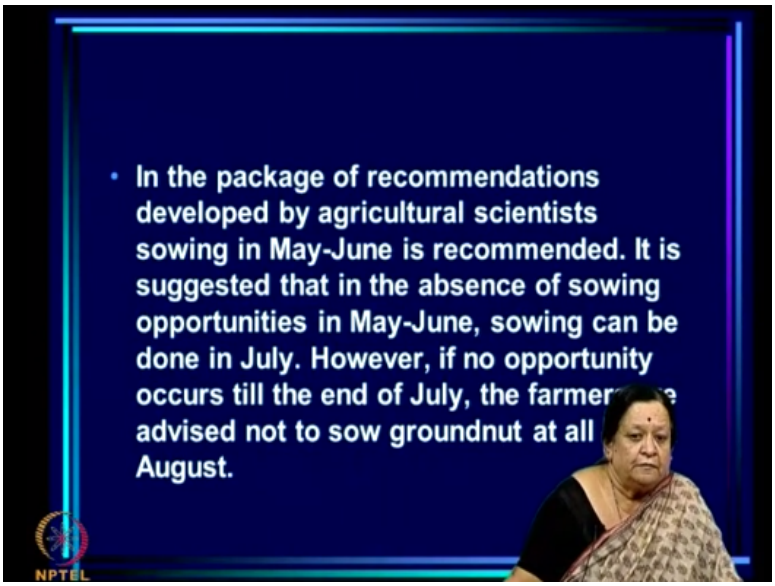

However, if no opportunity occurs till the end of July, then the farmers are advised not to sow groundnut at all in August. In fact, they recommend that some other crops should then be sown. However, on the basis of experience of about 2 decades, farmers do not sow until late June. So, although the recommendation is that you can sow in May if the soil moisture is adequate, they never do that.

They do not sow until late June and do so in August if no opportunity occurred earlier, despite the recommendation to the contrary. Remember, the recommendation is that if you do not get a sowing opportunity till the end of July, then please do not sow groundnut in August that is the recommendation.

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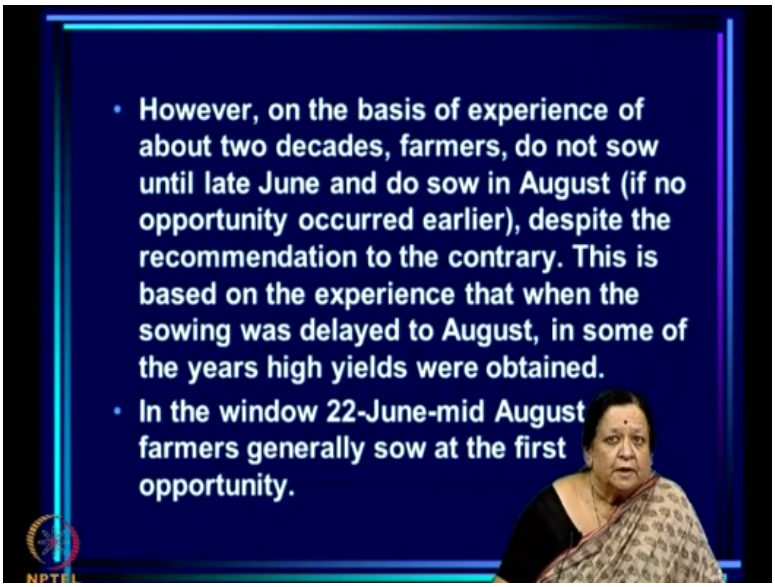

But, farmers anyway sow in August, despite the recommendation to this contrary, because they have experience that in some years when the sowing was delayed to August, they got very good yields, not all years, but in some of the years in which the sowing was delayed to August, the farmers got very good yield, so they do not believe that the recommendation is right. So, the window now they have adopted there is from 22nd June to mid-August.

And in this window, farmers generally sow at the first opportunity that is to say if the date is within the sowing window and the soil is moist enough, they will sow at the earliest opportunity. Now, this is the situation, so what is the problem posed by the farmers, given the background of the recommendations, which the farmers did not believe because they were inconsistent with the experience they had.

When we call for a meeting of the farmers, I will ask them, what are the problems that you would like us to address in trying to see how best to enhance yields of groundnut in the phase of rainfall variability. So, in that meeting the farmers suggested that one of the most important problems is identification of the optimum sowing window and what did they mean by optimum that which is associated with maximum production in the phase of rainfall variability of the region.

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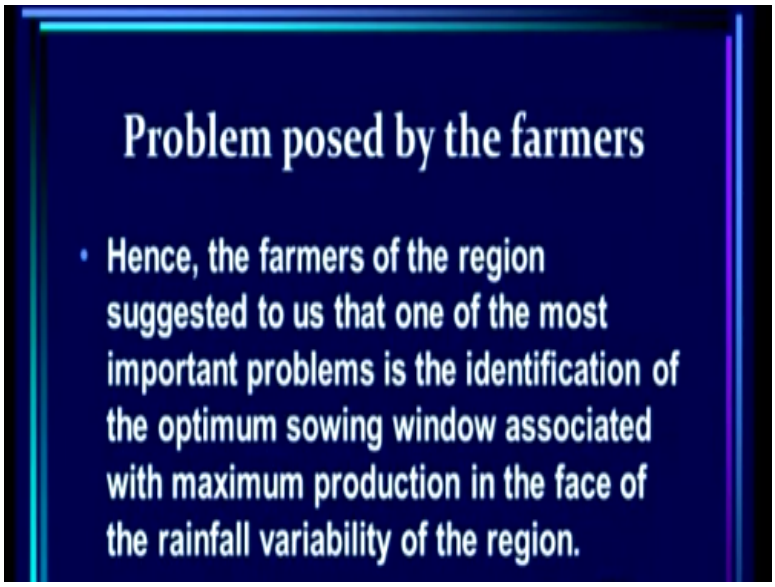

There is another way to look at the optimum as well, one can also look at the optimum sowing window as that which avoids crop failure altogether. So, minimum chance of crop failure or maximum chance of high production would be another set of goals that one could pose. Now, we of course used the modern tool to try and figure out what would be the optimum sowing day and the model we used was the PNUTGRO model.

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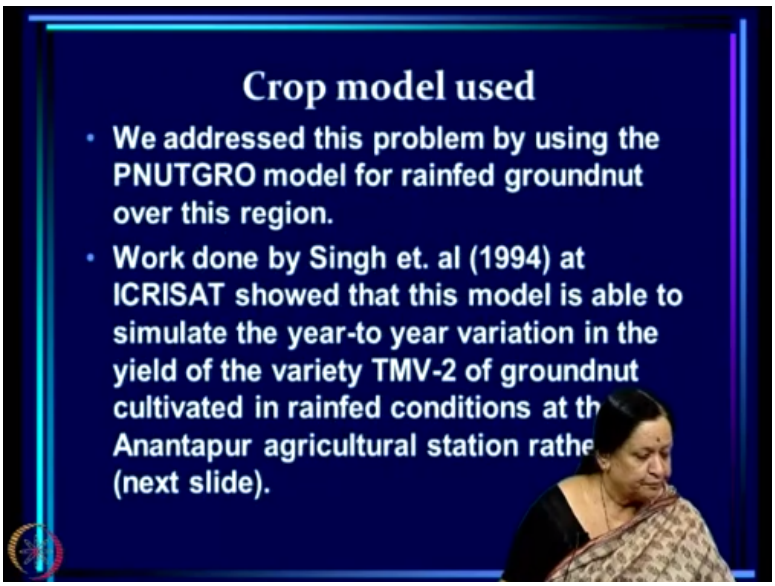

See, we were very fortunate that there was a group at ICRISAT led by Dr. Piara Singh, who had actually worked on this PNUTGRO model with the people who developed this model in US boot and others and who later on in collaboration with scientist at the Anantapur agricultural research station compared the simulated yields from PNUTGRO with the

observed yields at the Anantapur research station and actually showed that the model did very well.

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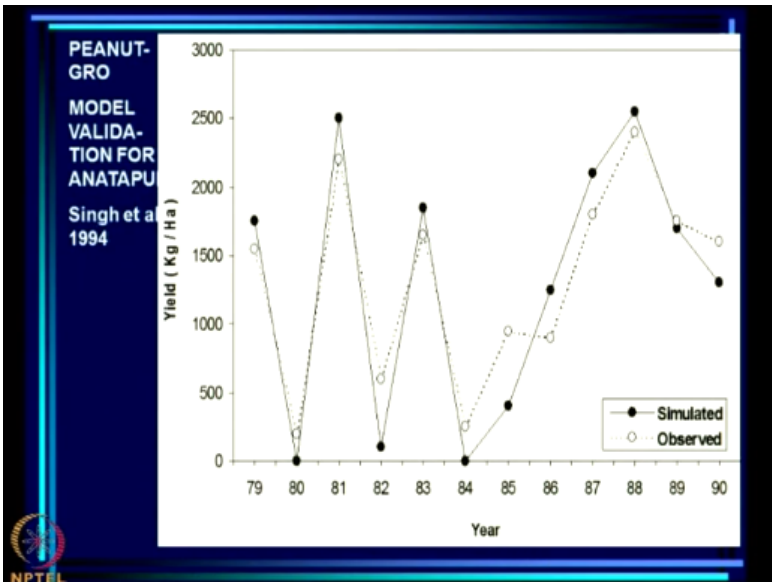

What you see here is simulated and observed yields from 1979 to 1990 and you see that the model is able to actually capture the impact of rainfall variability on crop yields from year-to year. I must of course emphasize that this model is indeed for rainfed crops. It is not for irrigated crops and this result of Piara Singh and others which were published in 1994 showed very clearly that in fact the model is able to capture the variation induced by the rainfall variation on the yields of groundnut at Anantapur.

So, this was a very big asset that we had a model that was already validated for the crop variety and for the region of interest. So, this was the big asset and "ya," so work done by Singh et. al at ICRISAT showed that this model is able to simulate year-to year variation in the yield of the variety TMV-2 of groundnut cultivated in rainfed conditions at the Anantapur agricultural research station.

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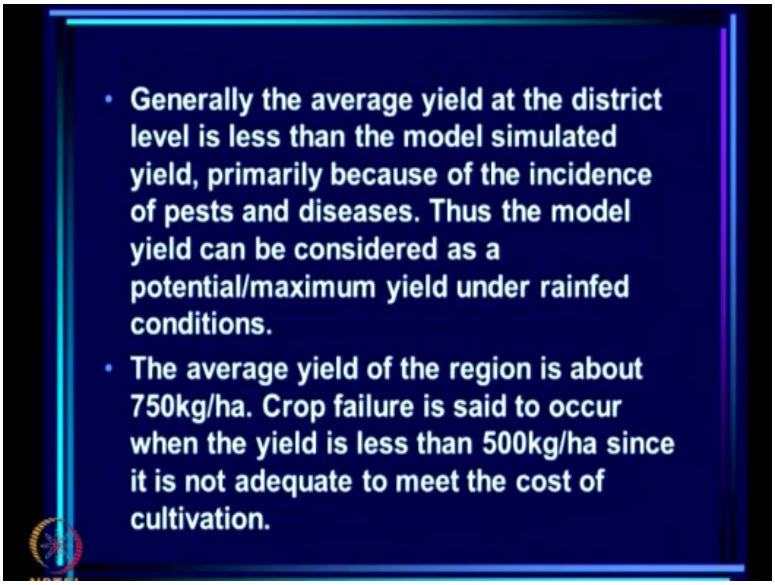

Now, generally the average yield at the district level is less than the model simulated yield, primarily because of the incidence of pests and diseases. Because, in real life, there are pests and diseases that are incident and the model does not have any impact of pests and diseases in it. It is only a model in which the plant grows, it experiences a moisture stress due to you know dry spells and so on, but there are no impacts of pests and diseases incorporated into the model.

So, the model yield can be considered as a potential or maximum yield under rainfed conditions. This is the best you could do in some sense in rainfed conditions, if you could somehow curb the pest disease incident. Now, the average yield for the region is about 750 kg per hectare and crop failure is said to occur when the yield is < 500 kg per hectare since at that yield level, it is not adequate to meet the cost of cultivation.

So, when the money you get by selling the groundnut is less than the cost of cultivation, it is a failure, it considered to be a crop failure. So, what we do is we consider a model yield of course < 500 kg per hectare as a crop failure because if the model yield is < 500, the farmers yield is bound to be < 500, so this is a crop failure.

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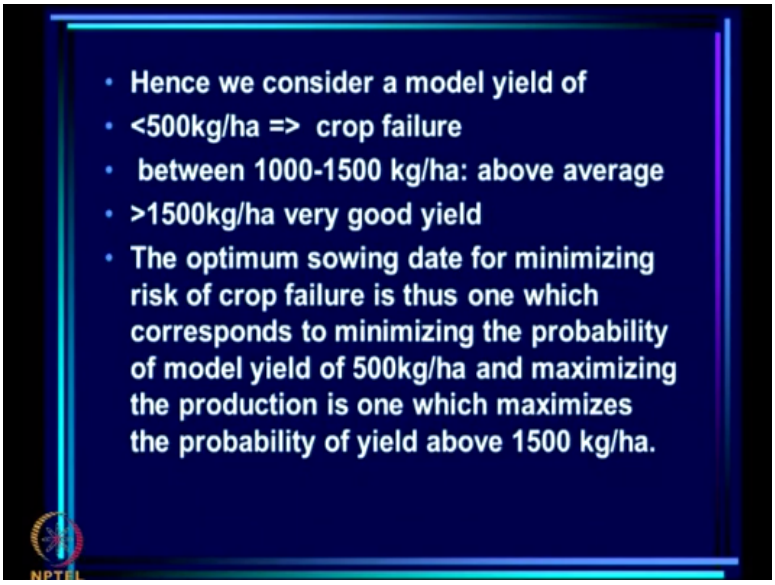

Then, we consider between 1000 to 1500 kg per hectare as above average and > 1500 kg per hectare as very good yield, so these are the 3 criteria we used. Now, what is our problem then the optimum sowing date for minimizing risk of crop failure is thus one which corresponds to minimizing the probability of model yield of 500 kg per hectare or less and maximizing the production which maximizes the probability of yield above 1500 kg per hectare.

Now, sensitivity to different meteorological inputs. Now, we got this model PNUTGRO model from ICRISAT from Dr. Piara Singh. Now, it required various meteorological inputs, okay. For example, it required daily values of maximum and minimum temperature, radiation and rainfall. Now, all these data were available at the Anantapur agricultural station for 1979 to 1998, which was the very good thing and that is the period for which you saw that the model was shown to be validated by Piara Singh and others, okay.

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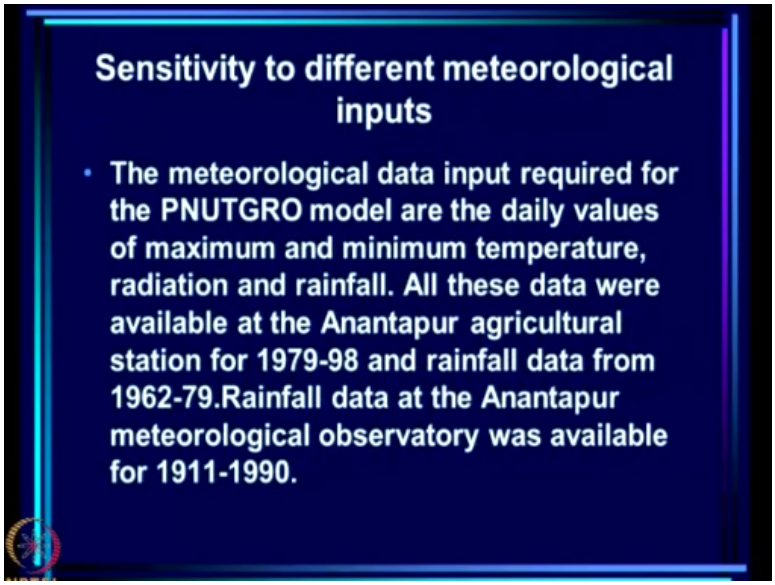

Now, Anantapur itself has rainfall data from 1962 to 1979, but does not have data and radiation and maximum and minimum temperature. In addition to the data at the Anantapur agricultural station, rainfall data at Anantapur meteorological observatory was available to us from 1911 to 1990 at the time we undertook this study. So, we have all the meteorological inputs, only over a short period.

But, if we could use the model for the entire period for which rainfall data is available, which is the long period here 80 years, then actually we would be able to get much more out of the model. So, the first question was r data and temperature and radiation that essential does it make a difference, whether you put in the year-to year variation of daily values of maximum and minimum temperature and radiation into the model.

So, this is the first thing we did, we tested the sensitivity of the model and we wanted to use the model to study variation of yield with sowing date that was very clear, question is the results we get for variation of the yield with sowing date using rainfall and daily averages of temperature and radiation are they different from results one would get with rainfall as well as actual data on temperature and radiation.

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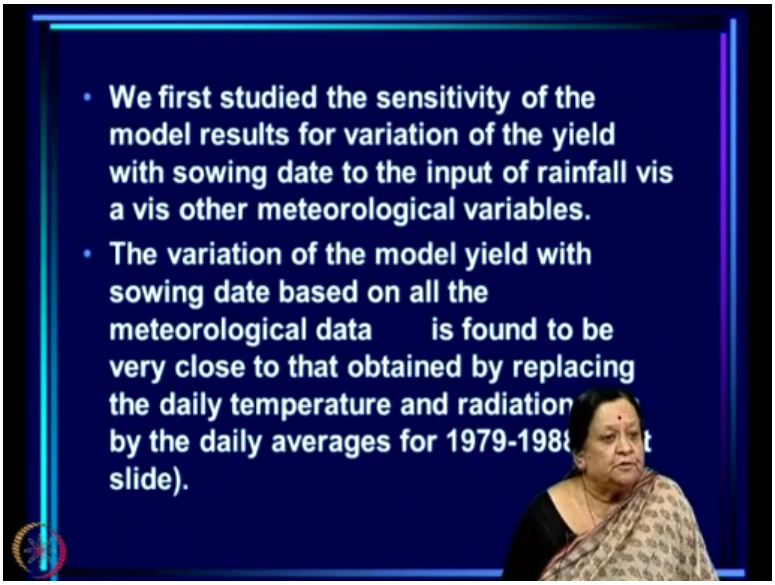

This is the first question we asked and what we found is that really the most critical element for the yield is the rainfall. So, variation of the model yield with sowing date based on all the meteorological data is found to be very close to that obtain by replacing the daily temperature and radiation by the daily averages for 1979 to 1988. In other words, we are giving as an input, the same pattern of daily variation of temperature and radiation year after year.

What happens, what you see is black is the actual and red are the points which where we used daily averages of temperature and radiation and you can see that the matching is in fact almost too good to be true, which shows that the variation and this is for different years as you can see and in different years, the variation of yield with sowing date is different, but you can see very clearly that even if we used daily averages of temperature and radiation and so on, the basic features are captured extremely well.

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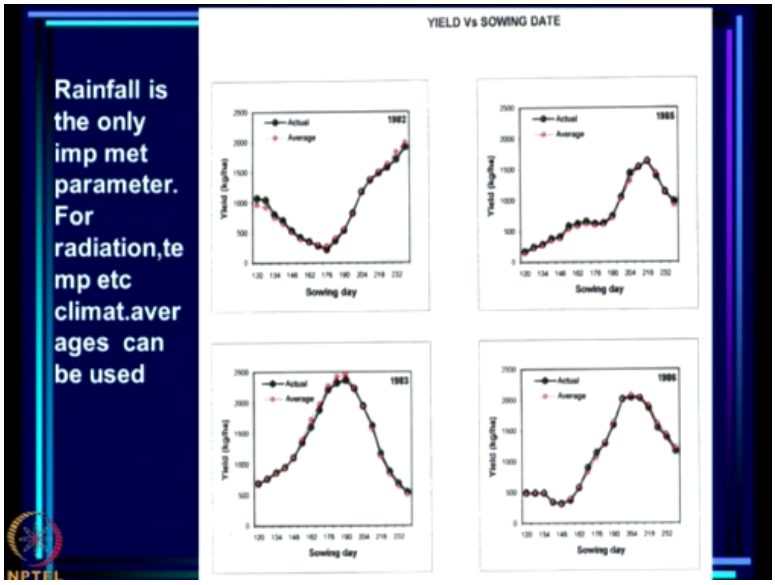

We do not have to worry about getting data, which varies from year-to year on temperature and radiation, so this was the big asset. So, the daily rainfall data from 1911 to 1990 can be used along with the climatological averages of the daily maximum and minimum temperature and radiation for deriving the variation of the yield with sowing date.

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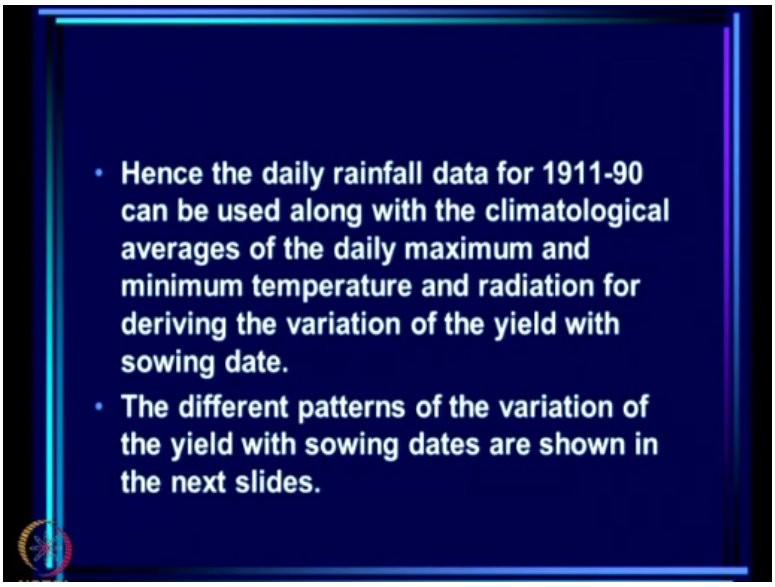

This is the first conclusion and that made it possible for us to use a big long data series rather than being restricted to some 10 to 15 years where all the meteorological data that the model demands actually are available. Now, let us see what the result that we got and in these results what we have done is sorted all the results into different types you will see it here. See the pattern; this is the first pattern, okay.

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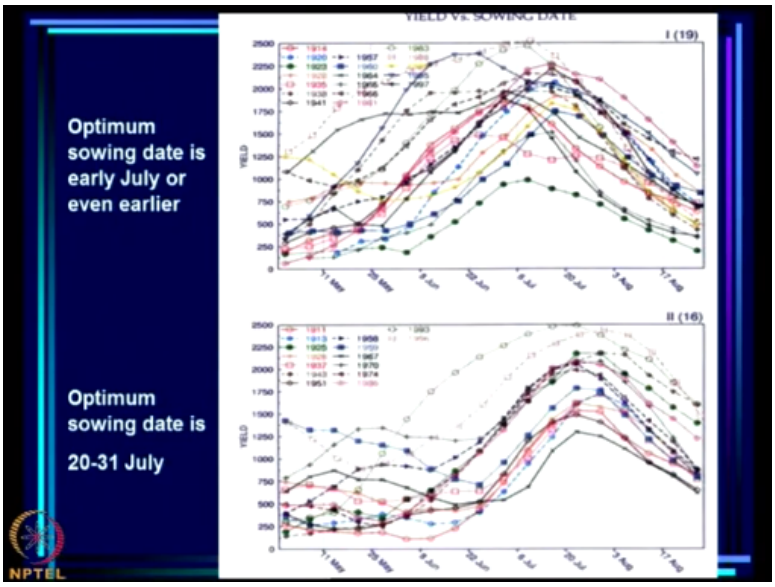

This is the first pattern and these are different years actually shown here and the common thing about this is that by and large the maximum yield occurs fall early July, okay or even earlier. This year it is even earlier, so the peak is occurring here for early July. This is the pattern for about 19 years that you see. Then, there are 16 years which is shown below in which the peak much later. So, this is when the optimum sowing date is between 20th and 31st July.

So, it is only towards the end of July between 20th and 31st July that you have a peak and these are again several years 16 years, these are 19 years. So, almost as many years the peak is somewhat later this is in early July or even earlier, this is now in 3rd week of July till the end of July. Now, these are earlier in which the peak is much later and in fact, it does not vary all that much, you know once the sowing date has gone beyond this for many, many years.

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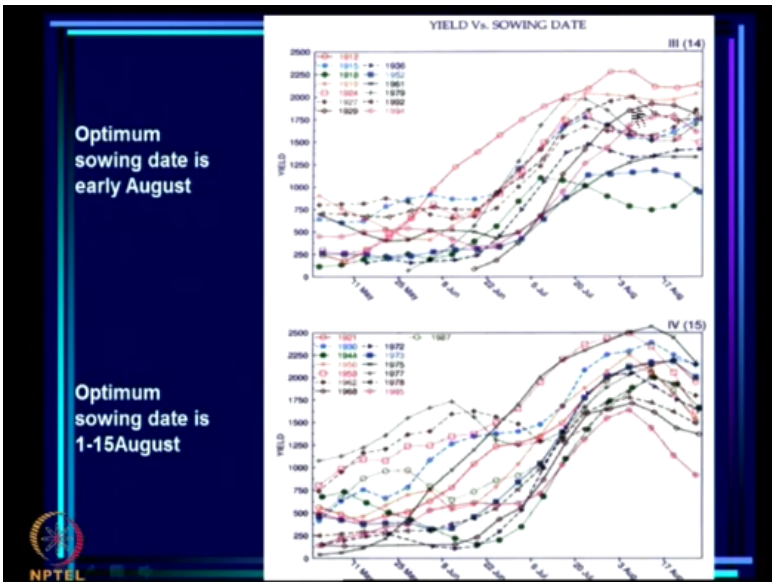

So, for some years like this you can see that the sowing date is early August, the optimum sowing date is early August. Maximum yield you get if you sowing early August after that it is flat. So, this is the case in which sowing date has now become even later and this is 14 years for which it is now early August and in this case, the optimum sowing date is between 1st and 15th August, this is again clash for which are 15 of them.

Now, this is where the optimum sowing date is either in early June or in late August. This is somewhat slightly confusing these 12 years or so. There can be a peak in early June and another very often bigger peak in late August. So, here actually one had to derive the optimum, it would be more in late August except for this particular year in which the peak is definitely in June. Then, there are some years, in which yield is very insensitive to sowing date.

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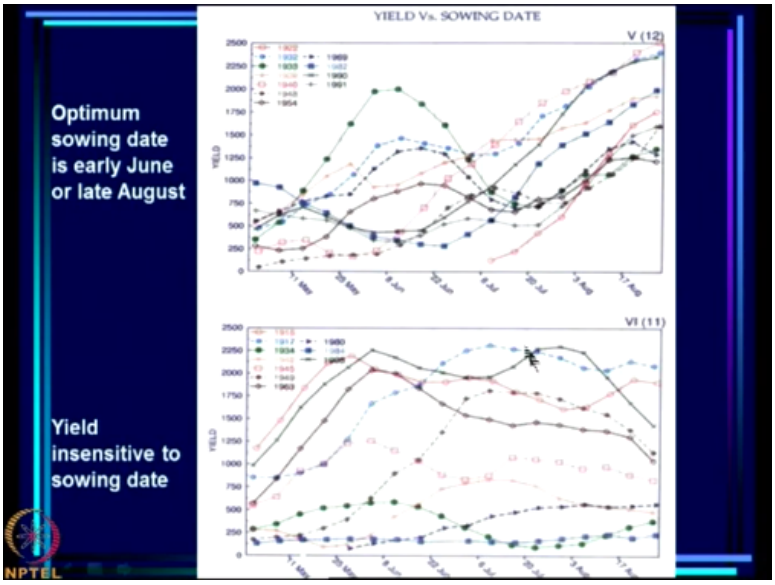

These are either years in which the rainfall is very good and very well distributed, these are these years here, where no matter where you sow you get very good yield. There also years in which the yield is low, no matter where you sow and these are very, very poor rainfall years in which also yield is not very sensitive to sowing date. So, note that in almost all the years the yield increases as the sowing date is postponed from May to late June, okay.

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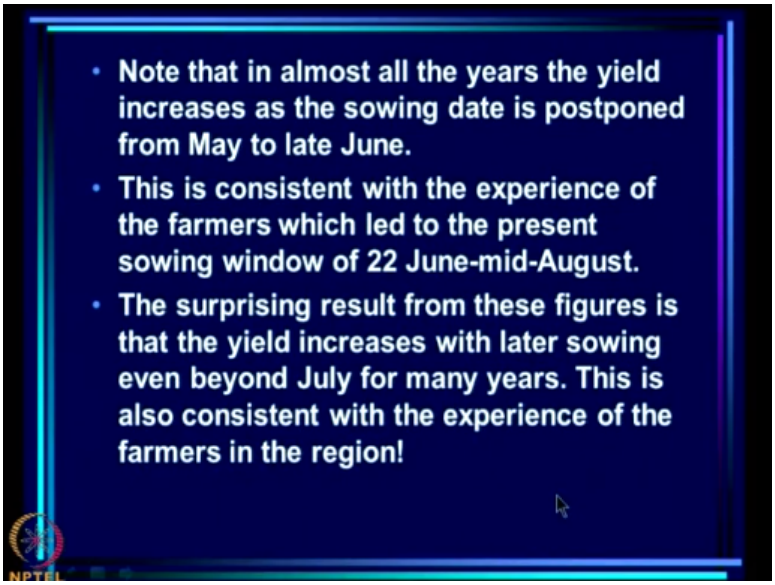

So, this is consistent with the experience of the farmers which led to the present sowing window of 22nd June to mid-August. The surprising result from these figures is that the yield increases with later sowing even beyond July for many years. This is also consistent with the experience of the farmers in the region, who refused to you know stop sowing groundnut in August when the opportunity did not arise earlier.

Now, yield is greater for sowing in late June, early July, only in 19 out of 87 years. Later sowing is associated with larger or at least as much yield in 80% of the years, okay. So, within that sowing window itself 22nd June to mid-August, the first part of the window, late June to early July relatively few years have optimum sowing date. It is the later part of the sowing window where 80% of the years have an optimum sowing date.

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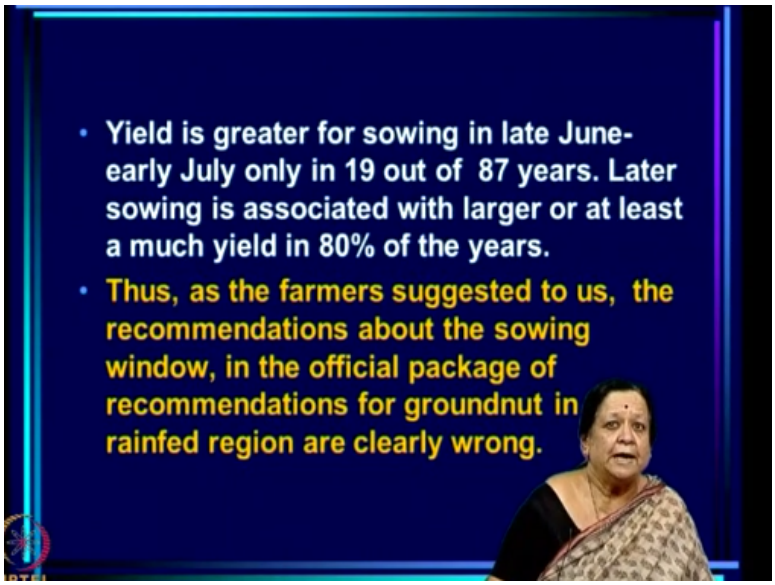

So, as the farmer suggested to us, the recommendations about the sowing window, in the official package of recommendations are clearly wrong. Now, the variation of the probability of crop failure that is to say, yield < 500 kg per hectare and probability of above average yield and very good yield is shown in the next slide. So, this is again results from the model minder and what you see here on top is the probability of crop failure, yield < 500.

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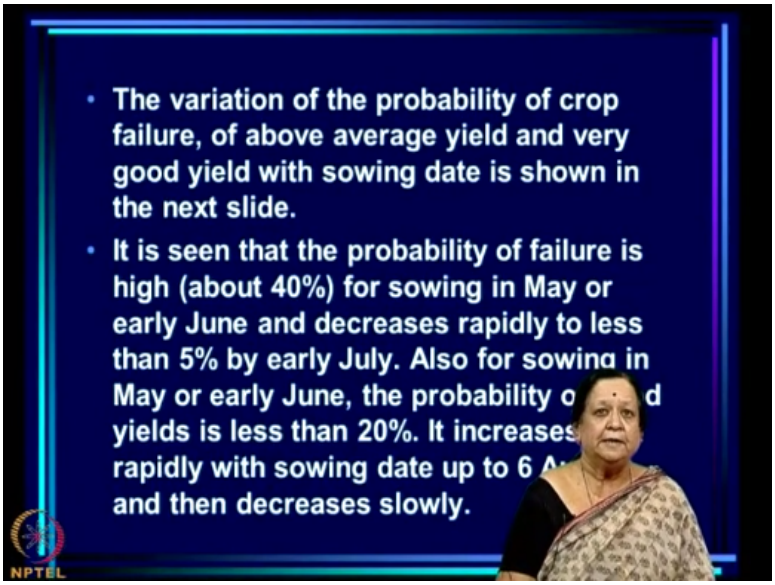

You can see that this sowing date we have started from 30th of April because they had recommended you can start sowing from May itself and in fact, the probability is very high for early sowing in May and so on, close to 50% chance of crop failure and it decreases sharply and it is actually < 20% by about 25th of June. So, the probability of crop failure has decreased markedly to < 20% by 20th of June and by early July, actually it is < 10% and remains flat.

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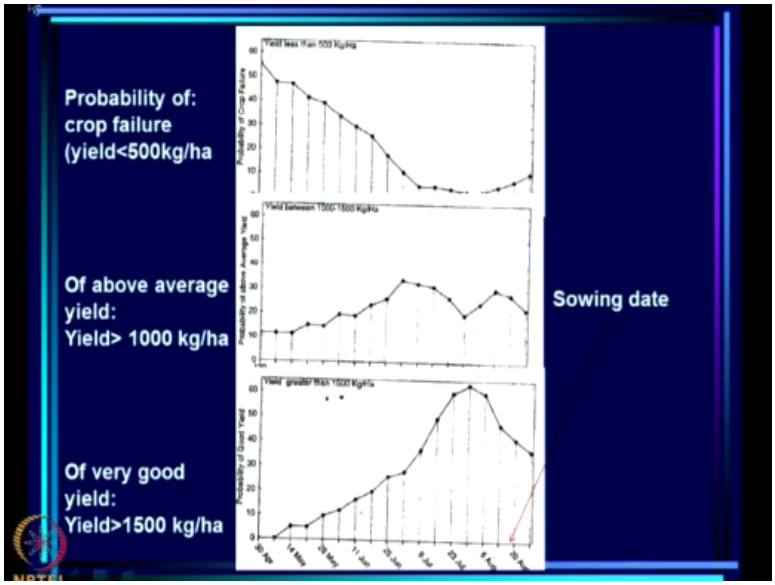

So, the farmers were quite right in abandoning the recommendations that the planting should be done in May or early June because then the probability of crop failure is huge more than 1 in 3 or around 1 in 2, so this is a very, very large probability here. Now, what is the probability of above average yield on the farm, now that actually increases and becomes large in the beginning of July and remains more or less same decreasing a little bit to end of August.

Now, on the other hand, the probability of very good yield again this is from the same model, it is an integral of all the patterns that you have seen, the probability of very good yield is very high, if you restrict the sowing to late July. Later part of the sowing window, remember their sowing window is 22nd June to mid-August. So, if we restrict to say last week of July and first week of August, then you get very high chance of very good yields.

So, this is a very, very interesting result. So, it is seen that the probability of failure is high about 40% for sowing in May or early June, decreases rapidly to <5% by early July. Also for sowing in May or early June, the probability of good yields is < 20%. It increases rapidly

with sowing date up to 6 August and then decreases a bit. So, for early sowing not only is the probability of crop failure very high.

The probability of very good yields is also very low here and then, it increases up to this maximum and then decreases a little bit, but not that much.

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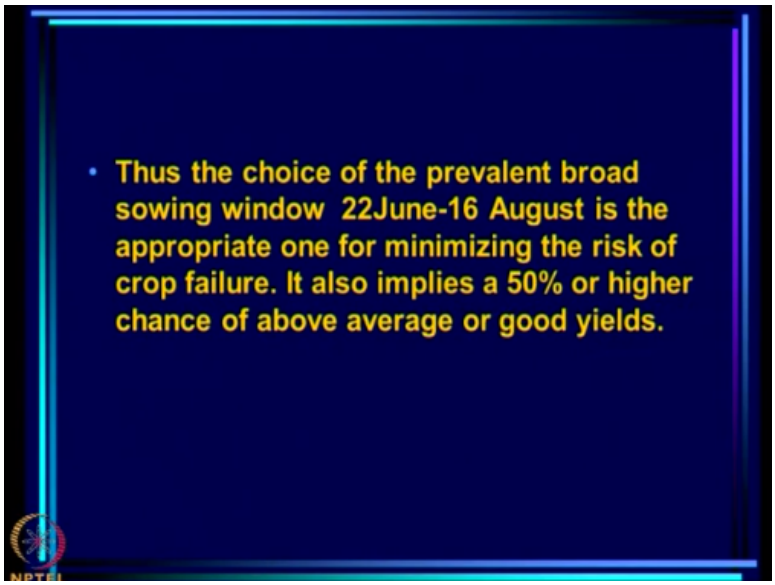

So, the choice of the prevalent broad sowing window 22nd June to 16th August is the appropriate one for minimizing the risk of crop failure. So, what the farmers have done is the right thing because they have now minimized the risks of crop failure. It also implies a 50% or higher chance of above average or good yields.

So, this broad window which they have adopted on the basis of the experience of about 2 decades is indeed and the appropriate one for minimizing the risk of crop failure and it is also reasonable because it implies about 50% or higher chance of good yields above average or good yields. Now, for sowing after mid-July, the probability of above average and very good yields is even higher than 50%.

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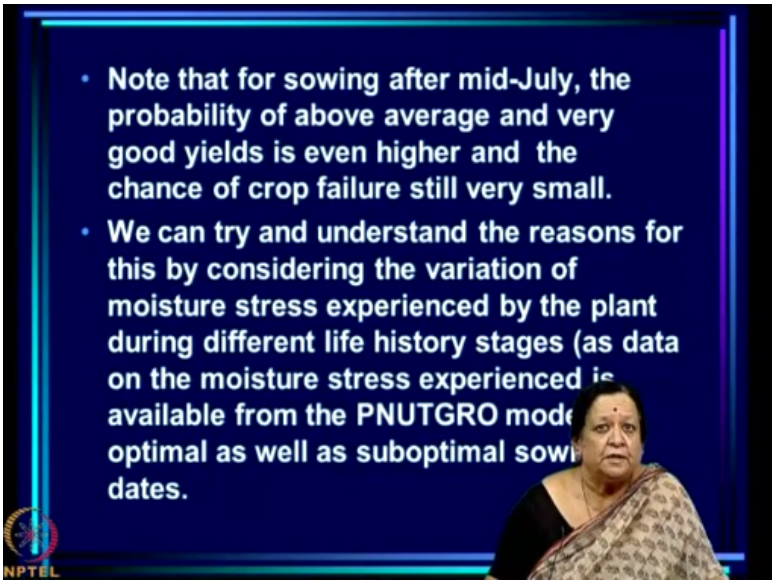

So, within the broad window, if we look at the smaller window or sowing after mid-July to mid-August then is the sowing window, the probability of above average and very good yields is even higher and the chance of crop failure is still very small, okay. So, what this model investigation has done is to show us that actually within the large sowing window is the smaller sowing window, in which the chance of getting higher yields is even higher than the sowing window which farmers have adopted by trial and error.

Now, it is very important to try and understand that the reasons for this. Now, why is this specifics window optimum? We have to understand the reasons because we would like to eventually extrapolate the results to areas where we do not have run the models if we can understand why is it that certain window is optimum for sowing for maximizing yield.

Then, we would be able to check whether that criteria is valid in other regions and come to the conclusion as to whether the window would be optimum for that region for that crop without having to make all this large number of runs with the model, okay. So, it is very important not only to get the results of Anantapur, but also try and understand why this has happened. So, to understand the reasons for this, we have to consider the variation of moisture stress expressed by the plant during different life history stages.

Now, why is that we not at in rainfed regions, the most critical element which limits the growth and yields of plants is the moisture stress. This is because the rainfall is scanty and variable. So, we would like to now see what is the relationship between the moisture stress

experienced by the plant in different life history stages to the optimum sowing date that we have found through these model studies.

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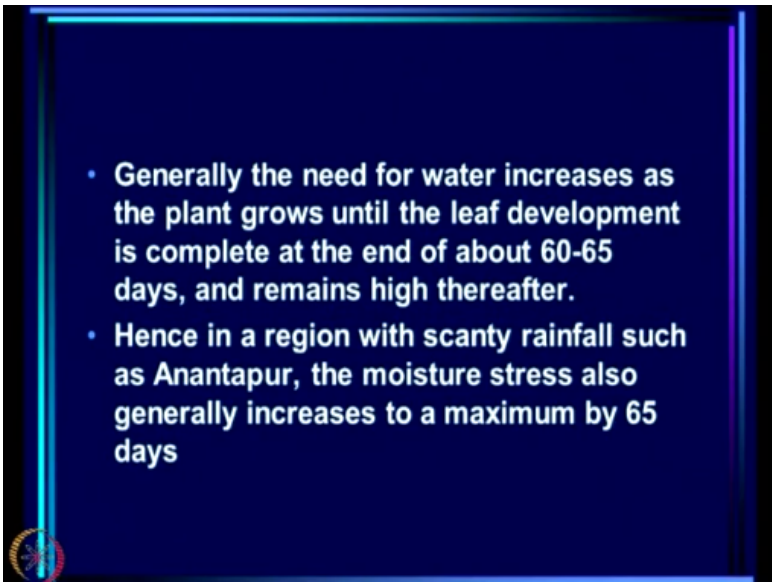

Now, generally the need for water increases as the plant grows until the leaf development is complete at the end of about 60 or 65 days and remains high thereafter. Hence in a region with scanty rainfall such as Anantapur, the moisture stress also generally increases to a maximum by about 65 days and see, now what we have done here is for a few years, we have plotted what is the moisture stress in the model and advantage is that the model actually computes the moisture stress on a daily basis while the plant is growing in the computer.

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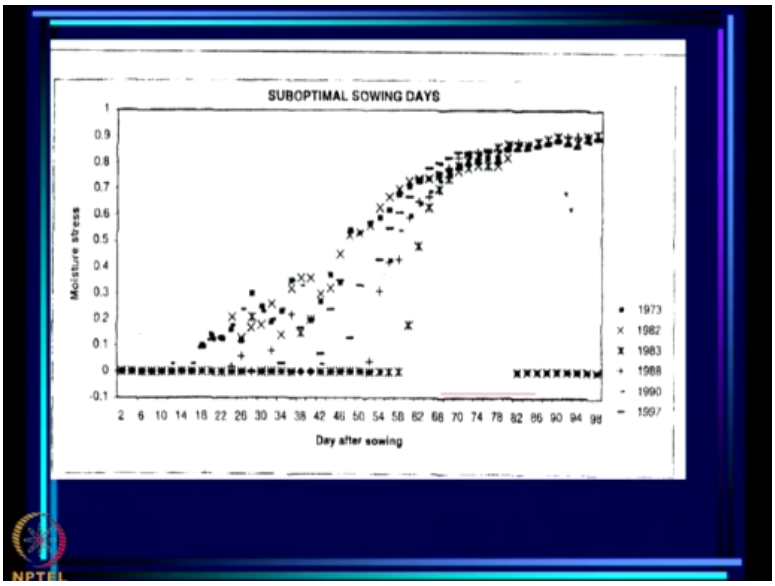

So, we have the moisture stress in the model for few years as a function of days after sowing, which is the x axis here and what we have done is purposely chosen suboptimal dates. In

other words, we have chosen dates which are not optimal sowing dates for those specific years. We have chosen dates which are outside the optimum sowing date and then, ask the question, how does the moisture stress vary during mid days after sowing?

And what you find is what I said before that as the plant grows, the moisture stress increases, it reaches a maximum when the plant all the leaves are out and then remains more or less steady thereafter, this is the 65 days, from 60 to 80 days or 65 to 85 days, the moisture stress experienced by most of the plants is maximum. These are the plants which are planted on suboptimal sowing dates.

Now, if we choose the optimal sowing dates, low and behold a very interesting phenomenon occurs. If the optimal sowing dates are chosen, in this period 60 to 80 days actually the plant experiences no moisture stress at all. This is where ordinarily maximum moisture stress would be experience by the plant this is when no moisture stress is experienced at all. So, for plants for which the sowing date is optimum, do not experience moisture stress at all during 65 to 85 days.

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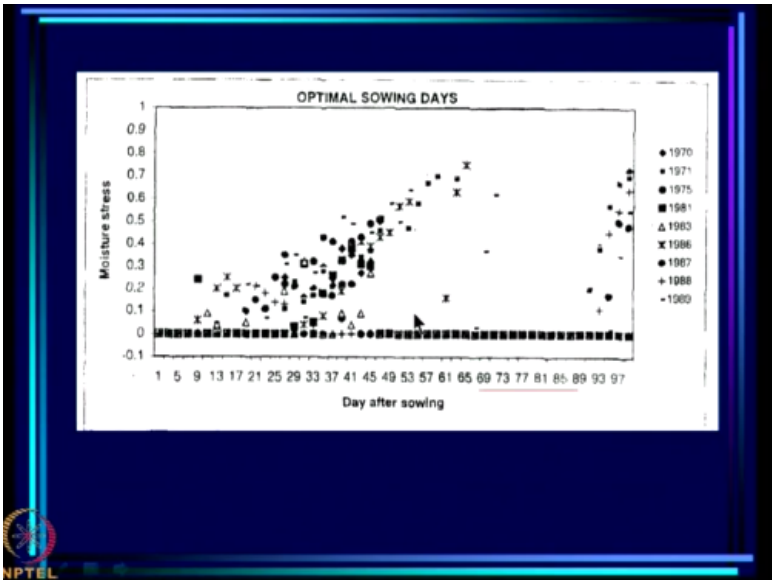

This suggests that out of the different critical stages suggested in literature, the most critical is the pod-filling stage, which occurs say 60 to 80 or 65 to 85 days after sowing. See, we looked at the considerable amount of literature to ask the question, which is the life history stage of the plant? Which is the critical life history stage in the sense that are dry spell during that stage would have a very large impact on the yield.

This is the critical stage and you know there is literature which suggest almost every stages critical, so some paper say the first month after sowing is very important and so on and so far, every life history stage is mentioned in one paper or another has been critical, but what this model has been able to show is that the most critical is the pod-filling stage, which occurs 65 to 85 days after sowing.

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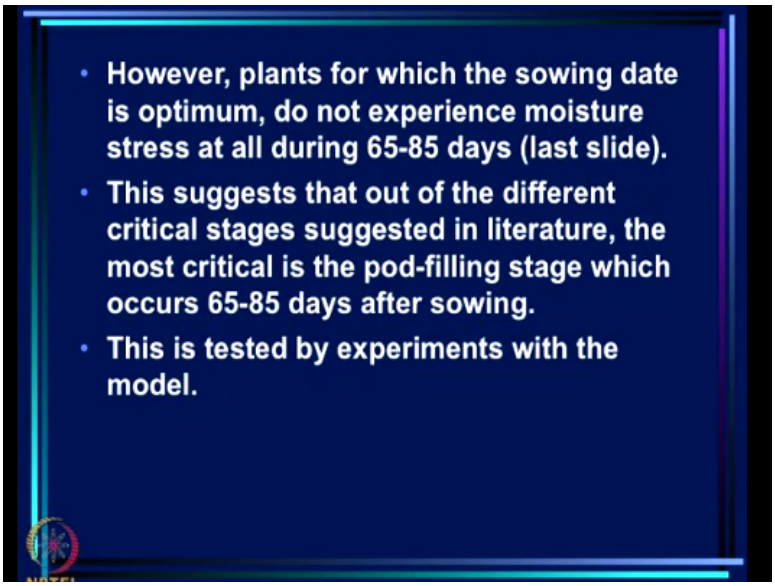

Now, in fact, we tested this result by more experiments with the model itself and that is what I will talk about in the next lecture. So, in this lecture, then we have seen the impact of using a very powerful tool like a crop model and we have found that in fact the farmer's choice of the sowing window which was empirically determined on the basis of their experience is the reasonable one, because it minimizes the risks of crop failure.

But, we also found that within that window there is the smaller window which would lead to higher yields than the farmers would get and so now, we are trying to understand, why are the yields high in this smaller sowing window, which we would recommend to the farmers and link it with the moisture stress experienced by the crops and link it also to the critical life history stages of the plant.

If we can succeed in doing that if we can actually unravel, what leads to the sensitivity of the crop to this dry spells in this particular time or lack of moisture stress in this particular time, the pod-filling stage, then we would be able to extend the results of our study, 2 cases where we do not have as many model runs as we have for this. So, in the next lecture, we will continue with analysis of this model.

There is one more thing, we will have to do, see I mentioned that we have not taken into account pests and diseases in the model because it is not part of PNUTGRO model, but in real life, pests and diseases can cause a lot of damage. Therefore, I will talk about the heuristic model we develop for the losses created by incidence of pests and diseases, how one can combine it with the PNUTGRO model and therefore, get closer to reality in terms of the yields one can get on the farmer fields. Thank you.