SURFACE ALBEDO AND RADIATION CHARACTERISTICS FOR FIVE DIFFERENT TILLAGE SYSTEMS IN THE RED RIVER VALLEY

By

Peter L. Migchels

A thesis
presented to the University of Manitoba
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ABSTRACT

In this study, incoming radiation, net radiation and reflected radiation readings were collected for five different tillage systems throughout the growing season. Also soil surface temperatures and soil temperatures at a depth of 11.5 cm. were collected.

From the collected radiation data, radiation balance equations were established on a monthly basis for each tillage system. From these equations the surface albedo was determined. The surface albedo from the equations were compared to the average albedo of the collected data for each tillage surface. Model surface albedo equations were established for each surface on a monthly basis for sky transmittance of greater than 0.5. This allows the calculation of surface albedo for a given soil moisture and a given solar zenith angle.

At the beginning of the growing season there were significant differences between the surface albedos at the 1% level. As the growing season progressed the albedos of the various tillage systems become more alike and at the end of the growing season there was no significant difference in the surface albedo at the 5% level.

In the monthly analysis there were no significant differences in either the soil surface temperature or the soil temperature at the 11.5 cm. depth.

An economic analysis was not performed, however the yields of the different tillage systems are significant. The trend

was that the tillage surface with the lowest albedo had the highest yields, and the tillage surface with the highest albedo had the lowest yields.

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LIST OF SYMBOLS

A	=	Surface albedo
E	=	Emissiuity
HC	=	Heating coefficient
I	=	Solar radiation reaching the earth's surface in W/m^2
IO	=	Solar radiation received at tyhe top of the earth's atmosphere in W/m^2
JO	=	Solar constant = 1353 W/m^2
L	=	Emitted longwave radiation in W/m^2
M	=	Soil moisture in %
N	=	Net radiation in W/m^2
R	=	Correlation coefficient
S	=	Incoming shortwave radiation in W/m^2
SB	=	Stefan-Boltzman constant = 5.6697 E-08 W/m^2K^4
T	=	Temperature in degrees Kelvin
WL	=	Wavelength in nm
WLM	=	Wavelength of maximum emission used in Wein's displacement law in nm
Z	=	Sun's zenith angle in degrees
a	=	Extinction coefficient used in Beer's law
m	=	Optical air mass
r	=	The radius vector of the distance between the sun and the earth
t	=	Time in seconds
v,w, x,y	=	Regression constants

CHAPTER I

INTRODUCTION

Most farmers would agree that their main objective is to maximize their total net receipts from their land. Escalating fuel costs, as well as the rising prices of machinery, will force farmers to become more energy conscious. On every farm there are many ways to save energy. This may be done by performing jobs more efficiently or by making better use of major inputs, such as labour, equipment and power sources.

The radiation balance of a soil surface plays an important part in the performance of a soil. Literature states that for practical purposes, the energy content of pohotsynthetically useful solar radiation can be taken as one-half of the radiative energy recorded with a solarimeter. For this reason, it would seem obvious that the more solar radiation retained by a crop surface, the more productive the crop. Also, if more solar radiation is retained by a soil surface, it would be expected that the soil will warm up quicker. This, in turn, due to evaporation because of a warmer soil, leads to an earlier planting date and more ideal planting and germination conditions.

If it is possible to increase the amount of solar energy retained by the crop and soil surface by reducing tillage operations, the amount of energy saved will be two-fold. First, the saving of vital fuel or other energy sources, which can then be used for other purposes, and second, the

increase in solar radiation which can be used for crop production by photosynthesis or for increasing soil temperature which in turn will increase yields. Since the tillage system that a farmer uses affects the radiation balance of the soil and crop surface, the farmer may have more control over his soil's performance than he had previously realized.

The purpose of this study was to investigate the radiative characteristics of the soil surface with an emphasis on the albedo of the surface under various tillage systems. From the radiation data collected, net radiation balance equations were determined for each tillage system, each month.

Albedo models were established through best-fit equations for both a.m. and p.m. for the different tillage systems each month. Monthly surface albedos from the net radiation equations were compared to the average albedo of the actual collected data.

CHAPTER II

REVIEW OF LITERATURE

2.1 Introduction

Many agricultural engineers, crop scientists, and soil scientists agree that more tillage is being done than is necessary to assure maximum net income from crop production. In some cases soil compaction from tractors and implements in a sequence of secondary tillage operations virtually eliminates the effects of primary tillage operations. Some tillage operations are designed to produce a good seedbed, but the degree of soil pulverization and firmness is excessive for optimum root growth.

2.2 Tillage Objectives

A farmer's objectives in selecting tillage methods should include minimizing labour and energy while maximizing yield and profit. The major objectives of tillage as defined by Kepner, Bainer and Barger (1977) are:

1. To develop a desirable soil structure for a seedbed or a rootbed. A granular structure is desirable to allow rapid infiltration and good retention of rainfall, to provide adequate air capacity and exchange within the soil, and to minimize resistance to root penetration. A good seedbed, on the other hand, is generally considered to imply finer particles and greater firmness in the vicinity of the seed.

2. To control weeds or to remove unwanted crop plants.

3. To manage plant residues. Thorough mixing of trash is desirable from tilth and decomposition stand

points, whereas retention of trash in the top layers reduces erosion. On the other hand, complete coverage is sometimes necessary to control overwintering insects or to prevent interference with precision operations such as planting and cultivating certain crops.

4. To minimize soil erosion by following such practices as contour tillage, listing and proper placement of trash.

5. To establish specific surface configurations for planting, irrigating, draining, harvesting operations, etc.

6. To incorporate and mix fertilizers, pesticides or soil amendments into the soil.

7. To accomplish segregation. This may involve moving soil from one layer to another, removal of rocks and other foreign objects or root harvesting.

In recent years there has been an increasing interest in minimum tillage systems to reduce crop production costs and improve soil conditions. The major objectives of minimum tillage are:

1. To reduce fuel and labour requirements.

2. To conserve soil moisture and reduce soil erosion.

3. To perform only the operations necessary to optimize the soil conditions.

4. To minimize the number of trips over a field.

5. To reduce capital investment in equipment.

In cases of zero-tillage operations the trash cover

and stubble from previous crops remains on the soil surface. Klacke (1979) gives the reasons for planting directly into stubble as:

1. The stubble increases water infiltration into the soil profile by breaking the impact of rainfall and retarding runoff.

2. The stubble retards evaporation of water from the soil profile by insulating the soil surface and reducing surface temperatures.

3. The stubble traps blowing snow and retains it for added soil moisture.

4. The stubble reduces both wind and water erosion by protecting the soil surface from the impact of both wind and water.

2.3 Infiltration Influenced by Tillage

Traditional tillage practices often create bare soil surfaces or soil physical conditions that restrict water infiltration early in the crop season. Rain falling on freshly tilled soil surfaces detaches and transports soil particles. As a result, the soil structure at or near the surface is changed.

Consider a bare soil surface which has become partially dry since the last rain or tillage operation. When the next rain begins, the soil surface is directly exposed to the impact of the raindrops. Horton (1941) found that three events commonly take place:

1. There is a breakdown of the crumb structure

of the soil surface, thereby decreasing the size of the soil pores and more or less filling the macro-openings. The result is progressive surface sealing.

2. There is actual packing or puddling of the soil surface.

3. There is a swelling of the colloids, causing a decrease in the water and air conducting pore space.

Once the accumulated rainfall effects create surface conditions conducive to runoff, subsequent rainfall, even after surface drying, quickly begins to run off.

In contrast, mulch and some minimum tillage practices create conditions conducive to infiltration and storage of rainfall in the subsoil. This stored moisture may be used later by crops during periods of limited rainfall. A soil cover plays an important part in the role of infiltration in that it dissipates the rainfall energy before it strikes the bare soil. Detachment and packing of the soil particles are then reduced as a result of the loss of energy to the soil cover.

2.4 Effects of Tillage Systems on Retained Solar Energy

Except for a small amount of heat from the inner core of the earth, the energy received at the earth's surface comes from the sun. This energy drives the important processes of evaporation and photosynthesis, heats the air, water and soil and supplies energy to other minor processes.

A large but variable portion of the solar radiation re-

ceived by crop and soil surfaces is reflected or reradiated to outer space. The radiative characteristics of crops and soil surfaces can exert an important modifying influence on the radiation balance in the surface space. Therefore, the parameters controlling potential rates of water loss and dry matter production are affected.

2.5 Solar Radiation

The earth receives energy from the sun mainly in the form of solar radiation. This solar radiation is the transmission of energy from the sun to the earth by means of shortwave electromagnetic waves. Although the sun produces radiation with wavelengths from 0.1 nm to over 10" nm, 99 percent of the solar radiation received by the earth has wavelengths from 200 nm to 4000 nm.

List (1958) gives the basic formula for computing the solar radiation received by a unit area in unit time at the top of the earth's atmosphere as:

$$dI0/dt = (JO/r^2) \cos z \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}1)$$

Where $I0$ = Solar radiation received, W/m^2

t = time, s

JO = solar constant, 1353 W/m^2

r = distance from sun to earth, in terms of a dimensionless ratio; $r = 1$ is the mean distance from the sun

z = sun's zenith angle, degrees

The amount of solar radiation that reaches any particular part of the earth's surface in any one day depends upon a number of factors, such as:

1. The solar constant which is the intensity of

the sun's radiation in space at the earth's average distance from the sun. The value of the solar constant is 1353 W/m^2.

2. The area of the surface upon which the radiation falls.

3. The inclination of the surface relative to the sun's rays, which depends upon time of day and season.

4. The transparency of the atmosphere.

5. The position of the earth in its orbit since the earth-sun distance varies.

These factors which influence the amount of radiation reaching the earth are only briefly mention. For a more detailed study refer to Threlkeld (1970), Duffie and Beckman (1974), or Kreith and Kreider (1978).

The solar radiation arriving at the outer atmosphere of the earth varies only $\pm$ 3.5 percent. The amount of solar radiation arriving at the earth's surface varies considerably. Approximately 43 percent of the solar radiation that reaches the outer atmosphere reaches the earth's surface. For monochromatic light (single wavelength) the attenuation through the atmosphere is given by Beer's Law:

$$I = I_0 \exp(-am) \quad (2\text{-}2)$$

Where I = final intensity, W/m^2

I_0 = initial intensity, W/m^2

a = extinction coefficient, dimensionless

m = optical air mass, dimensionless

Beer's law is valid only for single wavelengths

since the extinction coefficient varies with wavelength. It also varies with optical air mass and the nature of the attenuation (scattering, absoprtion or reflection).

All of the radiation that reaches the earth's surface is not absorbed. Some of the solar energy is reflected back to space. The earth reradiates much of the energy received from the sun. The amount of energy remaining is called net radiation.

The earth reradiates energy, as do all bodies at a temperature above absolute zero, in the form of electromagnetic waves. The emission and absorption of thermal radiant energy from a body are governed by the temperature of the body as well as the nature of the emitting or absorbing surface. The temperature of a black body bears an elementary relationship to the wavelength of maximum emission. This relationship is known as Wien's displacement law and is as follows:

$$WLM.T = 2897600 \text{ (nm.K)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2\text{-}3)$$

Where: WLM = wavelength of maximum emission, nm

T = black body temperature, K

In 1884 Boltzmann derived the total radiant emittancy of a black body, L, as proportional to the fourth power of its absolute temperature. This result had been found empirically by Stefan in 1879. This relationship is known as the Stefan-Boltzmann law:

$$L = E.SB.T^4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2\text{-}4)$$

Where L = emitted radiation, W/m^2

E = emissivity (E = 1 for a black body)

T = absolute temperature, K

SB = Stefan-Boltzmann constant $(5.6697(10)^{-8} W/(m^2K^4)$

2.6 Definition of Albedo

As mentioned previously, some of the solar radiation reaching the earth is reflected. The proportion of short wave radiation ($WL \leq 4000$ nm) reflected from a surface is defined as the albedo of the surface. Surface albedo is calculated as the outward radiation flux divided by the inward radiation flux.

Literature reveals that the following factors affect the albedo of a surface.

1. Surface roughness (the nature and height of the vegatation cover)
2. Colour of the surface
3. Moisutre content of the surface

Table 2-1 shows the albedo for various surfaces (Merva, 1975).

2.7 Relationship Between Albedo and Solar Elevation

Monteith and Szeicz (1961) observed that for grass the albedo increased from 0.23 at a solar elevation of 60 degrees to 0.28 at a solar elevation of 20 degrees, with a daily mean of 0.26. For bare soil the corresponding increase was from 0.16 to 0.19 with a mean of 0.17. It was also noted in this study that in June, reflection by short grass and bare soil was least at mid-day, and increased almost linearly with decreasing solar elevation.

Kalma and Stanhill (1969) found the mean albedo of and orange plantation to be 0.16. The albedo ranged from a minimum of 0.12 in late spring to a maximum value of 0.21 in late autumn.

In studies by Chia (1976), Piggin and Schwerdtfeger (1973) concluded that overcast days have an effective solar elevation of about 45 degrees. This is due to the fact that on a clear day the majority of solar radiation reaching the earth's surface is direct radiation. However, on an overcast day a higher proportion of the radiation reaching the earth's surface is diffuse radiation. Diffuse radiation has a higher proportion reflected from the surface due to the random angle of at which it hits the surface. Piggin and Schwertdtfeger (1973) are indicating that the amount of radiation reflected when overcast is similar to when the solar elevation is 45°. In the study by Graham and King (1961) the albedo increased at low solar elevations and the diurnal distribution was asymmetrical about noon.

In a study by Nkemdirim (1972a) albedo was expressed as a function of the solar zenith angle (the complementary angle of solar elevation).

The relationship between average albedo for each surface and zenith angle was found by regression analysis. A strong exponential relationship was obtained for most surfaces since R (curvilinear) was greater than 0.9.

All surfaces showed two characteristic albedo-zenith angle curves corresponding to morning or afternoon observa-

TABLE 2-1: Albedo Values for Various Surfaces (Source: Merva (1975)

Kind of Soil	Percent
Black soil, dry	14
Black soil, moist	8
Grey soil, dry	25-30
Grey soil, moist	10-12
Blue loam, dry	23
Blue loam, moist	16
Fallow, dry	8-12
Fallow, moist	5-7
Ploughed field, moist	14
Desert, loamy surface	29-31
Sand, yellow	35
Sand, white	34-40
Sand, bright-fine	37
Sand, river	43
Freshly ploughed, bare, black clay	5.5

Influence of Surface Roughness

Kind of Roughness	Percent
Flat, even	30-31
Covered with dust	28
Covered with pellicles (after moistening)	27
Covered with small pebbles	25
Covered with bigger pebbles	20
Newly ploughed field	17

Influence of Vegetation Cover

Vegetation	Percent
Spring wheat	10-25
Winter wheat	16-23
Winter rye	18-23
High grass, densely grown	18-20
Green grass	26
Grass-dried in sun	19
Tops of oak	18
Tops of pine	14
Tops of fir	10
Cotton	20-22
Lucerne (start and blossoming)	23-32
Rice field	12
Lettuce	22
Beets	18
Potatoes	19

Influence of Snow Cover

Type	Percent
Dense, dry clean	86-95
Clean, moist fine	63-64
Clean, moist granular	61-62
Porous-moist greyish	45-57
Light brown, wet	31
Dirty	29

tions. An example from Nkemdirim's research, for bare ground in the afternoon, was:

$$A = 0.0626 \exp (0.0216Z) \quad (2\text{-}5)$$

Where A = surface albedo

Z = zenith angle, degrees

0.0626 = dimensionless constant

0.0216 = constant, 1/degree

For bare ground in the forenoon the result was:

$$A = 0.1247 \exp (-0.003Z) \quad (2\text{-}6)$$

Where A = surface albedo

Z = zenith angle, degrees

0.1247 = dimensionless constant

-0.003 = constant, 1/degree

Nkemdirim also noted that the dependence of albedo on zenith angle is most marked on clear days while on overcast days very little dependence was observed.

In disagreement with the previously mentioned reports, Stanhill, Hofstede and Kalma (1966) state that only three surfaces (fishpond, orange orchard and evergreen maquis forest) showed any increase in albedo with decreasing solar altitude. The degree of cloud cover had no discernible influence on the values of albedo measured for any of the surfaces. Chia (1967) found that the albedo of vegetaion, but not that of bare soil, depended on the zenith angle of the sun.

2.8 Relationship Between Albedo and Vegetation Height

Chia (1967) noted that the albedo of sugar cane

increased with crop height until the leaves gave complete ground cover. Also a higher albedo was observed due to the presence of trash left on the ground from previous harvests. However, the effect of trash on the albedo became negligible after the crop formed a complete cover.

In a study by Stanhill (1970) the albedo was inversely related to the height of the vegetation canopy. This was presumably because of the greater opportunities for reabsorption of reflected radiation within deep canopies.

2.9 Relationship Between Albedo and Surface Moisture Content

Authors such as Monteith (1959), Graham and King (1961), Chia (1967), and Idso et al. (1975) noted that wet soils have a smaller albedo than lighter coloured soils. A wet soil will absorb more radiation so that more energy is available for evaporation and heating. The study by Idso et al. (1975) concluded that the albedo, when normalized to remove sun zenith angle effects, appeared to be a linear function of the water content of the upper most layer of the soil. The albedo was also well correlated with the average water content of deeper layers of soil. Measurements to a depth of 10 cm indicated that the relation was relatively independent of season.

Idso, Reginato and Jackson (1977a) noted that rain can decrease the soil albedo to on-half of its original value due to the darkening in colour and the increase in moisture content of the soil.

Bowers and Hanks (1955) reported that an increase in moisture content of a Newtonian silt loam from 0.8 to

20.2 percent would increase absorption of radiant energy by at least 14.2 percent of that in equivalent direct solar beams. They also noted that with both kaolinite and bentonite clays reflectance is a function of the surface roughness and therefore particle size. It was noted that the albedo increased exponentially as particle size decreased.

2.10 Reflection of Radiation as a Function of Wavelength

It is a well known fact that the entire visible spectrum is effective in producing photosynthesis in the wheat plant. Five photochemical reactions in plants are described in literature: (1) photosynthesis which is activated mainly by blue light at 435 nm and by red light at 675 nm with a minimum response to green at 460 nm; (2) chlorophyll synthesis which is activated mainly by blue light at 445 nm and by red at 650 nm; (3) phototropism at 370 nm in the ultraviolet region, and 445 nm and 475 nm in the blue; (4) photomorphogenic induction is active in the red at 660 nm; and (5) photomorphogenic reversal which is mainly active in the red at 730 nm.

Literature also states that plant foliage is essentially non-absorbing in the 750 to 1300 nm range. Radiation not reflected is transmitted through the leaf in this range. Reflectance in the visible range is determined by plant pigments, chiefly chlorophyll, which has an absorption which is maximum at 676 nm. The reflectance at this wavelength does not approach zero due to the specular reflection at the leaf surface.

Billings and Morris (1951) found in general that the reflectance curves of green leaves showed values of about 5 percent at 400 nm rising to a peak of about 15 percent at 550 nm with a gradual slope down to the 5 or 6 percent range at 675 nm. Above this wavelength the curves rise steeply to a plateau of approximately 50 percent reflectance in the infrared region.

The reflectance results with leaves indicated that there is a sharp rise at about 675 nm and continues to a plateau of about 50 percent extending from about 725 nm to the limits of observation, which for most authors was about 1100nm.

Literature states that for practical purposes, the energy content of photosynthetically useful radiation can be taken as half the radiative energy recorded with a pyranometer. From this it can be assumed that if less radiation energy is reflected there is more energy available for photosynthesis.

2.11 Albedo of Wheat

Idso, Reginato and Jackson, (1977a), in studies with six plots of durum wheat, noted a decline in albedo as the growing season progressed. This was due to the growth and proliferation of the leaves as they progressively shut out more of the higher albedo soil. In this study the albedo increased slightly as the heads started to emerge and then continued to decrease. There was a final increase in the albedo due to the ripening and browning of the crop. It was concluded in this study that the ripen-

final grain yield was a linear function of the minimum albedo reached.

Piggin and Schwerdtfeger (1973) noted that the daily albedo for wheat crop ranged from 0.13 to 0.25. After heading, the albedo of the wheat did not display a temporary leaf drying depression since it decreased uniformly from 0.23 to 0.18. This suggested that perhaps the leaf drying gradually exposed more soil.

Monteith (1959) found differences between the reflection coefficients of two plots of winter wheat and one plot of spring wheat. The spring wheat was sown on March 25. The albedo increased from 0.16 at the end of April, a value characteristic of the soil rather than the crop, to 0.20 - 0.21 in May and June. When the crop ripened at the beginning of August, there was a sharp drop in albedo to 0.14. This was due to the fact that more of the low albedo soil was being exposed through the crop canopy as the leaves dried.

The first plot of winter wheat sown on November 11 received ammonium sulphate on March 17. In May, the albedo was 0.27, but dropped suddenly to 0.20 at a the beginning of June and was maintained at 0.20 until ripening in August. The second plot sown on December 6 received no nitrogenous fertilizer. The crop was only 11 cm tall on May 5 compared with 19 cm for winter wheat plot number 1. The highest value of the albedo for this plot was 0.22 and there was decrease with ripening.

2.12 Surface Radiation Balance

Due to uneven topography, the existence of a plant cover, and other factors, the concept of soil surface loses its usual meaning of a mathematical surface and acquires a fairly arbitrary, indefinite and far from two dimensional character. It is therefore correct to speak not of the soil surface but of the "active surface". By the active surface it is meant the dynamic and active surface at which incoming solar energy is transformed.

In reality, this concept does not describe a surface but a very thin layer in which solar radiation is absorbed with subsequent heating and emission. Only in the limit may this layer be taken to have zero thickness. In the active surface heat is exchanged with the surface air and the underlying soil layers, resulting in temperature oscillations which involve a fairly deep soil layer whose thickness depends on the thermophysical characteristics of the soil and the period of the heat wave. This layer is bounded above by the active surface and below by the constant temperature of the deep soil layers.

In many problems of surface heat balance, an important meteorological variable is the net radiation absorbed by the surface. In a study by Monteith and Szeicz (1961) it was found that the radiative characteristics of agricultural surfaces can be described by the following linear regression equation:

$$N = (1-A)\ S + L \quad \ldots\ldots\ldots\ldots \quad (2\text{-}7)$$

Where N = net radiation, W/m^2

S = incoming shortwave radiation, W/m^2

L = the net longwave radiation, W/m^2

A = the shortwave radiation reflection coefficient or albedo

With a "heating coefficient" HC = dL/dN, the observed linear dependence of N on S in the absence of cloud may be expressed as:

$$N = S\ (1 - A)/(1 + HC) + L0 \quad \ldots\ldots\ldots\ldots \quad (2\text{-}8)$$

Where N = net radiation, W/m^2

S = incoming shortwave radiation, W/m^2

L0 = net longwave radiation when S = 0, W/m^2

A = albedo

HC = heating coefficient (the increase of net longwave radiation loss per unit increase of net radiation incoming)

It was also noted that for equal incoming shortwave radiation was always smaller in the afternoon than in the morning due to the higher afternoon surface temperatures.

2.13 Heating Coefficients

An increase in net radiation is associated with an increase in surface temperature to which the longwave loss is very closely related to equation 2-4. The heating coefficient is a measure of the change in upward longwave radiation for a change in net radiation at the crop or soil surface under cloudless skies. This relationship is only valid when L is a linear function of N, which is only under clear skies. Theheating coefficient is calculated from the slope of the regression line of N plotted

against S(1-A) as HC = (1-slope)/slope. Negative values of the heating coefficient imply a decrease in net longwave loss with an increase in incoming shortwave radiation.

The simplest hypothesis is that HC depends on wind, but is the same for all freely transpiring crops exposed to the same weather. Monteith and Szeicz (1961) found that for spring wheat, HC = 0.15; for sugar beets, HC = 0.21; and for grass HC = 0.22. The smaller HC for wheat implies a smaller diurnal variation of surface temperature for a given incoming radiation and this difference was noted to be consistent with the higher wind speed prevailing during the wheat observations. The normal row spacing of a cereal allows free air movement below the crop canopy and for a given weather the effective surface temperature of the cereal (and therefore HC) may be less than for a densely grown crop of sugar beets or grass exposed to the same weather. This supports the previous mentioned hypothesis.

In another study Monteith and Szeicz (1962) believe that HC is probably close to 0.1 for most agricultural crops and for natural vegetation with similar growh habits completely covering the ground and never short of water. If these conditions for potential transpiration are not met or if ground cover is incomplete, HC may lie between 0.1 and 0.2. For very dry soil they suggest that HC lies between 0.3 amd 0.4 Since transpirational cooling depends on wind and relative humidity as well as on radiation,

the heating coefficient, unlike the reflection coefficient, may vary with climate.

In a study by Davies and Buttimore (1969), heating coefficient values ranged between 0.17 and 0.51, with a value of 0.45 for wheat on July 19, 1967. The heating coefficient for bare ground on August 19, 1967 was 0.32.

2.14 Soil Temperature

Tillage operations clearly influence soil temperature and consequently influence crop growth. Pakaranodom (1972) noted that theoretical studies indicated that a soil with no cover becomes hotter in summer and colder in winter as compared to a soil with some type of covering.

Nerpin and Chudnovskii (1970) noted that a zero-tillage experiment showed that the range of average daily soil temperature at the 10 cm depth was $2^{o}C$ less during germination and $3.5^{o}C$ less over the entire growing season when compared to conventional tillage. The lower soil temperature resulting from zero tillage is possibly due to vegetation and trash cover.

Soil temperature is very important at planting time. Adverse soil temperatures cause crop failures, either directly or indirectly; seed germination and plant growth are dependent on an adequate soil temperature.

Soil temperature is affected by tillage primarily through changes in the thermal properties of the tillage layer. Most heat transfer within the soil is by conduction. The temperature in the upper soil layer fluct-

uates with alternating intervals of heat storage and heat loss. If the soil is covered with dense vegetation the daily maximum will be lower than that of uncovered soils. This is because of the shading effect.

In a study by Fuchs and Tanner (1968) surface temperature measurements were made using an infrared thermometer. The soil temperatures were compared to the net radiation balance at the surface. From this it was observed that the deeper in the soil the less the daily temperature fluctuation. This is to be expected since deeper in the soil the temperature remains constant.

Increased soil water content reduces the surface heating. A moderated microclimate, near the ground surface, occurs when the soil is wet and is a consequence of latent heat exchanges and the larger thermal conductivity and the volumetric heat capacity of the soil.

CHAPTER III

EXPERIMENTAL PROCEDURES AND EQUIPMENT

3.1 Introduction

This study was conducted at the University of Manitoba Glenlea Research Farm. Collection of data began on 79 05 18 and was concluded on 79 09 19. The collection of data was very dependent on both weather and sky condition. The field location was approximately 49° 38'N, 97° 9'W.

The plot layout is shown in Figure 3-1. The plots are 4 replications of 5 different tillage systems. The experimental design was a randomized complete block design. With the randomized complete block design, each block consists of a replication of each of the treatments. The treatments are assigned at random to the units in each block. From this plot layout, each tillage system can be analyzed as one unit and the different tillage systems compared. This eliminates the variation in plots of the same tillage system.

The tillage systems that were used ranged from intensive tillage to zero tillage. The field operations and the season of the operations for each of the tillage systems are as follows:

1. Intensive Tillage

Fall	- Moldboard plowing
	- Light tillage
	- Harrow
Spring	- Planting by press drill

2. Deep Tillage

Fall	- Deep tillage (chisel plow)

Each plot 15.24 m x 304.8 m

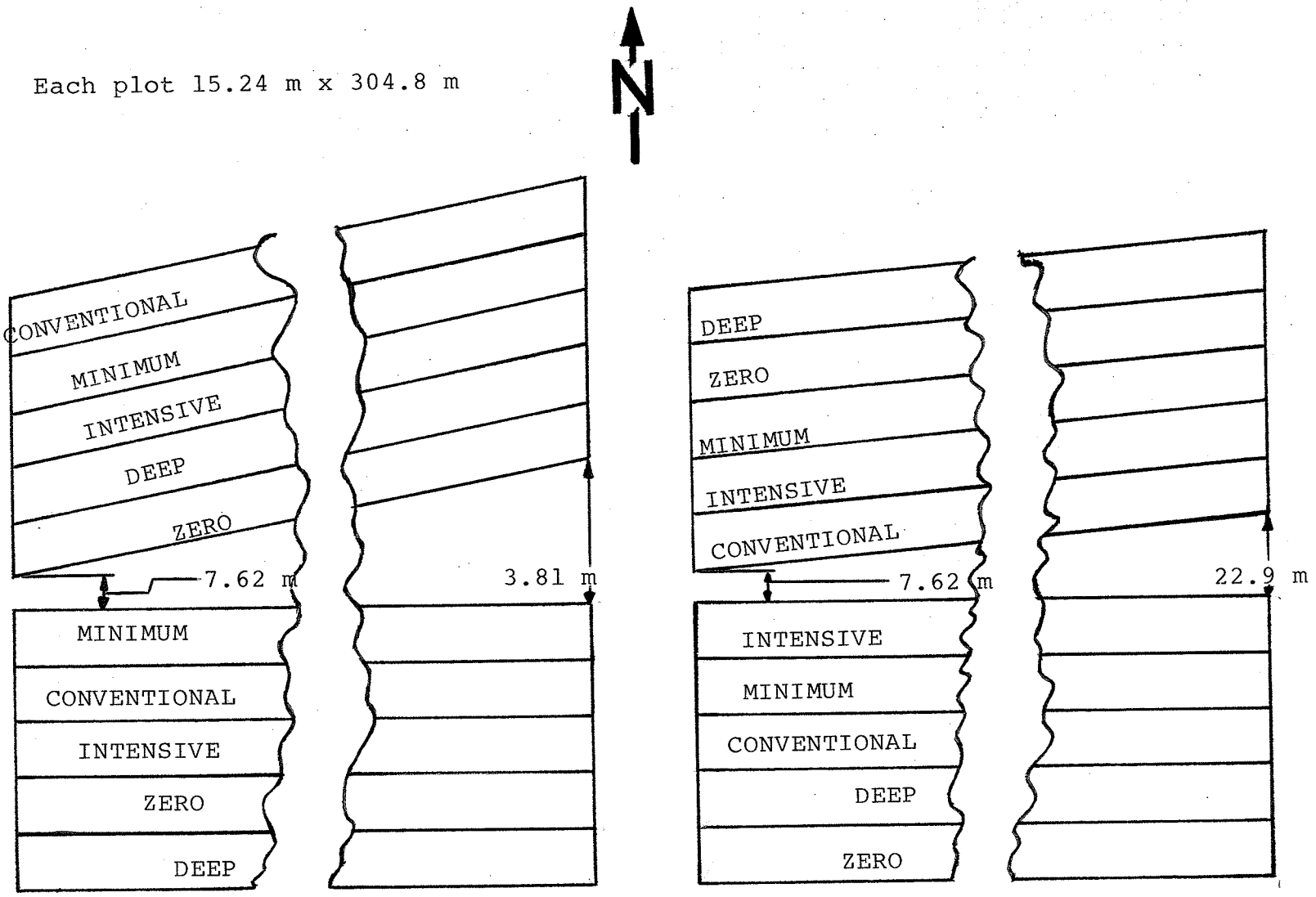


FIGURE 3-1 Plot Layout

- Harrow
Spring - Discer seeder
- Harrow

3. Conventional Tillage

Fall - Discer
Spring - Discer seeder
- Harrow

4. Minimum Tillage

Spring - Discer seeder
- Harrow

5. Zero Tillage

Spring - zero-till drill

The soils upon which the experiment was conducted were Scanterbury, McTavish and Osborne series (Michalyna, 1963). Both the Scanterbury series and McTavish series are moderately drained whereas the Osborne series is poorly drained.

Due to flooding in the Red River Valley in the spring of 1979, the planting season was delayed and therefore the harvest was later than usual. Collection of data was also delayed in the spring due to the flood. However, 25 days of data were collected before the planting began. This was considered sufficient data to evaluate the radiation characteristics of the tillage systems in spring conditions as existed in 1979.

The condition of the soil in the spring is of great importance to the farmer. A soil that will absorb more energy in the spring will warm up quicker. This in turn causes more evaporation of excess soil moisture and creates better germinating conditions for the crop. This allows the farmer to get on his land earlier to ensure an

adequate growing season for an earlier harvest date.

The tillage system which allows the soil to warm up faster in the spring thus has 2 major advantages:

1. The soil warms faster for ideal germination conditions for the seed.

2. An earlier planting date provides for a longer growing season and an earlier, more ideal harvest.

3.2 Solar Radiation Measurements

Solar radiation measurements were taken at various times during the period 79 05 18 to 79 09 19. The time of day for the measurement was randomized to cover most of the daylight hours. The measurements were taken at approximately 0.5 m above the intercepting surface.

Three radiation measurements (W/m^2) were taken:

1. Incoming solar radiation in the range from 250 nm to 2800 nm.
2. Reflected radiation in the range from 250 nm to 2800 nm.
3. Net radiation in the range from 200 nm to 20,000 nm.

From these three radiation measurements the upward longwave radiation can be calculated using equation 3-1.

$$L = S\ (A.S.\ +N) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3\text{-}1)$$

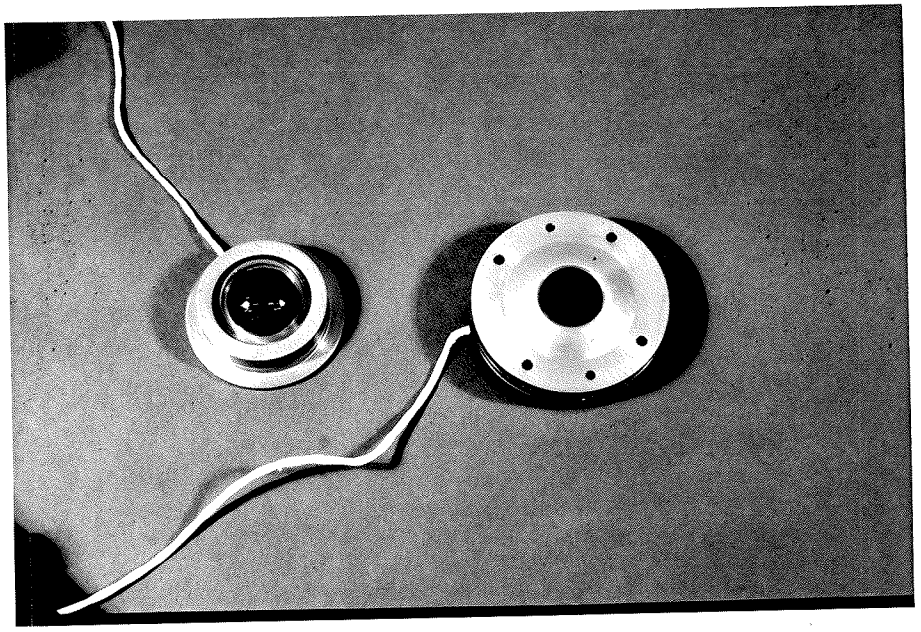
Where L = net upward longwave radiation, W/m^2

S = incoming radiation, W/m^2

AS = reflected shortwave radiation, W/m^2

N = net radiation, W/m^2

The sky transmittance can be calculated by dividing the incoming radiation by the total solar radiation at



(a) (b)

FIGURE 3-2 Radiometer Used in the Research

(a) Model 4048 180° View Angle Pyranometer

(b) Model 4064 Net Radiometer

the top of the atmosphere which can be calculated by equation 2-1. The solar radiation data can be observed for various sky transmittance.

3.3 Equipment for Measuring Solar Radiation

The instruments used for the solar radiation measurements are shown in Figure 3-2. Both instruments were manufactured by Spectran Instruments, Lattabra, California.

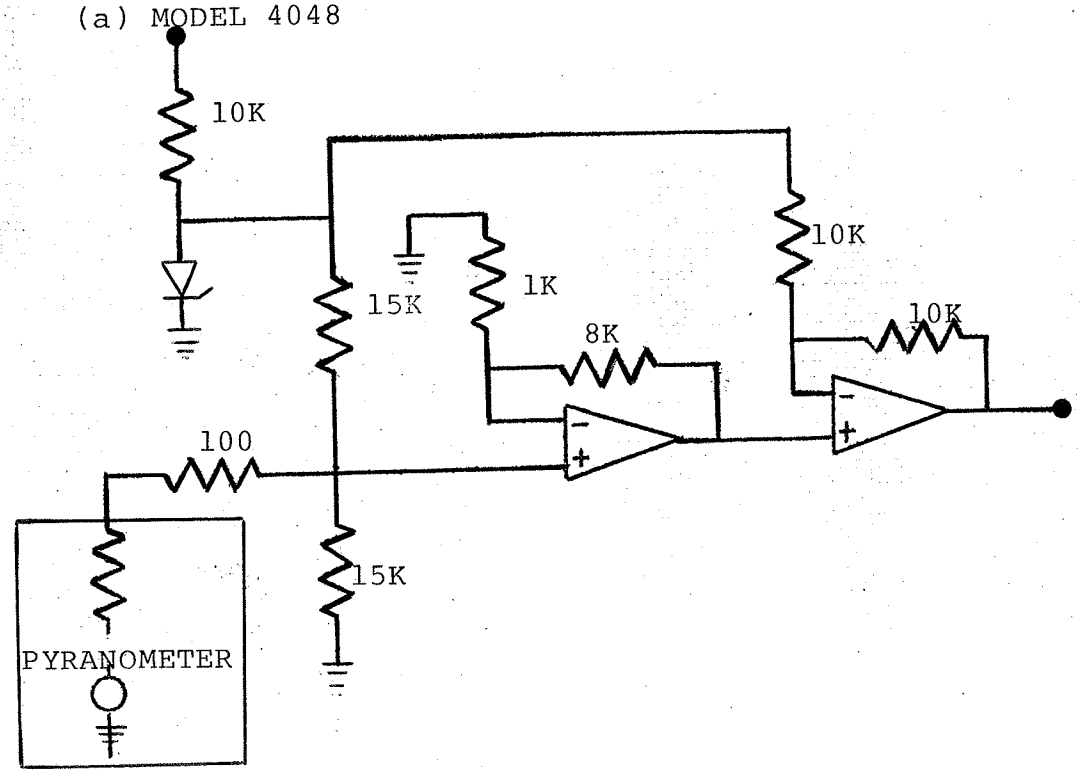
Figure 3-2 (a) shows the model 4048, 180° viewing angle pytranometer, which has a spectral range from 250 nm to 2800 nm. This spectral range covers over 97 percent of the incoming solar radiation. This device gives a voltage signal proportional to the solar radiation power density reaching it. Figure 3-2 (b) shows the Model 4064, net radiometer (pyrheliometer). Since this model has a dual sensor, there are two spectral ranges. The spectral range for the incoming solar radiation is from 200 nm to 6000 nm. This spectral range covers over 99.7 percent of the incoming solar radiation. The sensor measuring the outgoing radiation (reflected and emitted radiation) has a spectral range from 200 nm to 20,000 nm. This spectral range covers the majority of the emitted radiation at a temperature of 300 K. This dual-sensor device gives the solar energy that is retained by the surface. It gives a net signal, the difference between incident solar radiation and surface reflection and reradiation, from the area being monitored.

The manufacturer's specifications are shown in Table 3-1. The instrument calibrations used were as specified

TABLE 3-1: Manufacturer's Specification for Spectran Solar Transducers

Specification	Model 4048	Model 4064
Accuracy	± 2%	± 2%
Temperature Range	-20 to 40°C	- 20 to 40°C
Sensitivity	5 millivolts per solar constant	5 millivolts per cal/cm^2.min
Response Time (1/e)	1 Second	1 Second
View Angle	180° True Hemispherical View Angle	Dual Sensors each with 150° View Angle
Optical Window	Single Hemispherical Dome	Dual Optical Flat Window
Spectral Range	250 - 2800 nm	1) 200 - 6000 nm 2) 200 - 20,000 nm

(a) MODEL 4048



(b) MODEL 4064

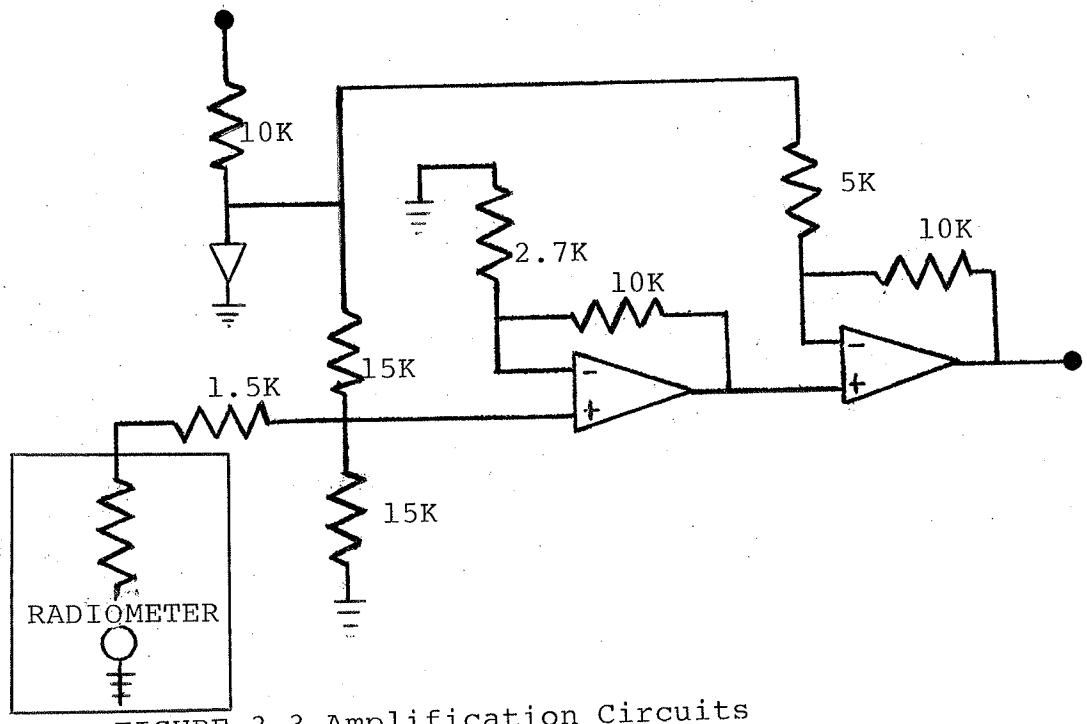


FIGURE 3-3 Amplification Circuits

by the manufacturer since recalibration was not possible during the course of this research.

The voltage meter used had a least count of 0.1 mv. Due to this fact and the fact of the possibility of small differences in the albedo between tillage systems, it was necessary that the output voltage of the instruments be amplified. The amplification circuits are shown in Figure 3-3.

The amplification circuits were calibrated on various sunny days. A best fit line was calculated for each day. Each of the calibration curves was used for both of these instruments. The calibration equations are shown in Appendix A.

An ISCO spectroradiometer with a chart recorder was used to determine the wavelengths of the reflected radiation. The spectroradiometer was used to determine whether different wave lengths were reflected by different tillage systems. The spectral range of the spectroradiometer was from 380 nm to 1350 nm. The restricted spectral coverage led to limited use of the spectroradiometer since only a small portion of the spectrum of the reflected radiation was covered. The spectroradiometer was used with a remote probe and was calibrated to the model 4048 pyranometer.

3.4 Temperature Measurement

Three temperature measurements were taken with the solar radiation measurements. The three measurements were air temperature, soil temperature at the surface and

soil temperature at a depth of 11.5 cm. Again the time of the readings each day was randomized to cover most of the daylight period.

Temperature measurements were taken to compare the temperatures of the different tillage systems. These were compared to the values obtained by Pakaranodom (1972).

3.5 Equipment for Measuring Temperature

An infrared thermometer, a mercury thermometer and copperconstantan thermocouples were used to measure temperatures. Monthly weather data was obtained from the Glenlea Research Station for reference and comparison. This weather data included:

1. Maximum and minimum temperatures
2. Precipitation
3. Soil temperatures at various depths at the station
4. Daily sunshine hours.

The infrared thermometer was used to measure the soil surface temperature. The term "surface" is used to refer to the surface intercepting the solar radiation. This surface will be the soil surface in the spring and the crop canopy in the later part of the growing season. The reason for using an infrared thermometer was to obtain a true reradiation temperature of the emitting surface irrespective of the air temperature.

Since the infrared thermometer measures directly the energy reradiated by the surface according to equation

2-4, it is apparent that the temperature measured depends on the emissivity to the -0.25 power. Various authors such as Fuchs and Tanner (1967) and Gates et al. (1965) estimate that the emissivities of the soil and plant surfaces range from 0.95 to 0.98. By assuming that the emissivity is equal to 1.0, Monteith and Szeicz (1962) and Gates (1963) estimated that this may cause a maximum error of 1°C.

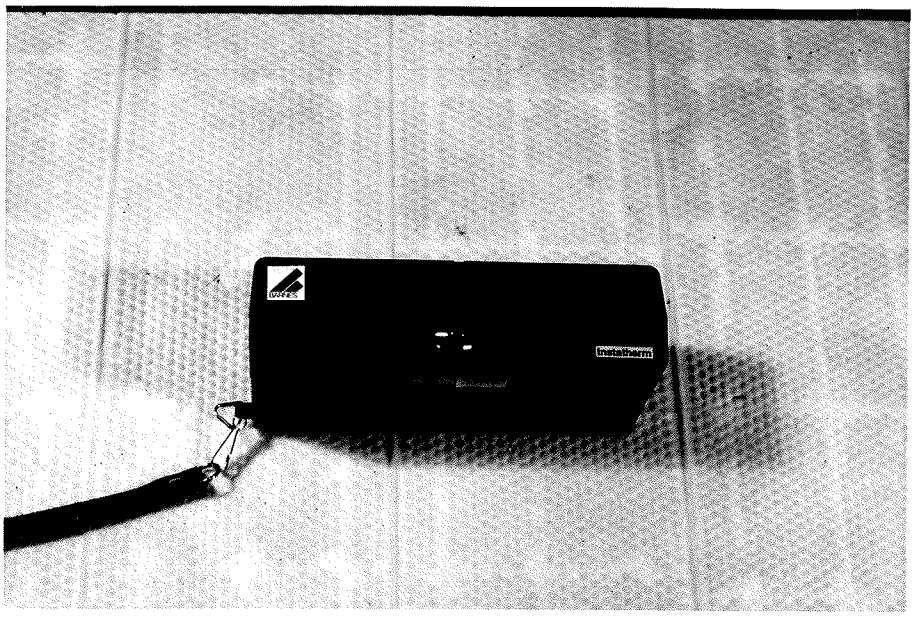
The infrared thermometer was a Barnes Insta-therm manufactured by Barnes Engineering Co. of Stanford, Conn. The infrared thermometer is shown in Figure 3-4. Figure 3-4 (a) shows the intercepting side and Figure 3-4 (b) shows the output side. The thermometer was calibrated before each temperature measurement.

A copper-constantan thermocouple with a potentiometer was used to measure the temperature at a depth of 11.5 cm in the soil. The thermocouple was mounted on the end of a probe which was pushed into the soil for each reading. The potentiometer was allowed to stabilize before the reading was taken.

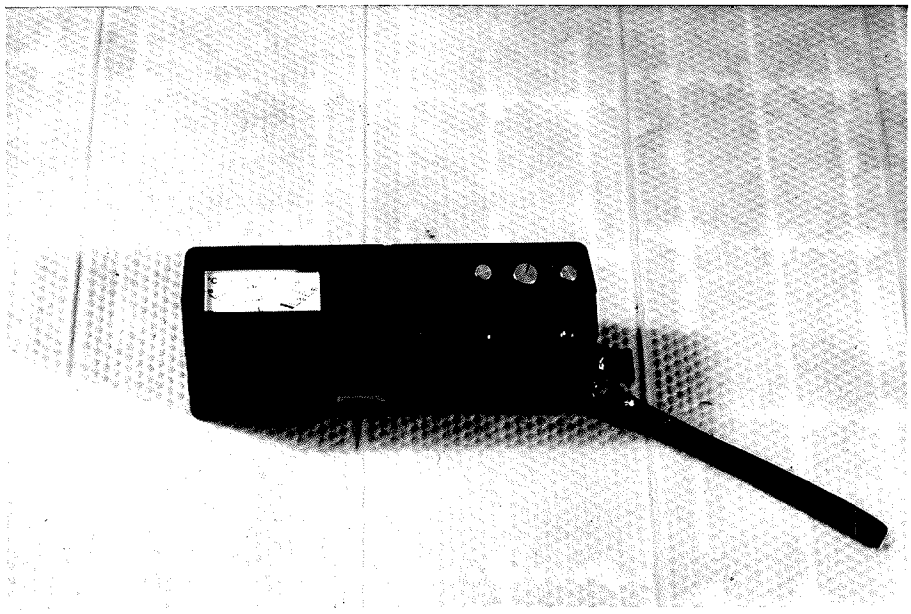
The probe on which the thermocouple was mounted is shown in Figure 3-5. The potentiometer is shown in Figure 3-6. This method of measuring soil temperature was believed to be the most accurate method with the least amount of soil disturbance.

A mercury thermometer was used to measure the air temperature. Unlike the other measurements, the air temperature was measured only once for each set of readings.

The temperature was measured at a height of approximately 1.2 m above the ground. The accuracy of $\pm$ 0.5^{o}C for the thermometer was considered acceptable. The air temperature was compared to the temperatures recorded by the research station.



(a)



(b)

FIGURE 3-4 Infrared Thermometer
(a) Sensing Side
(b) Read-out Side

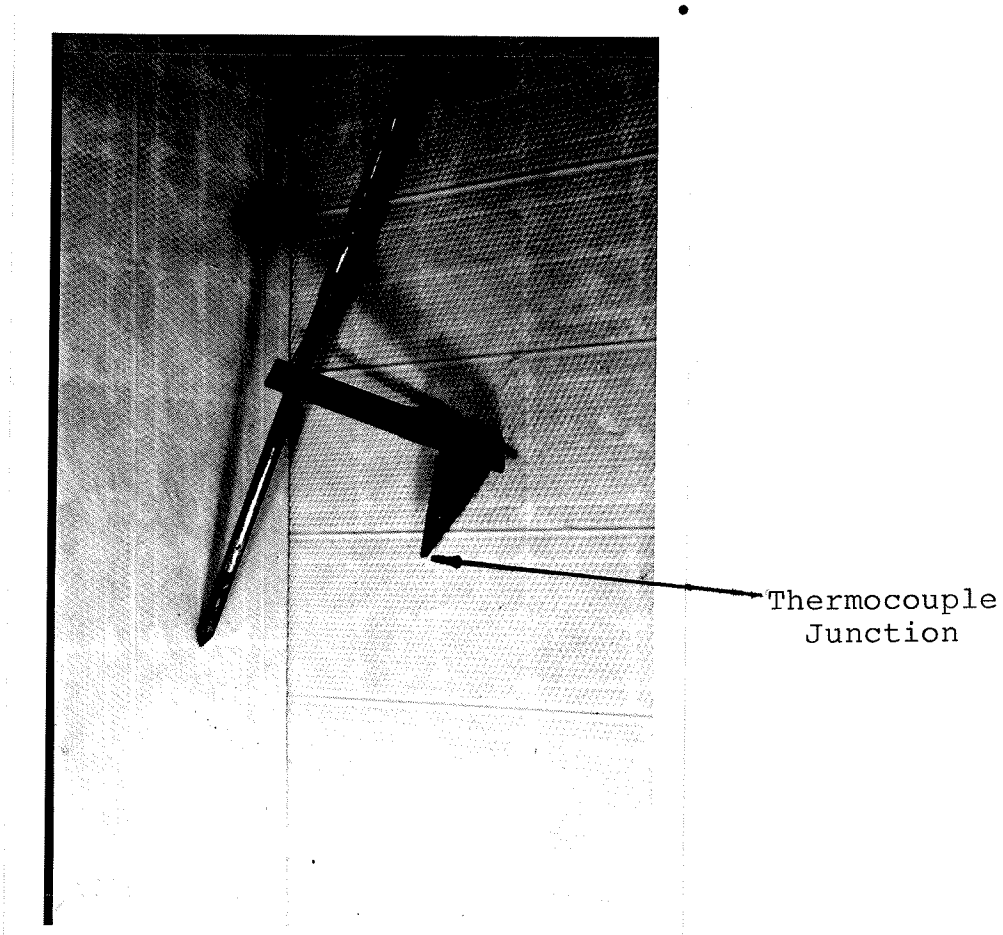


FIGURE 3-5 Probe with Thermocouple

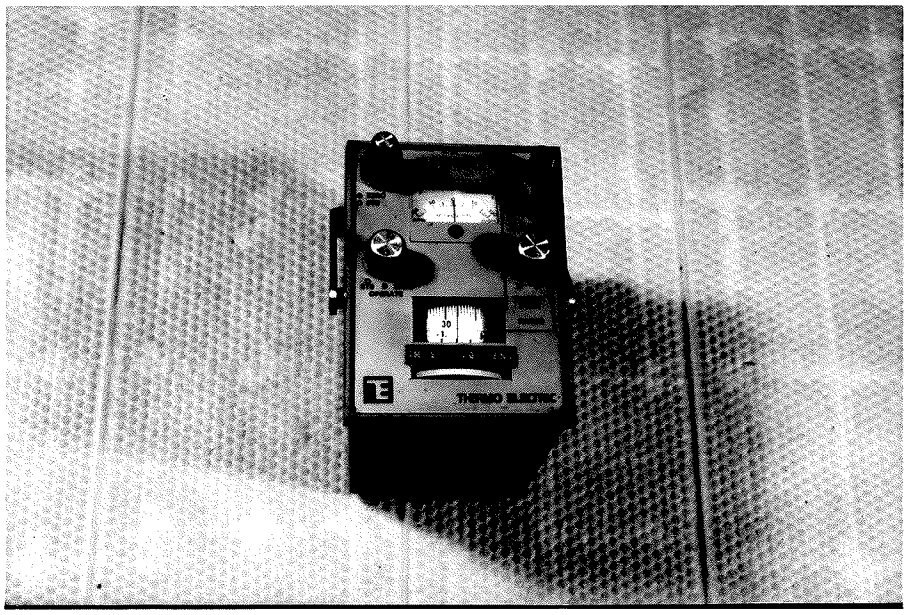


FIGURE 3-6 Potentiometer Used for Thermocouple Read-Out

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Introduction

Solar radiation plays a dominant role in establishing the thermal equilibrium of most plants in their natural environment. The solar radiation data that was collected was analyzed to determine the influence of the tillage system on this thermal equilibrium and the influence of the plant growth stages on the radiation balance. The growing season can be divided into 5 stages of plant development which corresponds to monthly designations. These stages are:

1. Before Planting, May 18 - June 13 (May)
2. Germination and Crop Emergence, June 13 - June 30 (June)
3. Growth and Development, July 1 - July 31 (July)
4. Head and Filling of Heads, August 1 - August 31 (August)
5. Ripening and Drying of Crop, September 1 - Harvest (September)

The collected data was analyzed in two major groups -

1. Before Planting
2. After Planting

The after planting group was then sub-divided into the various monthly designations and each analyzed as a group.

In all cases radiation balance equations were derived to give the radiation characteristics for the various

soil surfaces. The albedo obtained from these equations was compared to the average albedo of the collected data for that particular group.

Albedo models were established from the collected data for each monthly group. From these equations an approximation of the albedo can be calculated for a given soil moisture content and a given solar zenith angle.

4.2 Radiation and Reflection Characteristics of Soil Surfaces: Before Planting

4.2.1 Radiation Balance

The radiation balance of the soil surface in the spring is of great importance to the farmer. Monteith and Szeicz (1961) have shown that the radiative characteristics of agricultural surfaces can be described by equations 2-7 and 2-8. A regression analysis was performed with the data collected before planting for each of the five different tillage systems. The models proposed by Monteith and Szeicz were used. The results are shown in Tables 4-1 and 4-2 and Figures 4-1.

At high levels of incoming solar radiation the soil surface of the intensive tillage system retained the highest amount of solar radiation (Figure 4-1). The zero tillage system retained the least. However, for low levels of incoming solar radiation (less than 200 W/m^2) the zero tillage system retained the most solar radiation. Table 4-2 shows the order of net solar radiation for two different levels of incoming solar radiation.

The constant L0 in equation 2-8 is the net longwave

radiation balance for zero incoming radiation. A negative value indicates the net longwave radiation was upwards, which is a loss for the surface. This was the amount of radiation emitted by the soil surface at night.

The results in Table 4-1 show the albedo values of the soil surfaces for the different tillage systems. All of the regression equations have a correlation coefficient of 0.945 or higher. The zero tillage soil surface reflected the most radiation. From Table 4-1 the albedo of this surface was 0.144. This means that approximately 14.4 percent of the incoming shortwave radiation was reflected. The regression correlation coefficient was the lowest of the five equations. This was possibly due to the irregular surface cover due to the stubble, areas of bare soil and areas covered with straw. The minumum tillage soil surface had the second highest albedo. Approximately 10.2 percent of the incoming shortwave solar radiation was reflected. The correlation coefficient was the second lowest. Since the minimum tillage plots were not touched in the fall, the surface characteristics would be expected to be similar to the zero tillage surface. It was noted, however, that the zero tillage soil surface had more stubble than the minimum tillage plots. The percent of incoming solar radiation reflected from the soil surfaces of the conventional tillage system, deep tillage system and the excessive tillage system were 8.9, 7.2 and 6.5 respectively.

The arithmetical averages for the albedos from the

TABLE 4-1: Radiation Balance Before Planting

Tillage System	Equation	Albedo	Correlation Coefficient	Average Albedo of Collected Data
Zero Tillage	N=0.856(S)-139.71	0.144	0.945	.172
Minimum Tillage	N=0.898(S)-174.29	0.102	0.963	.167
Conventional Tillage	N=0.911(S)-173.87	0.089	0.973	.147
Deep Tillage	N=0.928(S)-158.64	0.072	0.976	.104
Intensive Tillage	N=0935(S)-163.85	0.065	0.976	.090

TABLE 4-2: Net Radiation for Two Levels of Incoming Shortwave Radiation

Tillage System	Incoming Radiation (S) (W/m^2)	Net Radiation (N) (W/m^2)
Zero Tillage	200	31.59
	800	545.5
Minimum Tillage	200	5.30
	800	544.07
Conventional Tillage	200	8.37
	800	555.11
Deep Tillage	200	27.01
	800	583.95
Intensive Tillage	200	23.18
	800	584.27

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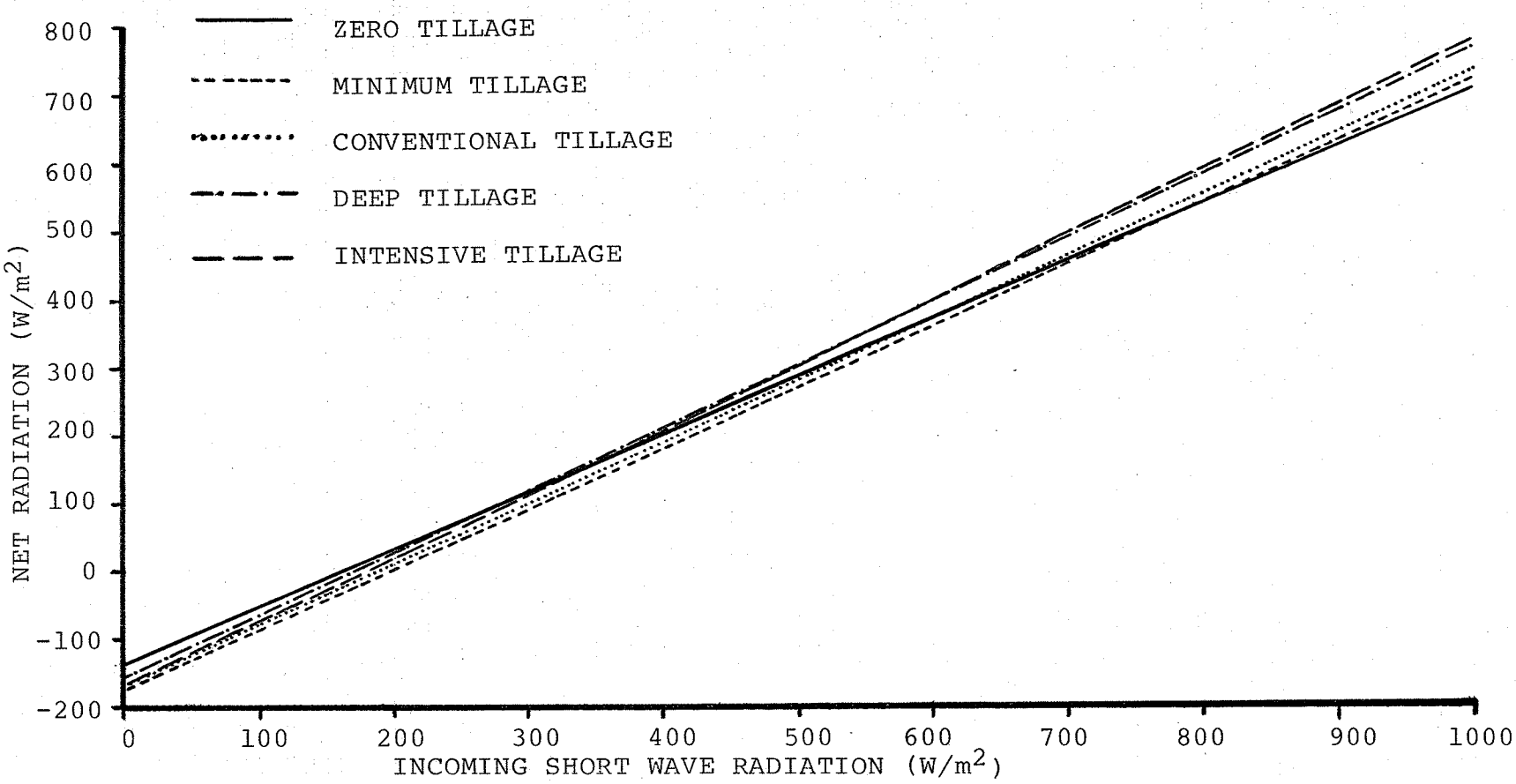


FIGURE 4-1 Radiation Balance Before Planting

data differ from the albedo using the Monteith model. However, the trend remained the same, with the zero tillage surface having the highest and the excessive tillage having the lowest. It should be noted that for the five different tillage systems, the more stubble or surface cover, the higher the surface albedo. The zero tillage surface had the most crop cover in the spring and also the highest albedo. The excessive tillage surface had the least crop cover and the lowest albedo. This was due to the fact that the soil had a lower albedo than the stubble.

Monteith and Szeicz (1961) found that heating coefficients are only valid for clear skies. Davies and Buttimore (1969) disagree with this. In this study, for the data collected before planting, the sky transmittance was calculated and the heating coefficients were calculated for 3 different sets of data, which are as follows:

1. All collected data
2. Data for sky transmittance greater than 0.5
3. Data for sky transmittance between 0.5 and 0.25.

The equations and heating coefficients are shown in Table 4-3.

The most realistic values for the heating coefficients are from the equations using all the collected data. The values are similar to the values Montieth and Szeicz (1961) obtained. From these equations the intensive tillage system had the largest heating coefficient. This implies

TABLE 4-3: Radiation Balance Equation Using Heating Coefficients: Before Planting

Tillage System	Equation	Heating Coefficient	Correlation Coefficient
1. All Collected Data			
Zero Tillage	N=0.957 (1-A)S - 99.21	0.0455	0.946
Minimum Tillage	N=0.993 (1-A)S - 127.09	0.0067	0.965
Conventional Tillage	N=0.984 (1-A)S - 123.53	0.0165	0.972
Deep Tillage	N=0.959 (1-A)S - 112.82	0.0426	0.975
Intensive Tillage	N=0.944 (1-A)S - 116.39	0.0589	0.973
2. Sky Transmittance Greater Than 0.5			
Zero Tillage	N=1.167 (1-A)S - 266.39	-0.143	0.926
Minimum Tillage	N=1.136 (1-A)S - 241.82	-0.120	0.952
Conventional Tillage	N=1.126 (1-A)S - 240.44	-0.112	0.966
Deep Tillage	N=1.180 (1-A)S - 301.56	-0.153	0.976
Intensive Tillage	N=1.126 (1-A)S - 277.61	-0.112	0.972
3. Sky Transmittance 0.5 To 0.25			
Zero Tillage	N=0.527 (1-A)S - 66.33	0.896	0.886
Minimum Tillage	N=0.607 (1-A)S + 29.16	0.648	0.981
Conventional Tillage	N=0.712 (1-A)S - 1.13	0.404	0.984
Deep Tillage	N=0.884 (1-A)S - 56.75	0.131	0.949
Intensive	N=0.791 (1-A)S - 36.31	0.263	0.970

that the intensive tillage surface will warm up the quickest during the day and cool off the quickest at night.

The equations using the data for sky transmittance of more than 0.5, all had negative heating coefficients. Negative values of heating coefficients are surprising since they define a decrease in net longwave radiation loss as net radiation increases.

The equation using the data for sky transmittance of between 0.5 and 0.25 had heating coefficients which ranged from a low of 0.1311 for the deep tillage surface, to a high of 0.8961 for the zero tillage surface.

Figure 4-2 show the data from Table 4-3 graphically. From this figure the estimated longwave loss can be determined for the various sky conditions. That is, the longwave loss is the difference between a line, starting at the origin having a slope of 1, (i.e.) NET RADIATION = NET SHORTWAVE RADIATION, and the line for the respective sky condition.

4.2.2 Reflection as a Function of Wavelength

A spectroradiometer was used to determine the reflection from the soil surfaces of the different tillage systems, as a function of wavelength. Figure 4-3 shows a typical plot for incoming radiation for a sunny day just after the crop had been planted, as taken by the spectroradiometer.

Figure 4-4 shows the reflected radiation as a function

of wavelength for the soil surfaces of the different tillage systems. From Figure 4-4 it can be seen that the general trends of all the tillage systems were the same. Only the amount of radiation reflected varied between the different tillage systems. The surface reflection has a low at a wavelength of 450 nm. Then the reflection slightly increases as the wavelength increases. At a wavelength of approximately 700 nm, the reflection rises sharply. This high level of reflection remains until a wavelength of approximately 900 nm. The reflection then decreases to a low level at a wavelength of 950 to 1050 nm. There was a second rise and plateau in the radiation that was reflected in the range of 1050 to 1200 nm wavelength. Then there is a final decrease in the reflected radiation. The deep tillage soil surface had a peak in the reflected radiation at a wavelength of 1120 nm instead of a second plateau.

The soil surface of the zero tillage system had the highest overall albedo. From Figure 4-4 it can be noted that for most wavelengths the zero tillage surface also had the highest reflection. Figure 4-5 shows the percent of incoming radiation that is reflected for each wavelength, for each of the different tillage systems.

The results in this study are similar to those found by Billings and Morris (1951). The major difference between the study by Billings and Morris (1951) and this present study is that in the study by Billings and Morris,

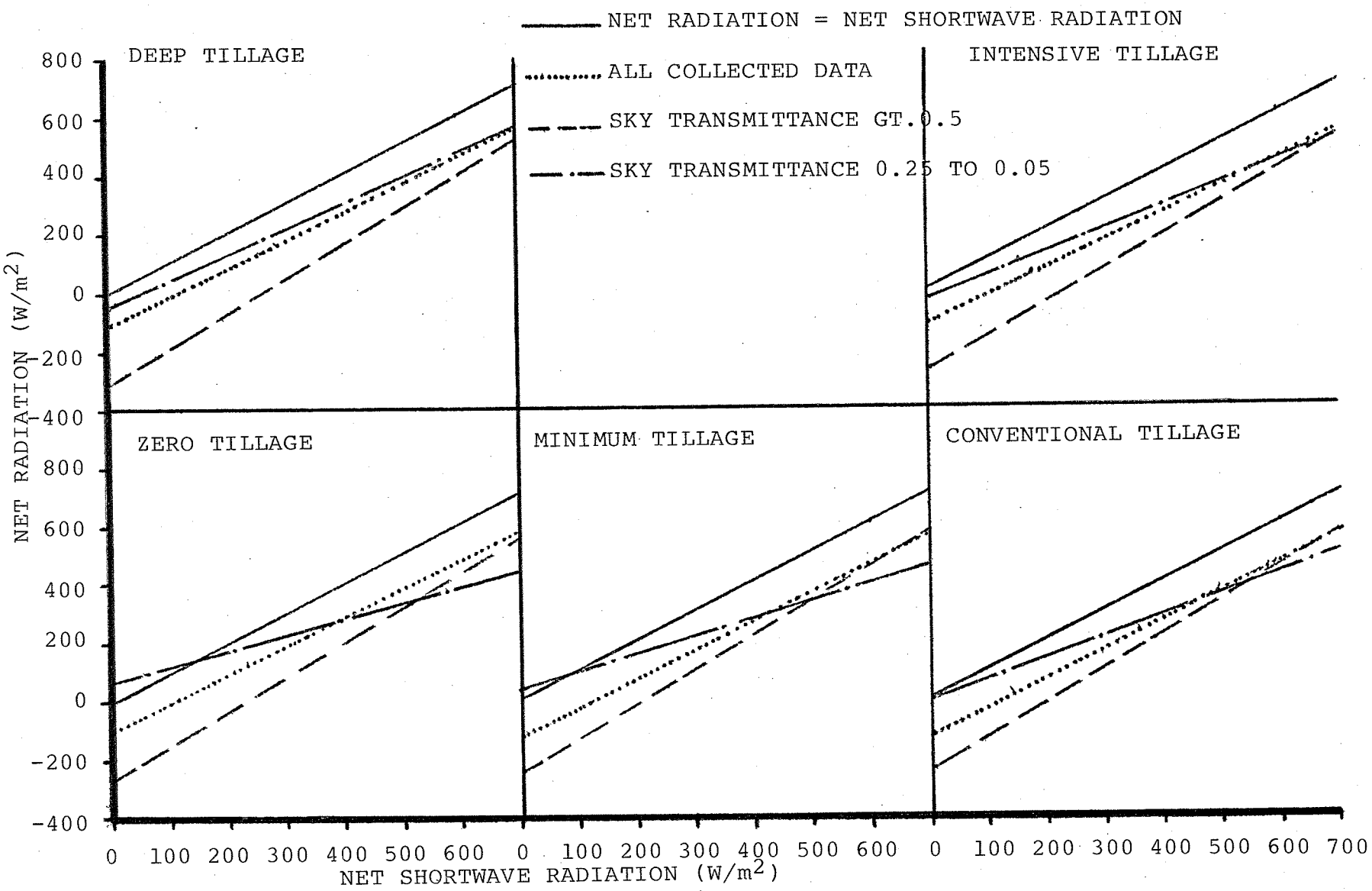


FIGURE 4-2 Radiation Balance Before Planting

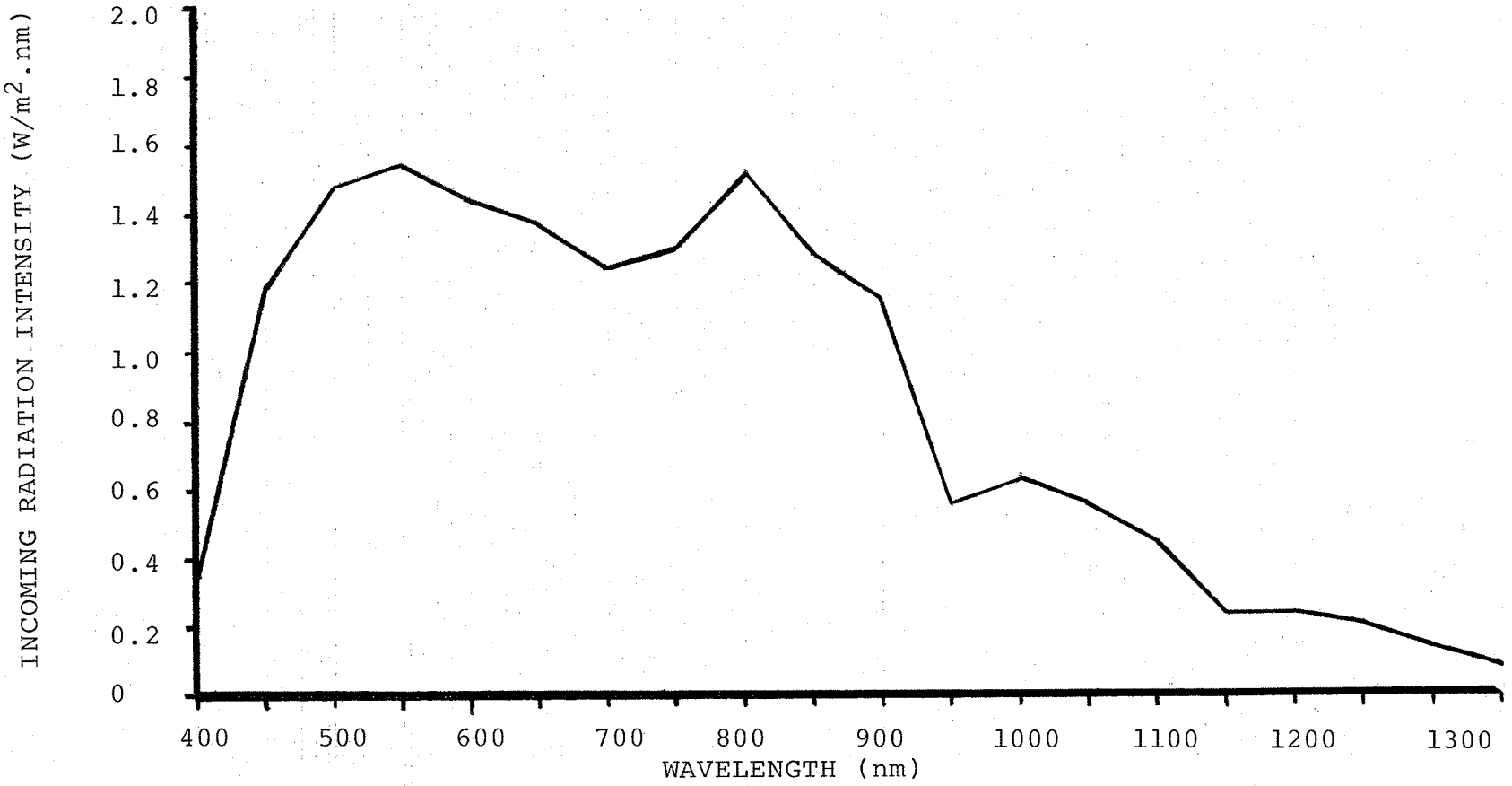


FIGURE 4-3 Incoming Radiation as a Function of Wavelength

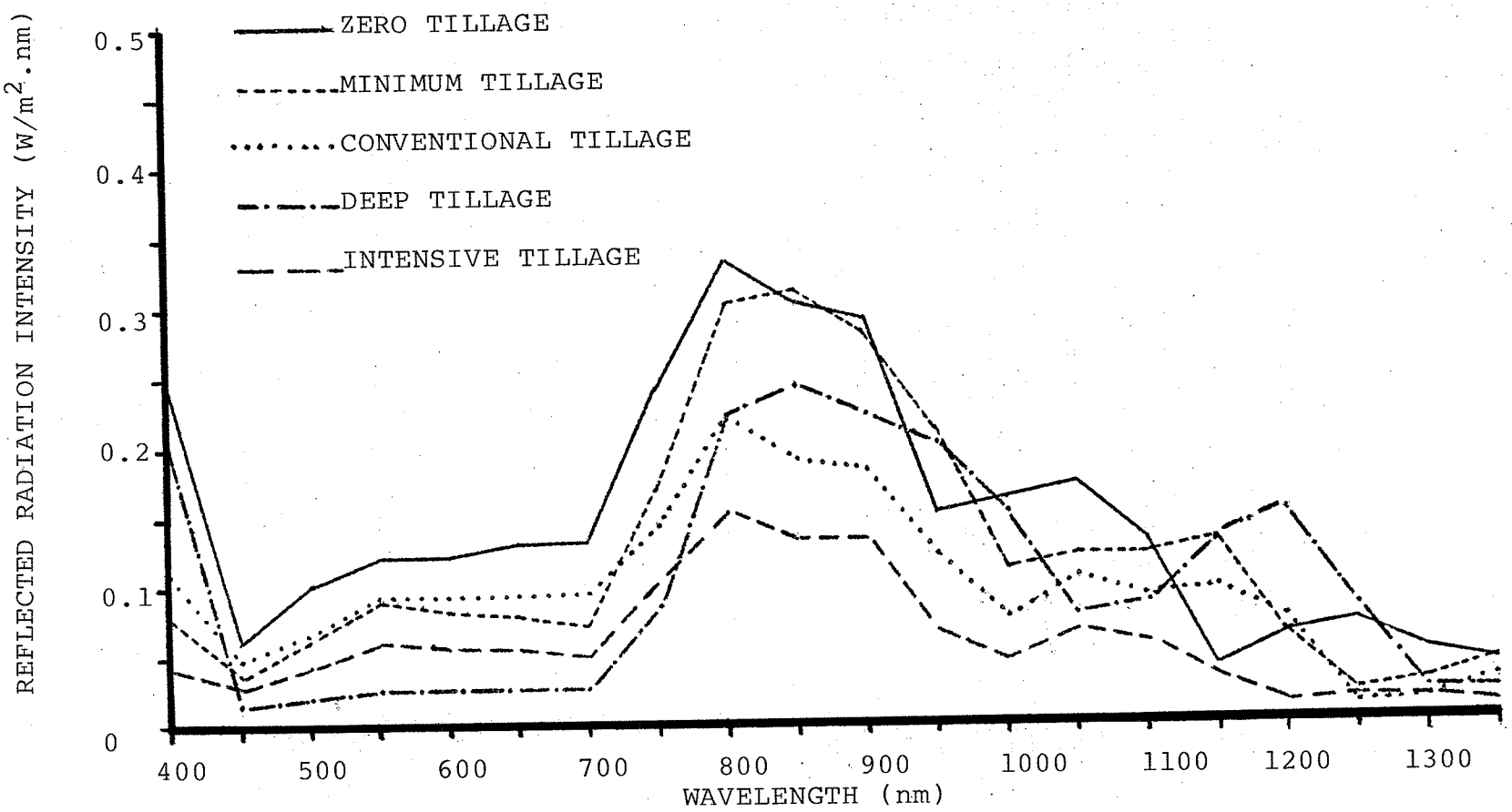


FIGURE 4-4 Reflected Radiation From Different Tillage Systems as a Function of Wavelength

at wavelengths above 700 nm. the percent of reflected radiation was almost constant at approximately 50 to 70 percent. In this present study the percent of reflected radiation did not stay constant but peaked at wavelengths of approximately 950 nm. 1150 nm. and at 1300-1350 nm. The peaks varied in height for the different tillage systems.

Table 4-4 shows the albedo values obtained from the spectroradiometer, as well as the soil moisture and zenith angle for each system. These values agree with the previous data that has been discussed.

4.2.3 Albedo Models

In the studies conducted by Nkemdirim (1972 a and b) the albedo was expressed as a function of the solar zenith angles. Various authors have also noted that wet soils have a smaller albedo than dry soils of the same colour. From the data collected before the crops were planted, two models for the albedo have been developed.

The first model is in the form of:

$$A = W + xM + yZ \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4\text{-}1$$

Where A = albedo

M = soil moisture (percent)

Z = Zenith angle (degrees)

w, x and y are regression constants

The second model is an exponential equation in the form of:

$$A = v + wM + x \exp(yZ) \quad \ldots\ldots\ldots\ldots\ldots \quad 4\text{-}2$$

Where A = albedo

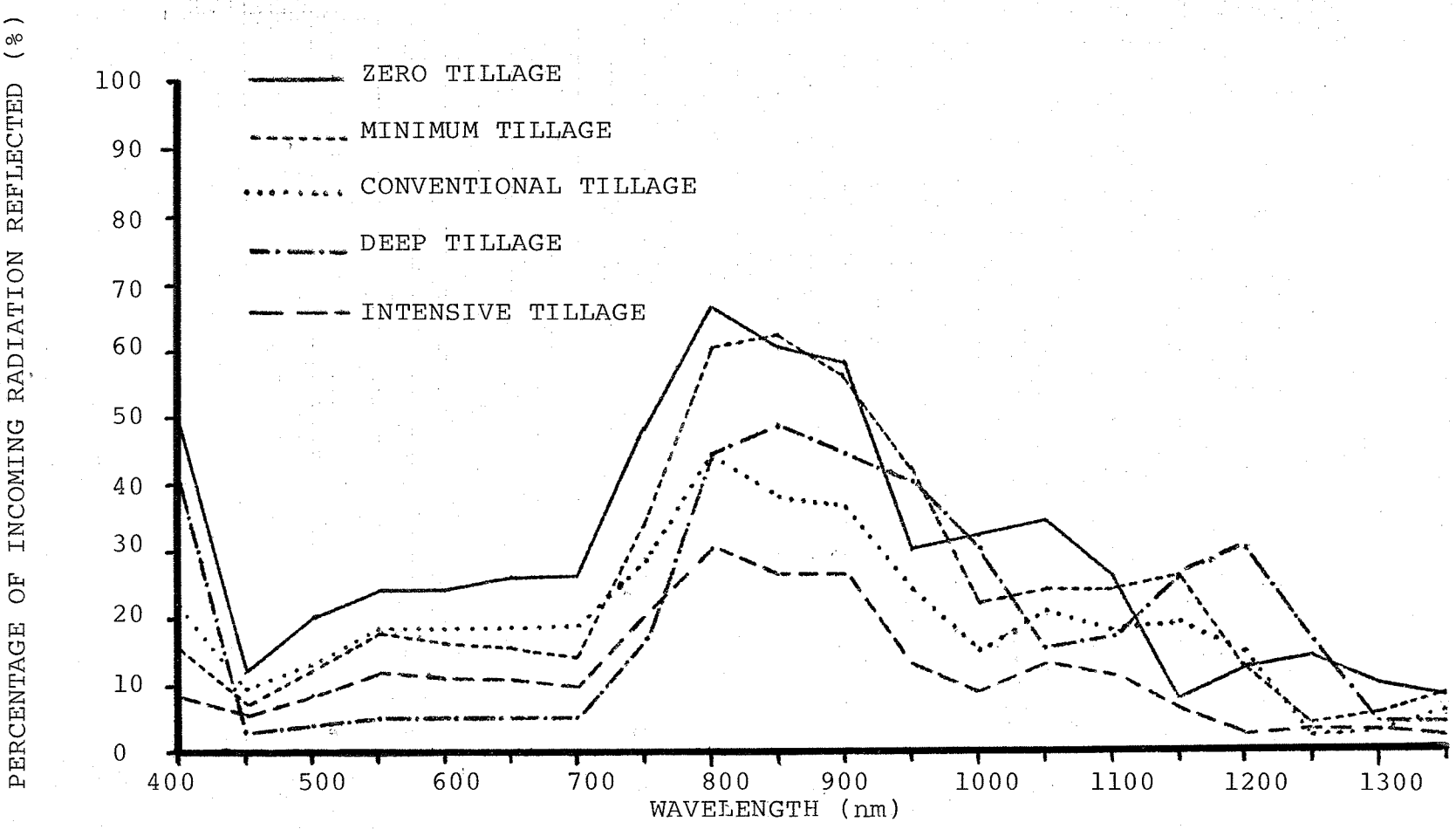


FIGURE 4-5 Percentage Reflected as a Function of Wavelength

TABLE 4-4: Spectroradiometer Results After Planting but Before Crop Emergence

Tillage System	Incoming Radiation (W/m^2)	Reflected Radiation (W/m^2)	Albedo	Moisture Content 1/
Zero Tillage	952.93	140.08	0.1470	20.18
Minimum Tillage	885.61	106.45	0.1202	11.02
Conventional Tillage	925.23	100.85	0.1090	17.59
Deep Tillage	961.05	95.24	0.0991	17.18
Intensive Tillage	778.77	53.19	0.0683	15.78

1/ Average soil moisture content of top 5 cm. of soil in percent

M = soil moisture (percent)

Z = zenith angle (degrees)

v, w, x and y are regression constants

The data were analyzed for both forenoon and afternoon. It should be noted that the forenoon and afternoon were two distinctively different models. In all cases, the data were for sky transmittance of greater than 0.5. The first model for each tillage system is shown in Table 4-5. The second model for each tillage system is shown in Table 4-6. It should be noted that in every case the multiple correlation coefficient was higher for the multiple linear equation. In all but one case, the multiple correlation coefficient was higher for the afternoon than the before noon model.

Figure 4-6, to 4-14, (even), are plots of the albedo versus soil moisture for the albedo model equations. For these plots a zenith angle of 30 degrees was used, this is approximately solar noon. In most cases the trend was a decrease in albedo for an increase in soil moisture content. This agrees with most other authors.

Figure 4-7 to 4-15, (odd), are plots of the albedo versus zenith angle for the albedo model equations. For these plots a soil moisture of 20 percent was used. There is a clear trend in all cases for an increase in albedo for an increase in zenith angle. This is also indicated in literature.

For sky transmissivities less than 0.5 the corre-

TABLE 4-5: Albedo Equations (A = w + xM + yZ. For sky transmittance of greater than 0.5)

Tillage System and Time	Equation	Correlation Coefficient
Zero Tillage		
a.m.	A =1.05E-01 - 7.30E-04M+2.53-03Z	0.5177
p.m.	A = 1.03E-01 4.90E-04M+2.14E-03Z	0.7865
Minimum Tillage		
a.m.	A = 1.63E-01 - 1.22E-03M+1.54E-03Z	0.650
p.m.	A = 4.11E-02 + 5.0 E-05M+3.20E-03Z	0.827
Conventional Tillage		
a.m.	A = 5.41E-02 - 6.7 E-04M+3.29E-03Z	0.619
p.m.	A = 4.96E-02 - 6.0 E-05M+2.47E-03Z	0.707
Deep Tillage		
a.m.	A = 3.72E-02 + 1.1 E-04M+1.65E-03Z	0.511
p.m.	A = 4.13E-02 - 1.6 E-04M+1.43E-3Z	0.640
Intensive Tillage		
a.m.	A = 2.11E-02 - 4.0 E-04M+2.08E-03Z	0.491
p.m.	A = 3.63E-02 - 2.9 E-04M+1.11E-03Z	0.534

TABLE 4-6: Albedo Equations (A=v+wM+xEXP (yZ). For sky transmittance of greater than 0.5)

Tillage System and Time	Equation	Correlation Coefficient
Zero Tillage		
a.m.	A = 1.32E-03 + 1.63E-05M+1.01E-01 EXP (1.33E-02Z)	0.430
p.m.	A = 3.41E-05 + 7.82E-06M+1.07E-01 EXP (1.04E-02Z)	0.694
Minimum Tillage		
a.m.	A = 9.27E-05 - 1.43E-05M+1.15E-01 EXP (1.03E-02Z)	0.376
p.m.	A = 1.56E-03 - 2.80E-05M+8.67E-02 EXP (1.56E-02Z)	0.756
Conventional Tillage		
a.m.	A = 1.23E-03 + 2.44E -5M+7.01E-02 EXP (2.03E-02Z)	0.562
p.m.	A - 1.68E-03 - 3.85A-05M+8.14E-02 EXP (1.31E-02Z)	0.594
Deep Tillage		
a.m.	A = 3.08E-05 - 5.09E-07M+5.47E-02 EXP (1.61E-02Z)	0.500
p.m.	A = 4.4E-05 + 1.00E-06M+ 5.43E-02 EXP (1.18E-02Z)	0.517
Intensive Tillage		
a.m.	A = 6.05E-04+9.96E-06M + 3.39E-02 EXP (2.43E-02Z)	0.488
p.m.	A = 2.34E-03-6.57E-05M + 4.19E-02 EXP (1.12E-02Z)	0.413

lation was very small and was not considered.

In studies conducted by Nkemdirim (1972 a and b) it was noted that the forenoon values of albedo were lower than the afternoon values for similar zenith angles. This was not the case in this study.

From the models obtained in this study before crops were planted, it was noted that only for small zenith angles the afternoon albedo values were higher than the albedo for the morning. For zenith angles greater than 20 degrees the albedo, obtained from the models for the forenoon, were higher than the afternoon values. It should be realized, however, that in the location of this study the zenith angle is never below 25 degrees, due to the latitude of Winnipeg. From this it can be stated that the albedo in this location is higher in the forenoon than in the afternoon.

4.3 Statistical Analysis of Albedo: Before Planting

An analysis of variance was performed on the collected albedo data. This is shown in Appendix B. From the analysis it was concluded that the differences in albedos were due to the differences in the tillage treatments. It was found that the average albedos for the zero tillage plots, the minimum tillage plots and the conventional tillage plots were not significantly different at the 5 percent level. The albedos of these plots were significantly different from the deep tillage plots and the intensive tillage plots at the 1 percent

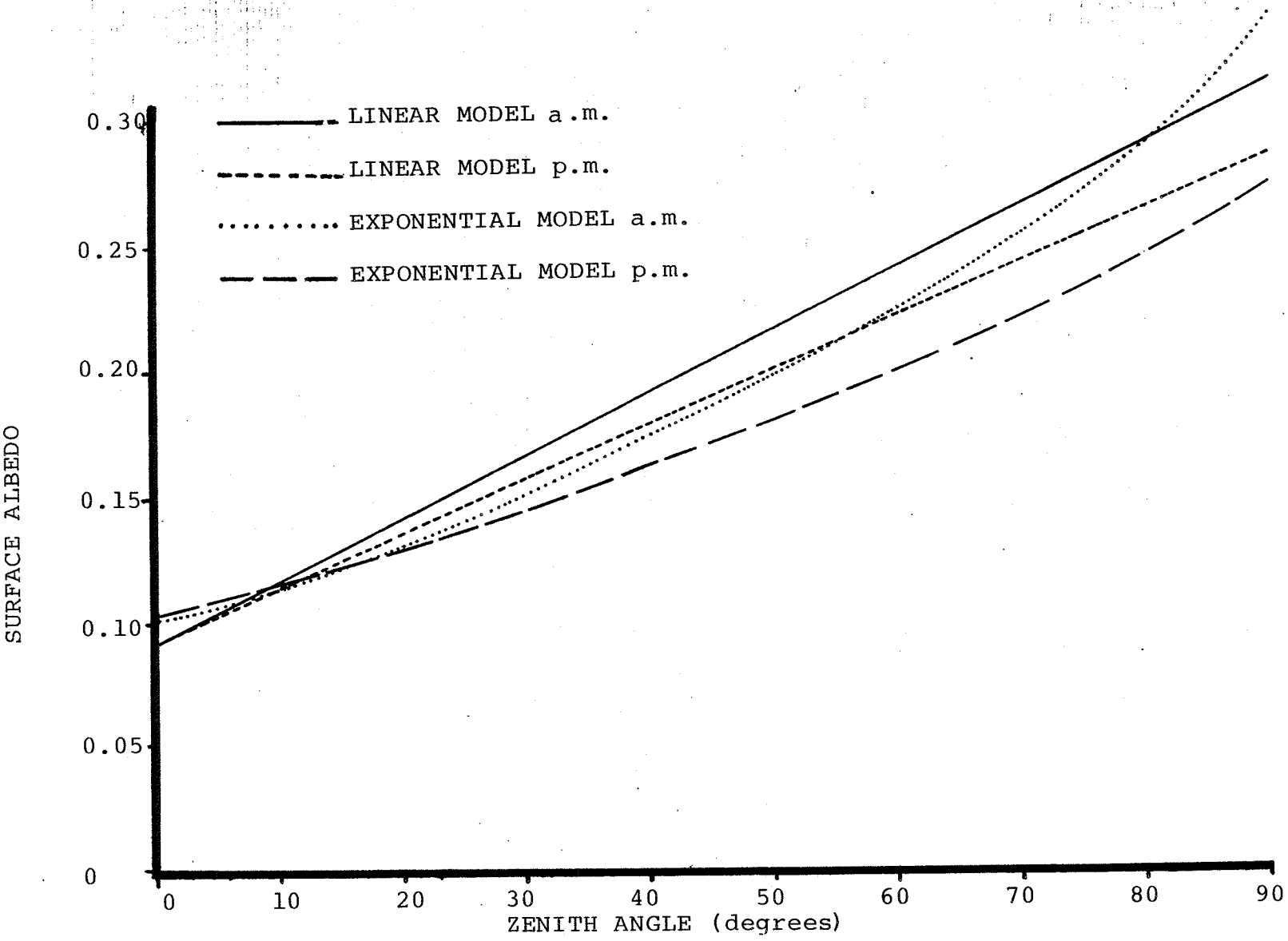


FIGURE 4-6 Albedo Model vs. Zenith Angle for Zero Tillage

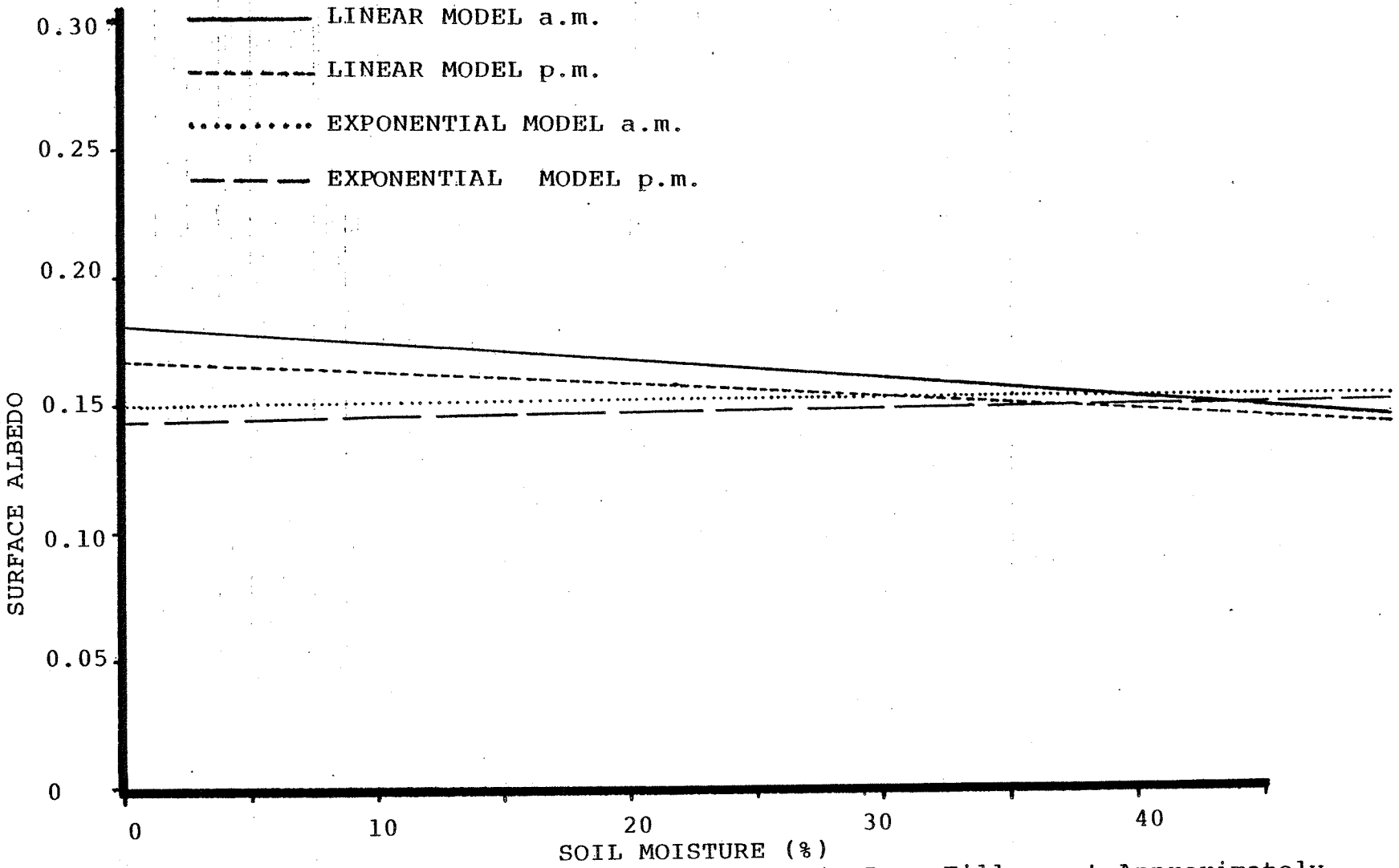


FIGURE 4-7 Albedo Model vs. Soil Moisture For Zero Tillage at Approximately Solar Noon

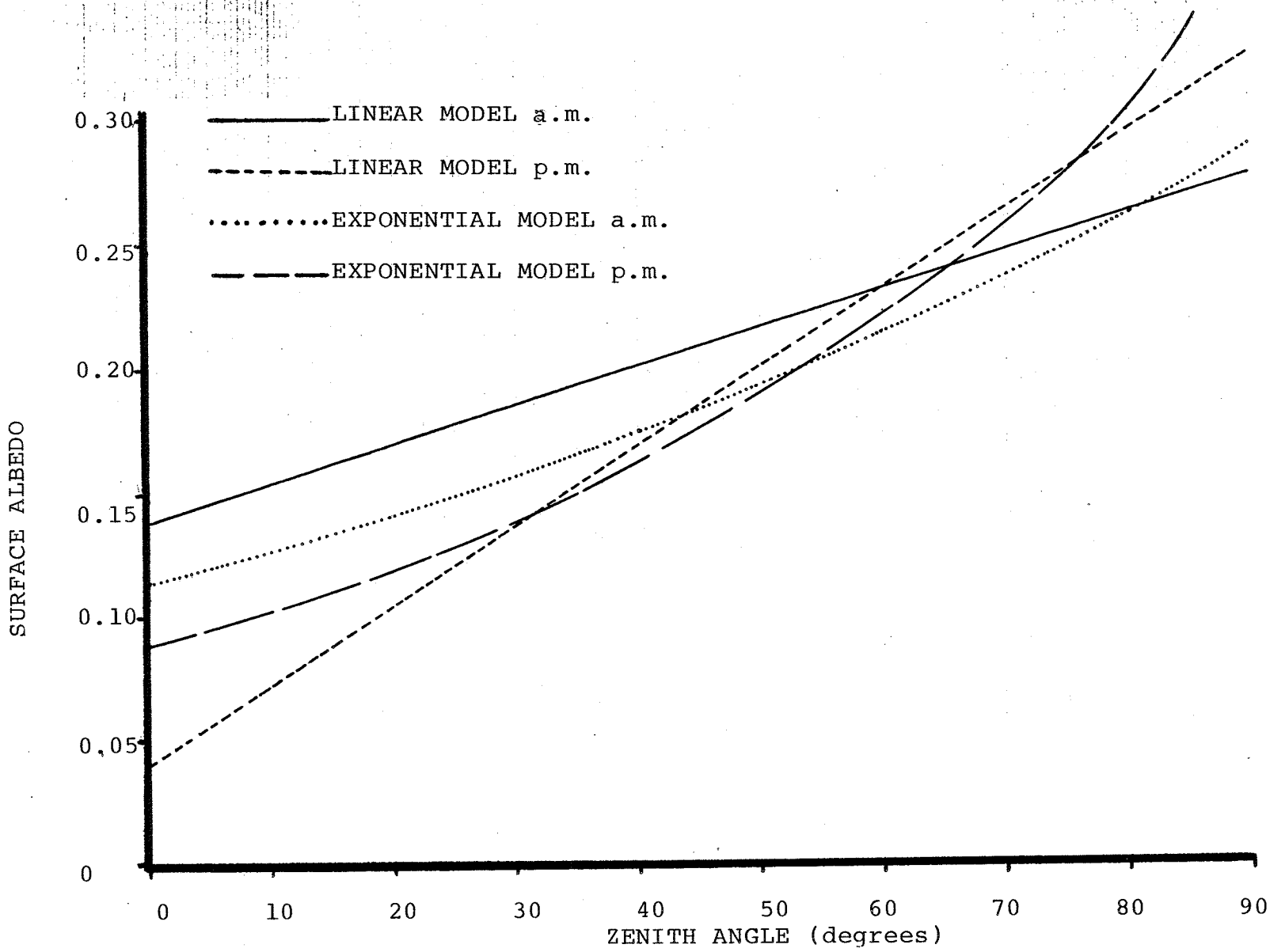


FIGURE 4-8 Albedo Model vs. Zenith Angle for Minimum Tillage

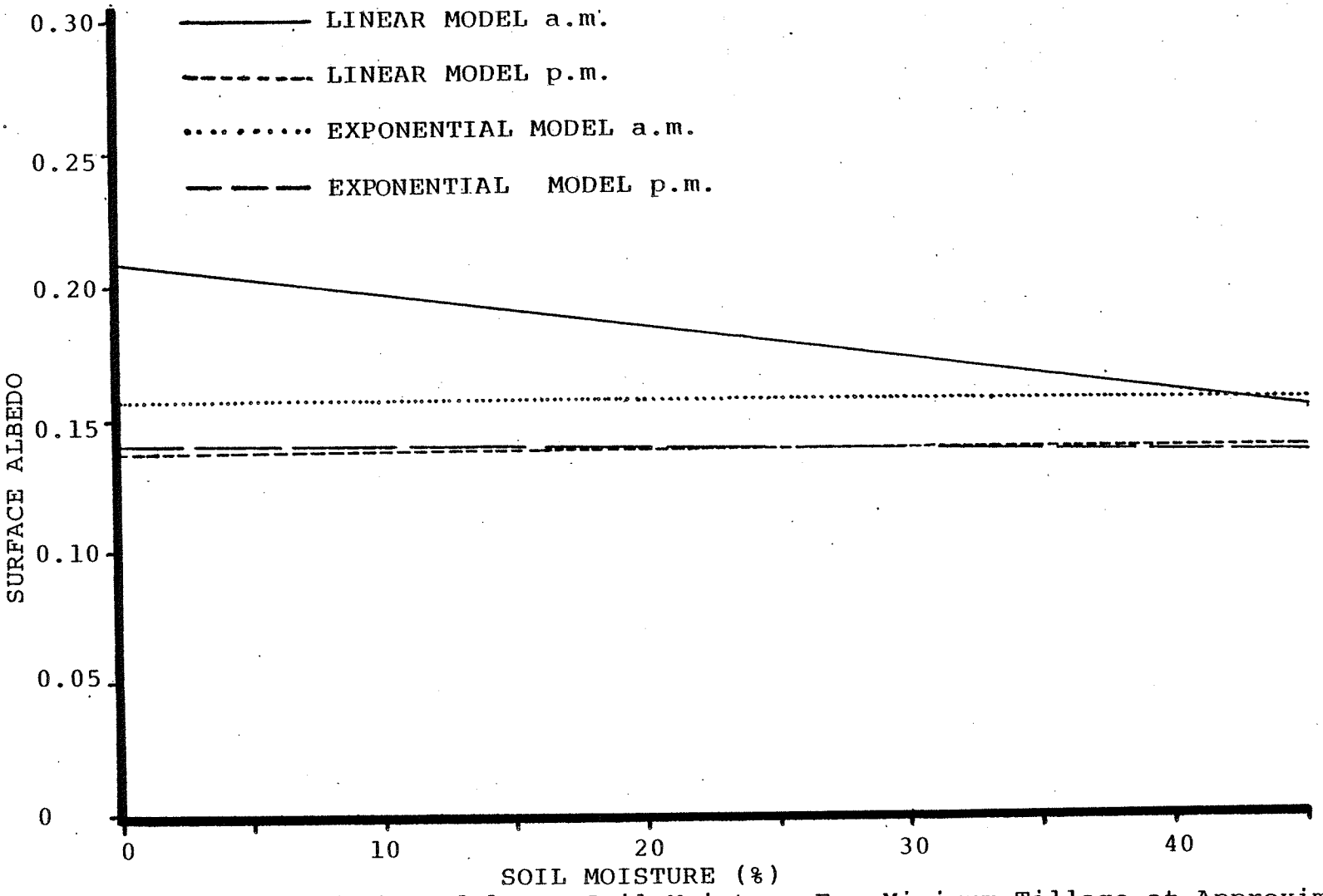


FIGURE 4-9 Albedo Model vs. Soil Moisture For Minimum Tillage at Approximately Solar Noon

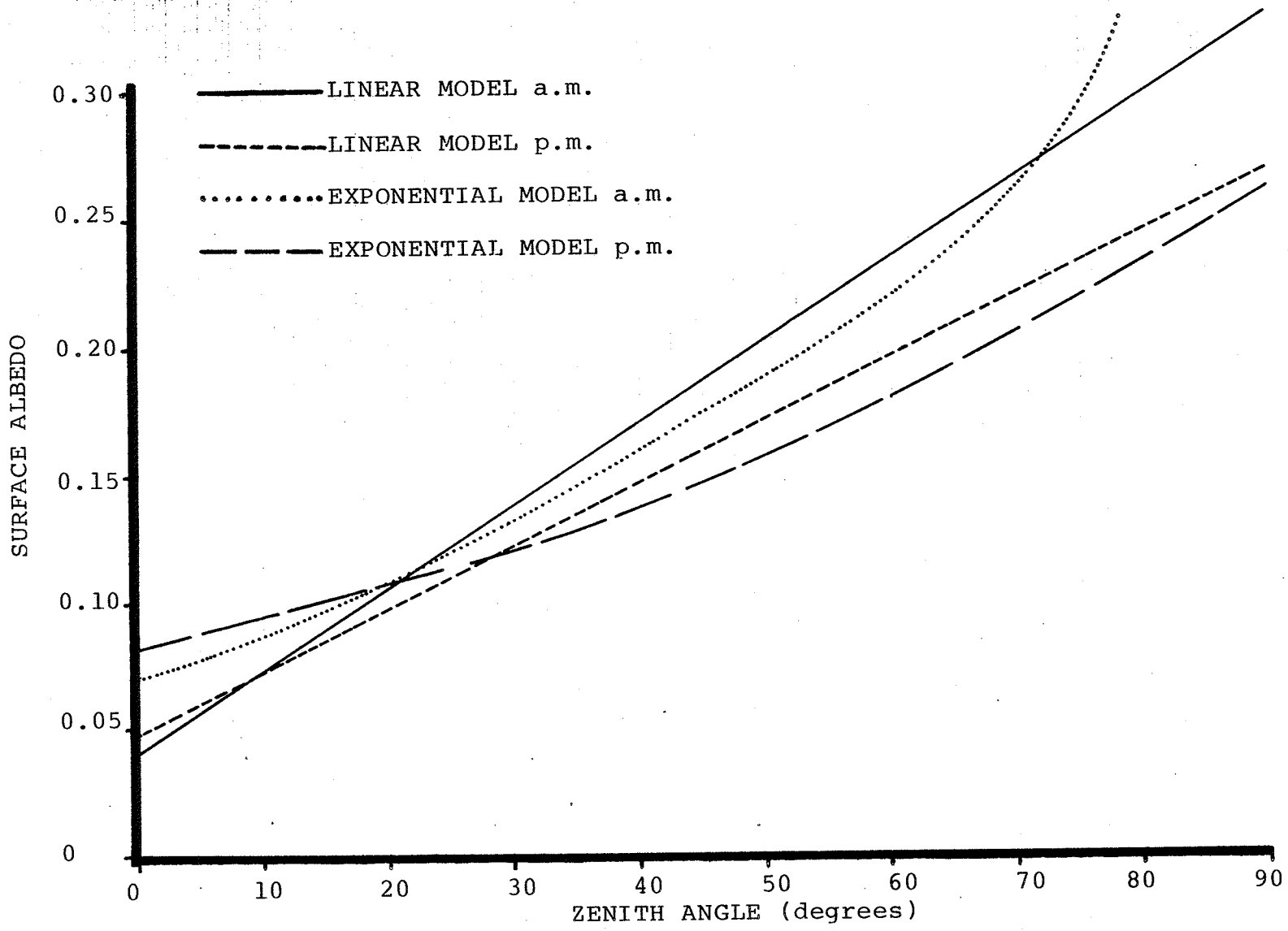


FIGURE 4-10 Albedo Model vs. Zenith Angle for Conventional Tillage

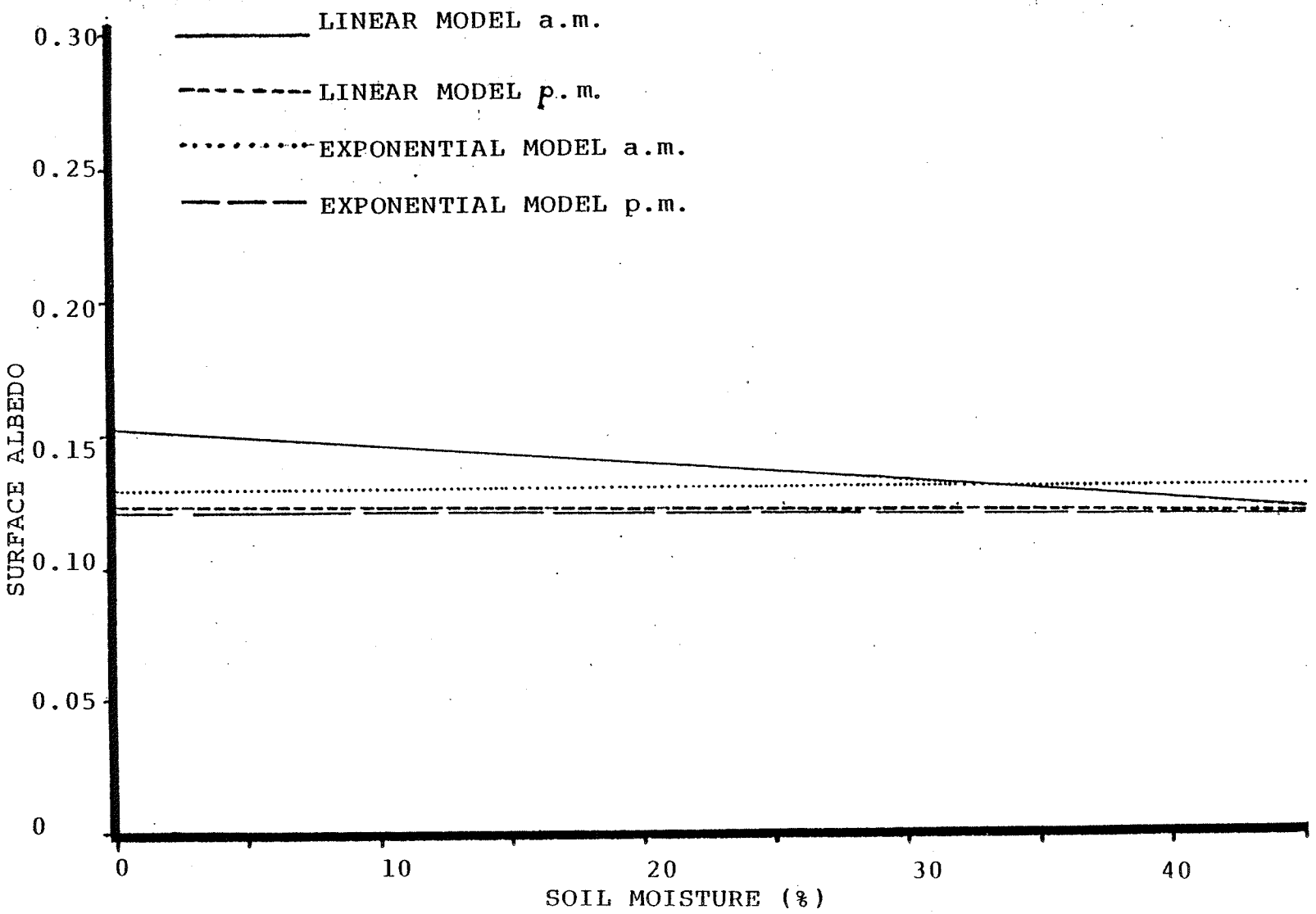


FIGURE 4-11 Albedo Model vs. Soil Moisture For Conventional Tillage at Approximately Solar Noon

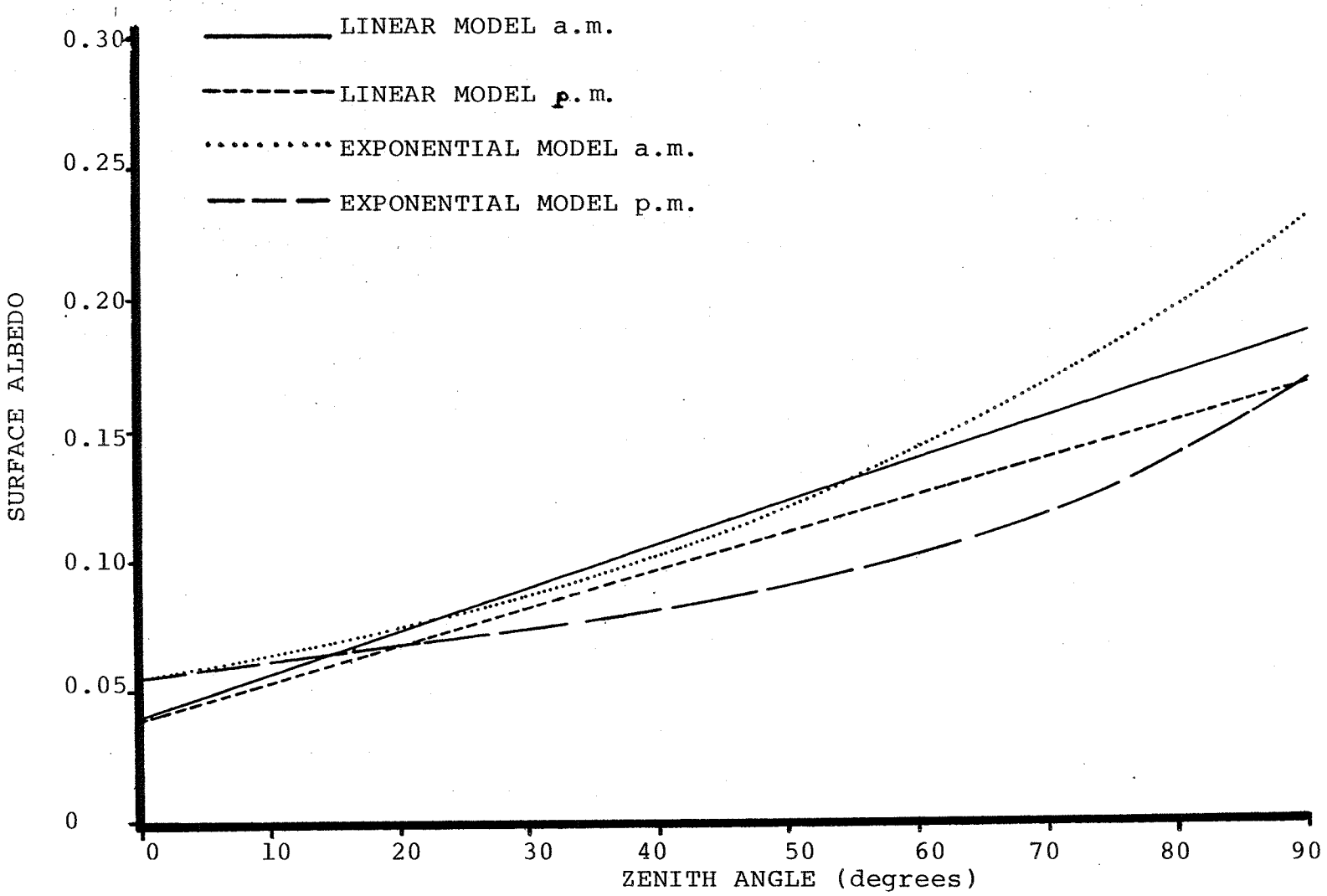


FIGURE 4-12 Albedo Model vs. Zenith Angle for Deep Tillage

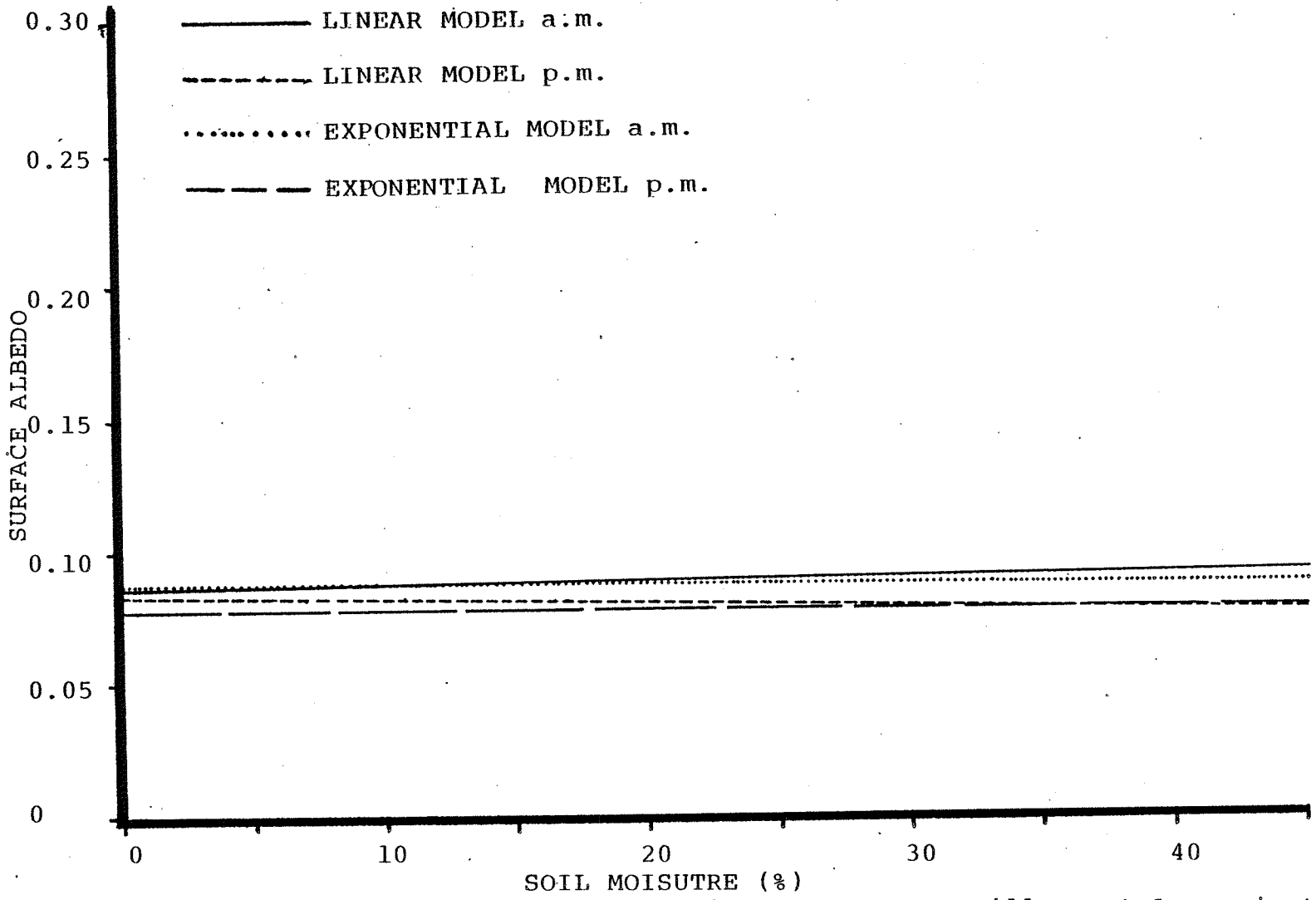


FIGURE 4-13 Albedo Model vs. Soil Moisture For Deep Tillage at Approximately Solar Noon

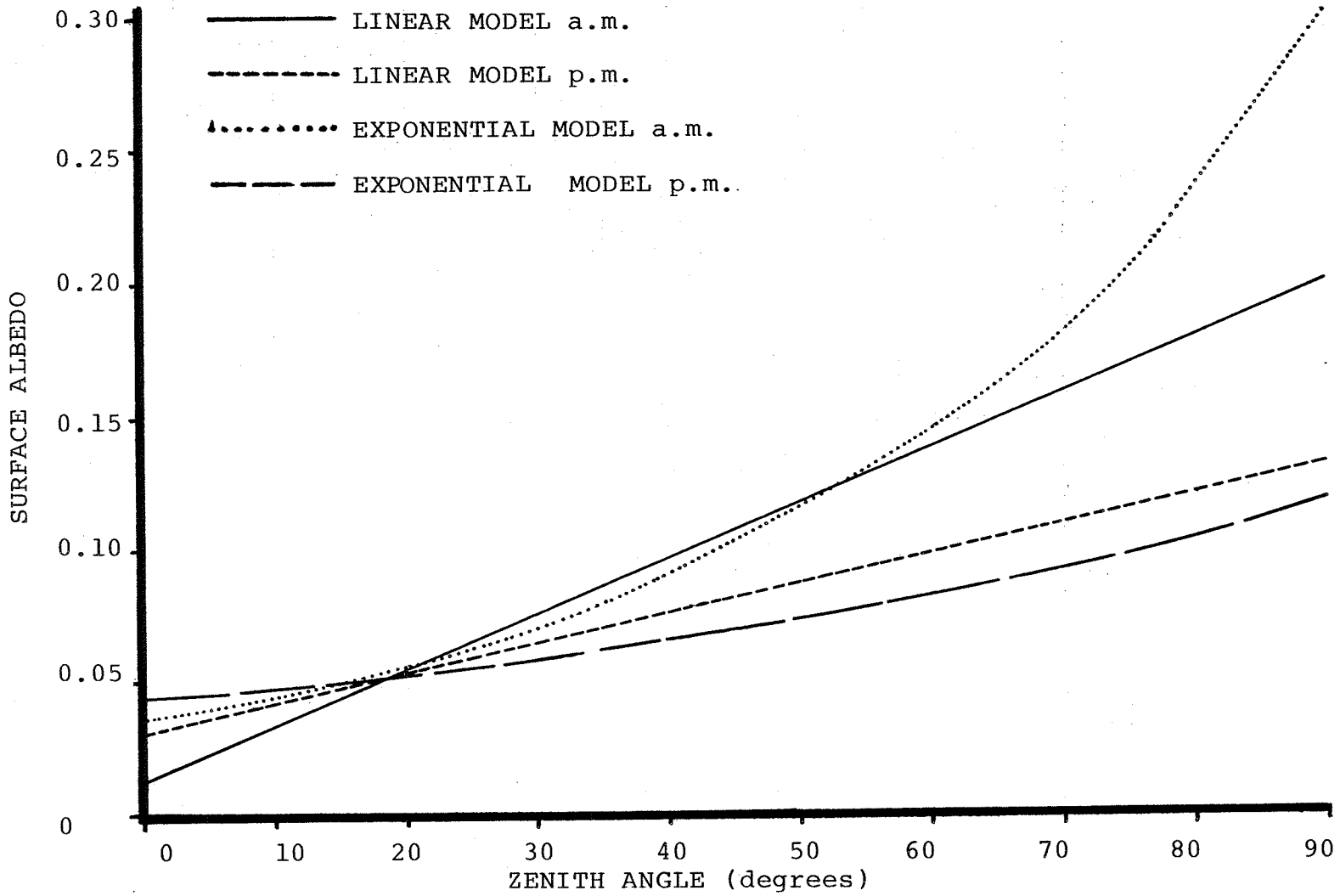


FIGURE 4-14 Albedo Model vs. Zenith Angle for Intensive Tillage

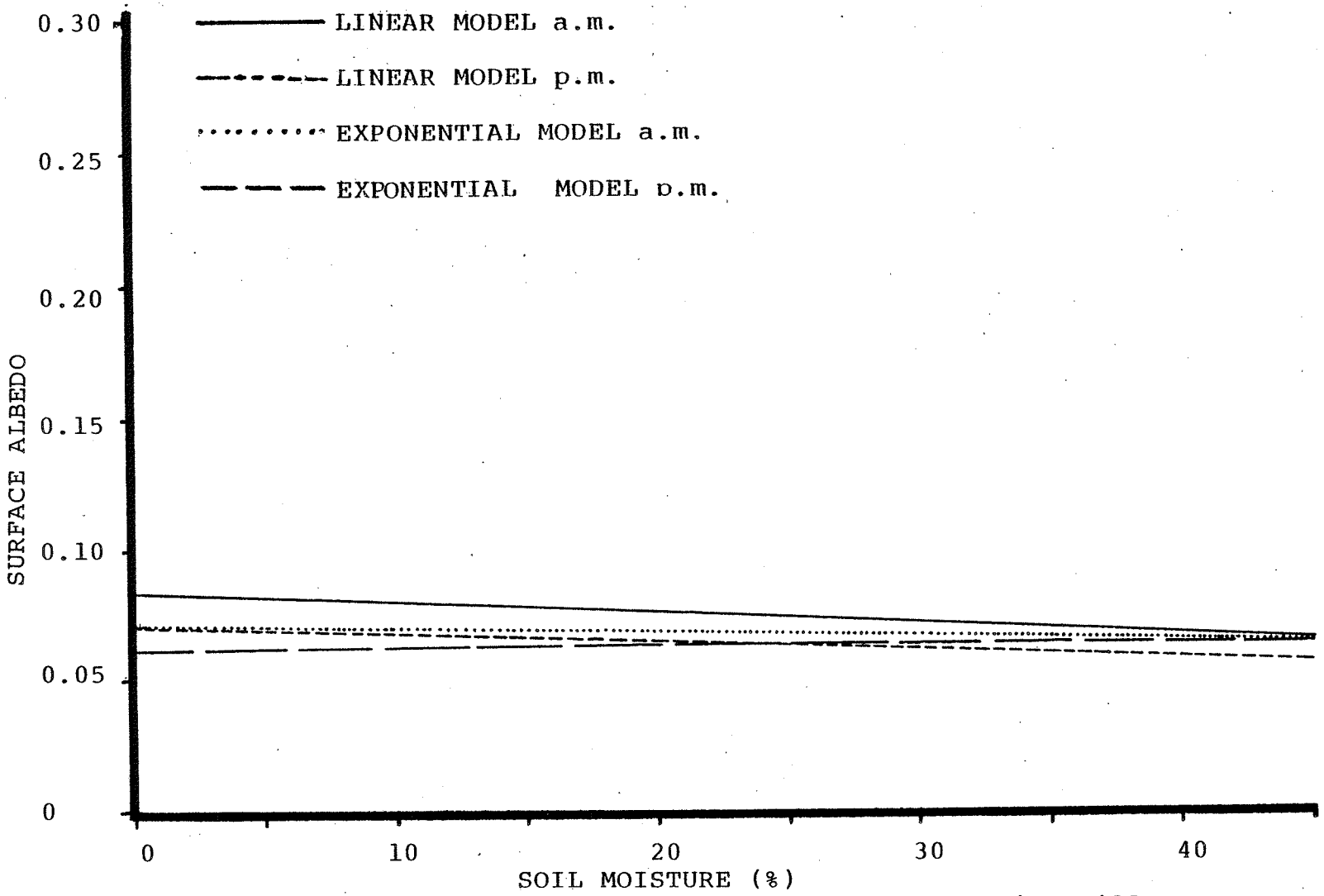


FIGURE 4-15 Albedo Model vs. Soil Moisture for Intensive Tillage at Approximately Solar Noon

level.

To account for the significant differences (or lack of significant differences) it should be noted that the zero tillage plots, the minimum tillage plots and the conventional tillage plots, all had a certain amount of trash and stubble on them. The latter two tillage systems had no trash cover.

4.4 Soil and Surface Temperatures: Before Planting

The average soil and surface temperatures are shown in Table 4-7. From this table it can be noted that the zero tillage system had the second highest soil temperature, however, it also had the lowest average surface temperature. Meanwhile the intensive tillage system had the lowest average soil temperature, but this tillage system had the highest average surface temperature. The temperature difference between the soil temperature and the surface temperature is an indication of the thermal diffusivity of the soil. From this we can say that the thermal diffusivity of the zero tillage system is the highest and the thermal diffusivity for the intensive tillage system is the lowest.

An analysis of variance was performed on the collected soil and surface temperatures. This analysis is shown in Appendix B. From the analysis it was concluded that there were no significant differences in the soil temperatures or the surface temperatures at the 5 percent level.

TABLE 4-7: Soil and Surface Temperatures: Before Planting

Tillage System	Average Soil 1/ Temperature T1(^{o}C)	Average Surface Temperature T2(^{o}C)	T2-T1 (^{o}C)
Zero Tillage	14.78	27.97	13.19
Minimum Tillage	14.70	28.21	13.51
Conventional Tillage	14.69	28.82	14.13
Deep Tillage	14.84	28.35	13.51
Intensive Tillage	14.66	28.96	14.30

1/ measured at 11.5 cm. depth

4.5 Radiation and Reflection Characteristics of Soil Surfaces: After Planting

4.5.1 Radiation Balance

After the plots were planted the range of the albedo between the different tillage systems became less and less as the growing season advanced. In the spring condition, the average surface albedos ranged from a high of 0.172 for the zero tillage surface to a low of 0.090 for the intensive tillage surface. In the month of September (at the end of the growing season) the albedos for the tillage surfaces ranged from a high of 0.177 for the zero tillage surface to a low of 0.162 for the intensive tillage system. In all cases for each month, the order of surface albedo, from highest to lowest was: zero tillage, minimum tillage, conventional tillage, deep tillage and intensive tillage, respectively.

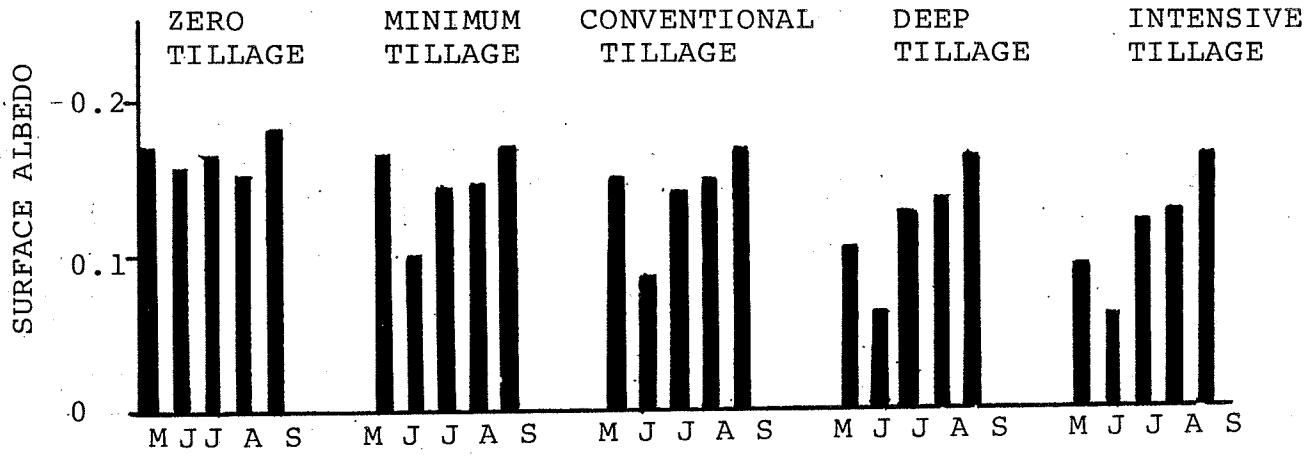
As the growing season progressed the crop cover had more of an influence on the albedo, than the actual soil surface. From this it would be expected that as the growing season advances, the tillage surface with an albedo higher than the albedo of the crop, will have a decreasing albedo and vice-versa. This is the expected trend and this is the trend of the monthly average albedo of each tillage system as can be seen from Figure 4-16 (a).

A regression analysis was performed with the data collected each month, in the form of equations 2-7 and 2-8. The results are shown in Tables 4-8 and 4-9. The albedos obtained from the regression equations did not

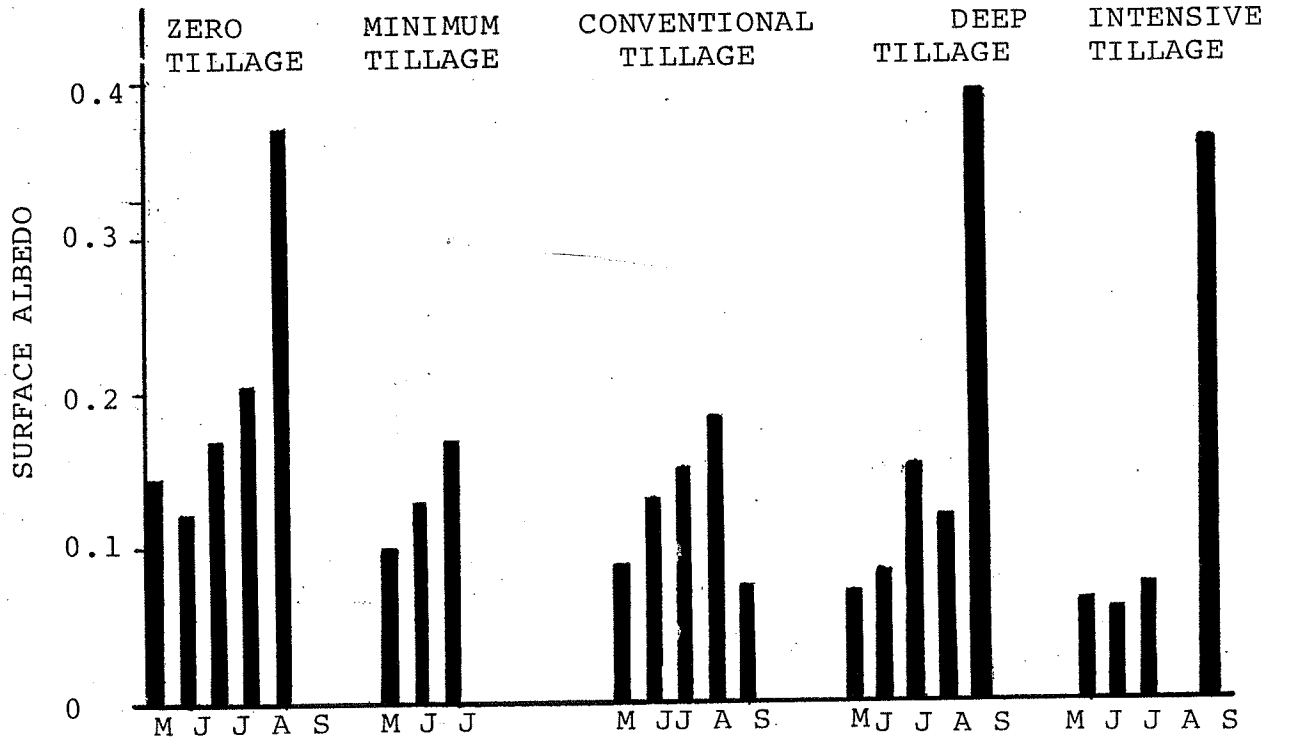
follow the previously mentioned expected trend. Figure 4-16 (b) shows the monthly albedo obtained from the Monteith equations for the various tillage systems.

In the month of August the albedo derived from the equations did not follow a trend. The albedo for the zero tillage surface increased from 0.16 in July to 0.20 in August. For every other surface the albedo decreased. For the month of September the following albedo were derived, in decreasing order: Deep Tillage surface, 0.392; zero tillage surface, 0.370; Intensive tillage surface, 0.361; Conventional tillage surface, 0.075.

The range of the albedo from the Monteith equations did not decrease as the average albedos did. This can also be seen from the Figure 4-16. The heating coefficients followed the same trend as the albedo derived from the Monteithequations. The expected trend is an increase in the heating coefficient as the temperature increases. This increasing trend was followed in the zero tillage surface, deep tillage surface and the intensive tillage surface. The minimum tillage surface and the conventional tillage surface had a lower heating coefficient in September than in August. A smaller heating co-efficient implies a smaller diurnal variation of surface temperature for a given incoming radiation. Figure 4-17 shows the heating coefficients for each month for the various tillage systems. Figure 4-18 shows the albedo for various days throughout the growing season and before planting. The data plotted are within one half of



(a) AVERAGE ALBEDO FROM COLLECTED DATA



(b) ALBEDO OBTAINED FROM EQUATIONS

FIGURE 4-16 Surface Albedo for Each Month

TABLE 4-8: Radiation Balance: After Planting

Tillage System	Month	Equation	Correlation Coefficient	Albedo	Average Albedo of Collected Data
Zero Tillage	June	R = 0.879 (S) - 137.97	0.921	0.121	0.157
	July	R = 0.832 (S) - 133.71	0.954	0.168	0.165
	August	R = 0.796 (S) - 144.00	0.911	0.204	0.149
	Se3ptember	R = 0.630 (S) - 66.69	0.876	0.370	0.177
Minimum Tillage	June	R = 0.870 (S) - 103.32	0.925	0.130	0.098
	July	R = 0.833 (S) - 123.06	0.951	0.168	0.143
	August	R = 1.009 (S) - 313.80	0.919	-	0.147
	Setpember	R = 1.365 (S) - 619.22	0.881	-	0.170
Conventional Tillage	June	R = 0.868 (S) - 92.52	0.915	0.132	0.085
	July	R = 0.849 (S) - 136.10	0.948	0.151	0.140
	August	R = 0.816 (S) - 144.97	0.943	0.184	0.147
	September	R = 0.925 (S) - 288.50	0.818	0.075	0.167
Deep Tillage	June	R = 0.917 (S) - 127.86	0.926	0.083	0.062
	July	R = 0.848 (S) - 135.85	0.936	0.153	0.125
	August	R = 0.883 (S) - 202.71	0.915	0.117	0.135
	September	R = 0.608 (S) - 51.59	0.879	0.392	0.163
Intensive Tillage	June	R = 0.944 (S) - 150.39	0.921	0.057	0.058
	July	R = 0.877 (S) - 152.31	0.945	0.123	0.119
	August	R = 1.000 (S) - 285.39	0.947	0.000	0.126
	September	R = 0.639 (S) - 65.22	0.905	0.361	0.162

TABLE 4-9: Radiation Balance Equations Using Heating Coefficients: After Planting

Tillage System	Month	Equation	Correlation Coefficient	Heating Coefficient
Zero Tillage	June	R = 1.006 (1-A)S - 111.49	0.921	-0.006
	July	R = 0.946 (1-A)S - 108.29	0.959	0.057
	August	R = 0.916 (1-A)S - 132.40	0.920	0.092
	September	R = 0.734 (1-A)S - 51.15	0.900	0.362
Minimum Tillage	June	R = 0.911 (1-A)S - 61.42	0.924	0.098
	July	R = 0.909 (1-A)S - 91.29	0.954	0.100
	August	R = 1.155 (1-A)S - 295.49	0.931	-0.134
	September	R = 1.324 (1-A)S - 421.75	0.914	-0.245
Conventional Tillage	June	R = 0.879 (1-A)S - 37.98	0.915	0.138
	July	R = 0.934 (1-A)S - 107.89	0.952	0.071
	August	R = 0.922 (1-A)S - 124.18	0.945	0.085
	September	R = 1.033 (1-A)S - 240.28	0.865	-0.032
Deep Tillage	June	R = 0.938 (1-A)S - 96.02	0.931	0.066
	July	R = 0.917 (1-A)S - 108.76	0.947	0.089
	August	R = 0.993 (1-A)S - 185.63	0.921	0.007
	September	R = 0.694 (1-A)S - 34.25	0.899	0.441
Intensive Tillage	June	R = 0.962 (1-A)S - 118.23	0.929	0.040
	July	R = 0.948 (1-A)S - 126.39	0.947	0.055
	August	R = 1.100 (1-A)S - 257.07	0.948	-0.091
	September	R = 0.703 (1-A)S - 33.49	0.925	0.424

an hour from solar noon. In the early growing season and before the crop was planted, there was a large change on a day to day variation. This large variation can be accounted for by high variations in soil moisture contents. In the spring, the rain influenced the surface albedo greatly. However, as the season progressed and crop cover blocked out the soil, and the rain had a smaller effect on the albedo. Also it should be noted from Figure 4-18, that as the season progressed the variation of the albedo between the tillage system also decreased. this was expected as discussed previously.

4.5.2 Albedo Models

From the data collected for the various tillage systems during the months after planting, a multiple linear regression was performed. The model used was a multiple linear equation in the form of equation 4-1. This was done for both before noon and afternoon for each of the months. The equations are shown in Table 4-10.

For comparison plots of June a.m. and p.m. and September a.m. and p.m. are shown in Figure 4-19 through to Figure 4-22 respectively. From these figures it can be noted that the morning albedo values are in most cases higher than the afternoon values in June, but lower in September. The amount of scatter between the different tillage systems is much less in September than in June. This was the expected trend, as previously mentioned, due to the more consistent surface in the fall. These plots

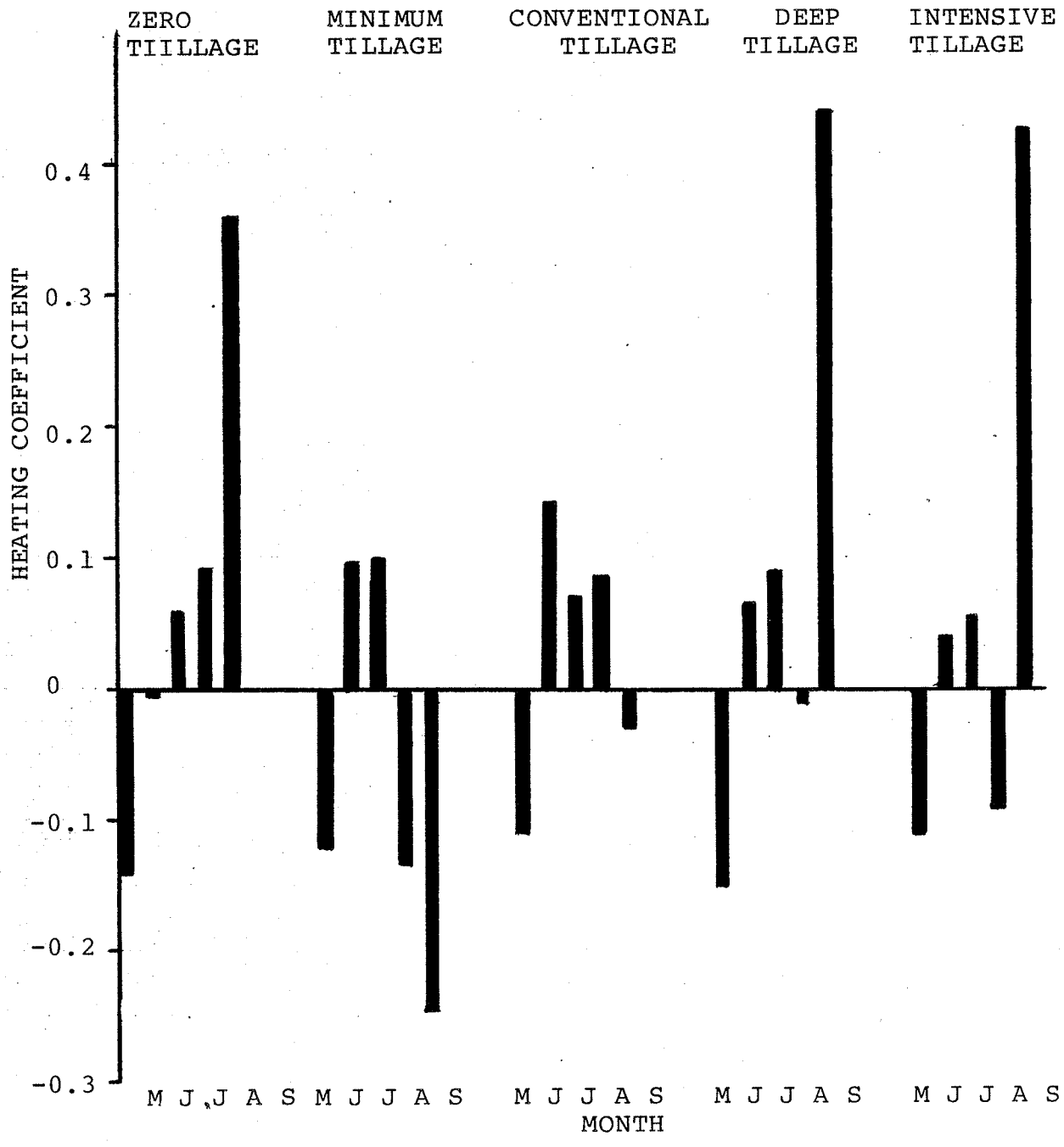


FIGURE 4-17 Heating Coefficients for Each Month

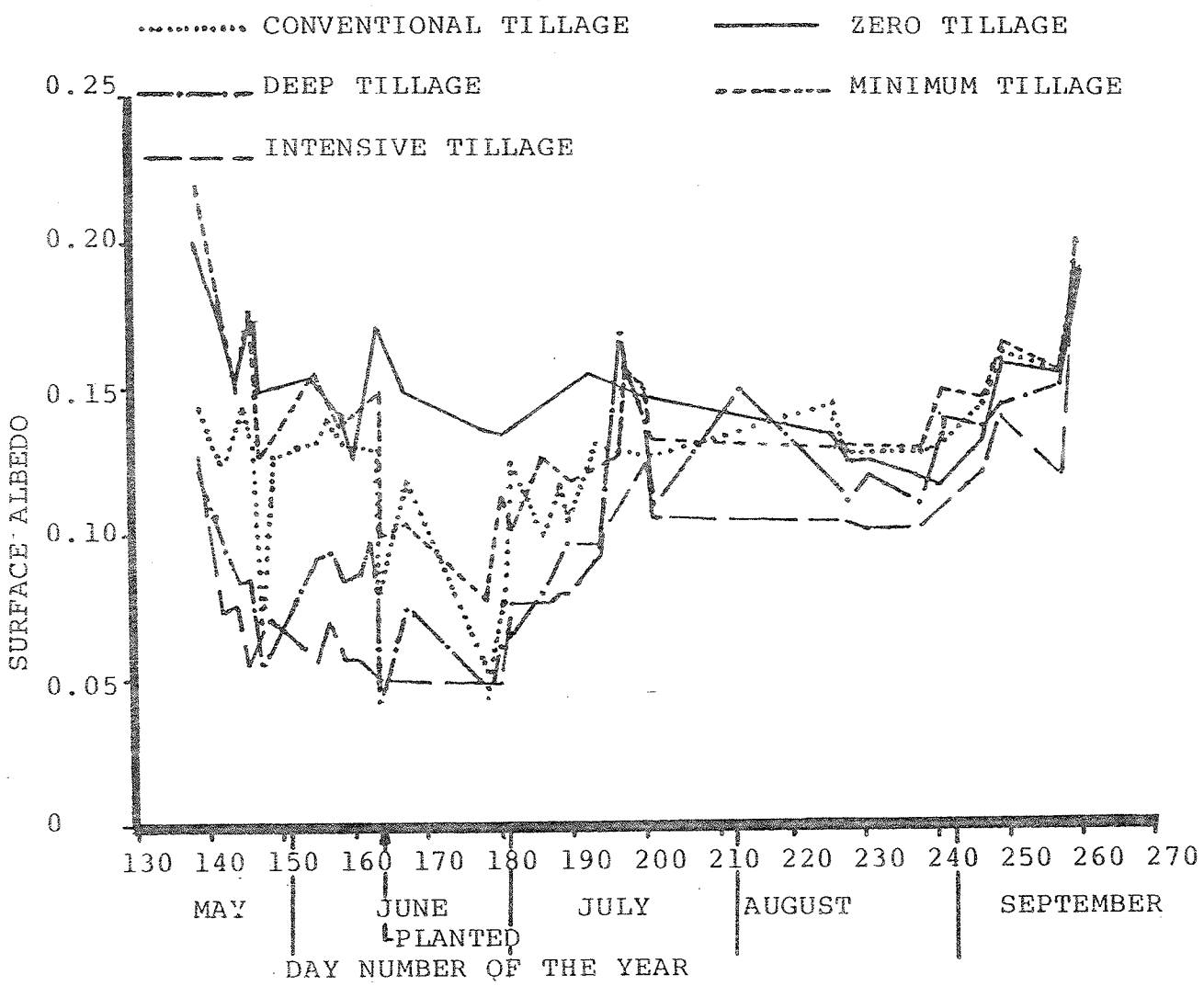


FIGURE 4-18 Albedo at ± ½ Hour of Solar Noon vs. Day Number

are for a zenith angle at solar noon (approximately 30 degrees for June and approximately 50 degrees for September) and a soil moisture content of 20 percent.

From Table 4-10 it should be noted, that the multiple correlation coefficient for the mornings ranged from 0.217 to 0.939. The range for the afternoon is less, ranging from 0.575 to 0.866. From this it can be stated that the afternoon albedo values are more consistent (i.e. more predictable). This is probably due to the fact that in the mornings dew may or may not be present which would tend to have an influence on the albedo.

In most cases the equations for the month of September had the highest multiple correlation coefficient, for each tillage system.

For most of the equations it should be noted that the solar zenith angle had more of an influence on surface albedo than the soil moisture content. That is if the zenith angle is increased it had more of an effect on the surface albedo than if the soil moisture was increased or decreased.

4.6 Statistical Analysis of Albedo: After Planting

Analysis of variance procedures were performed on the collected albedo data for each month. These are shown in Appendix B. In all cases the computed F for the tillage treatment was higher than the tabulated F at the 5 percent level. In all cases except for one, the computed F for the tillage treatments was higher than the tabulated F at the 1 percent level.

TABLE 4-10: Albedo Equations: After Planting (A=w +xM + yZ For sky transmittance greater than 0.5)

Tillage System	Month and Time of Day	Equation	Multiple Correlation
Zero Tillage	June a.m.	A = 1.85E-01-5.20E-04M+1.25E-02Z	0.733
	June p.m.	A = 1.12E-01-8.50E-04M+2.12E-03Z	0.609
	July a.m.	A = 1.24E-01+1.60E-04M+1.20E-03Z	0.531
	July p.m.	A = 5.63E-02_1.25E-03M+2.06E-03Z	0.800
	August a.m.	A = 2.00E-01+9.00E-05M-1.32E-03Z	0.328
	August p.m.	A = 4.81E-02+2.20E-04M+2.20E-03Z	0.696
	September a.m.	A = 5.04E-02-8.10E-04M+2.89E-03Z	0.989
	September p.m.	A = 1.38E-01-1.71E-03M+2.08E-03Z	0.839
Minimum Tillage	June a.m.	A = 7.33E-02-4.20E-04M+1.02E-03Z	0.217
	June p.m.	A = 1.81E-01-1.45E-03M-1.83E-03Z	0.719
	July a.m.	A = 5.60E-02-3.20E-04M+2.84E-03Z	0.917
	July p.m.	A = 1.95E-02+1.43E-03M+2.43E-03Z	0.773
	August a.m.	A = 2.76E-01+4.60E-04M-3.53E-03Z	0.720
	August p.m.	A = 4.35E-02+5.00E-04M-2.19E-03Z	0.656
	September a.m.	A = 1.49E-02+2.00E-04M+3.42E-03Z	0.876
	September p.m.	A = 1.47E-01-3.80E-04M+6.88E-03Z	0.817
Conventional Tillage	June a.m.	A = 3.04E-01+7.90E-04M-8.47E-03Z	0.559
	June p.m.	A = 1.40E-01-1.24E-03M-1.13E-03Z	0.678
	July a.m.	A = 5.12E-03+7.00E-05M+2.84E-03Z	0.871
	July p.m.	A = 1.97E-02+1.47E-03M+2.39E-03Z	0.752
	August a.m.	A = 2.55E-01+4.10E-04M-3.01E-03Z	0.643
	August p.m.	A = 3.11E-02+4.40E-04M+2.42E-03Z	0.723
	September a.m.	A = 2.75E-02-1.10E-04M+2.76E-03Z	0.876
	September p.m.	A = 3.74E-02-1.55E-03M+3.92E-03Z	0.866

(concluded on next page)

TABLE 4-10: Albedo Equations: After Planting (A=w + xM + yZ For sky transmittance greater than 0.5) (concluded)

Tillage System	Month and Time of Day	Equation	Multiple Correlation
Deep Tillage	June a.m.	A = 6.90E-02+8.60E-04M-4.80E-04Z	0.506
	June p.m.	A = 3.30E-02-9.80E-04M+1.42E-03Z	0.710
	July a.m.	A = 3.35E-02-5.00E-05M+2.57E-03Z	0.624
	July p.m.	A = 1.44E-02+1.55E-03M+2.94E-03Z	0.827
	August a.m.	A = 2.18E-01-2.30E-04M-2.01E-03Z	0.815
	August p.m.	A = 5.04E-02+1.90E-04M+1.85E-03Z	0.575
	September a.m.	A = 6.23E-02-8.40E-04M+2.51E-03Z	0.735
	September p.m.	A = 6.33E-02-3.07E-03M+3.07E-03Z	0.748
Intensive Tillage	June a.m.	A = 1.92E-02+1.20E-04M+2.53E-03Z	0.554
	June p.m.	A = 6.77E-02-1.01E-03M+1.70E-04Z	0.680
	July a.m.	A = 3.06E-02-1.13E-03M+3.20E-03Z	0.904
	July p.m.	A = 5.10E-03+2.07E-03M+2.09E-03Z	0.762
	August a.m.	A = 3.00E-01+2.90E-04M-4.57E-03Z	0.750
	August p.m.	A = -5.48E-03+1.19E-03M+2.47E-03Z	0.732
	September a.m.	A = -1.96E-03-2.50E-04M+3.48E-03Z	0.819
	September p.m.	A = 1.55E-01-2.77E-03M+1.87E-03Z	0.828

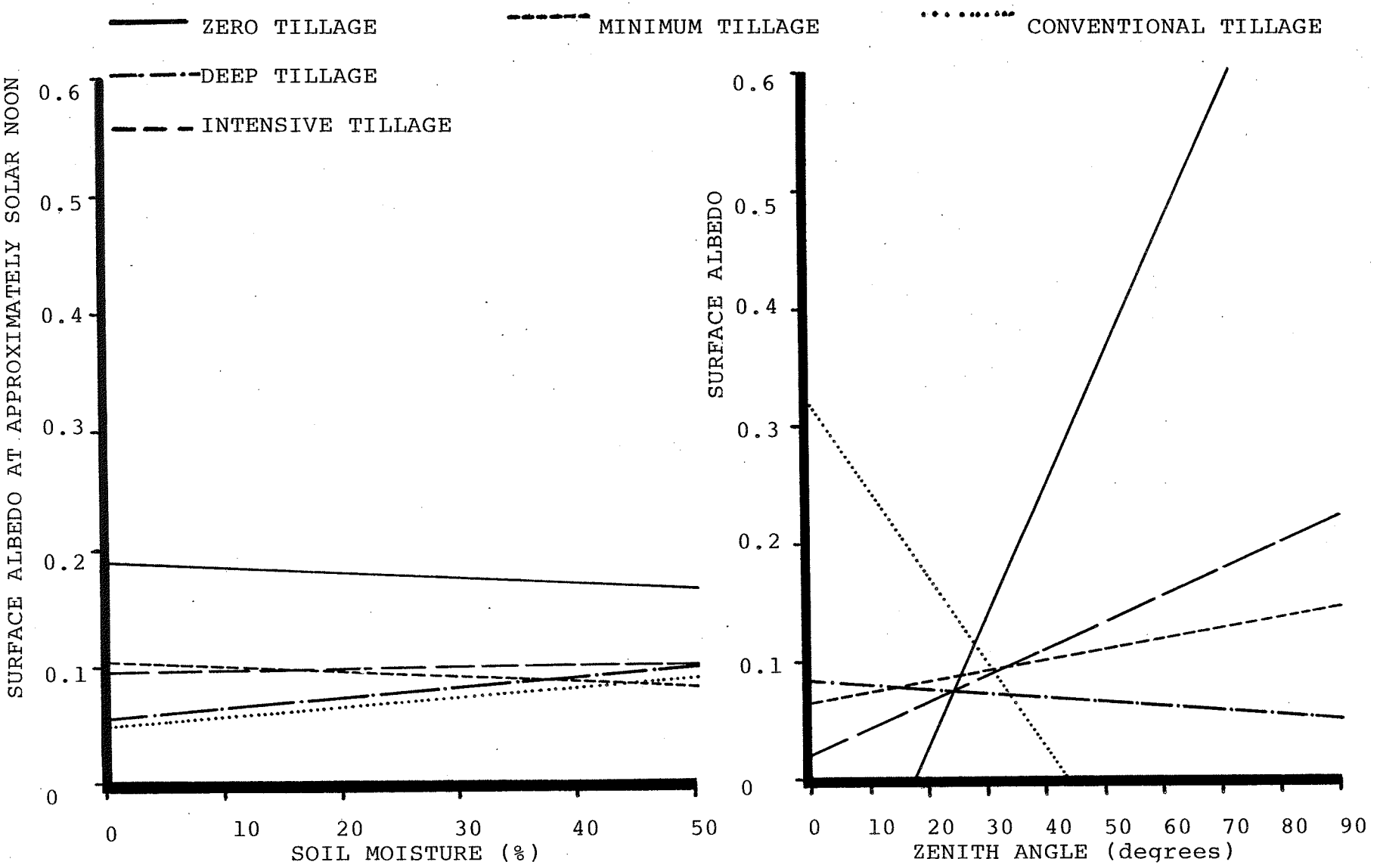


FIGURE 4-19 Albedo Model for June a.m.

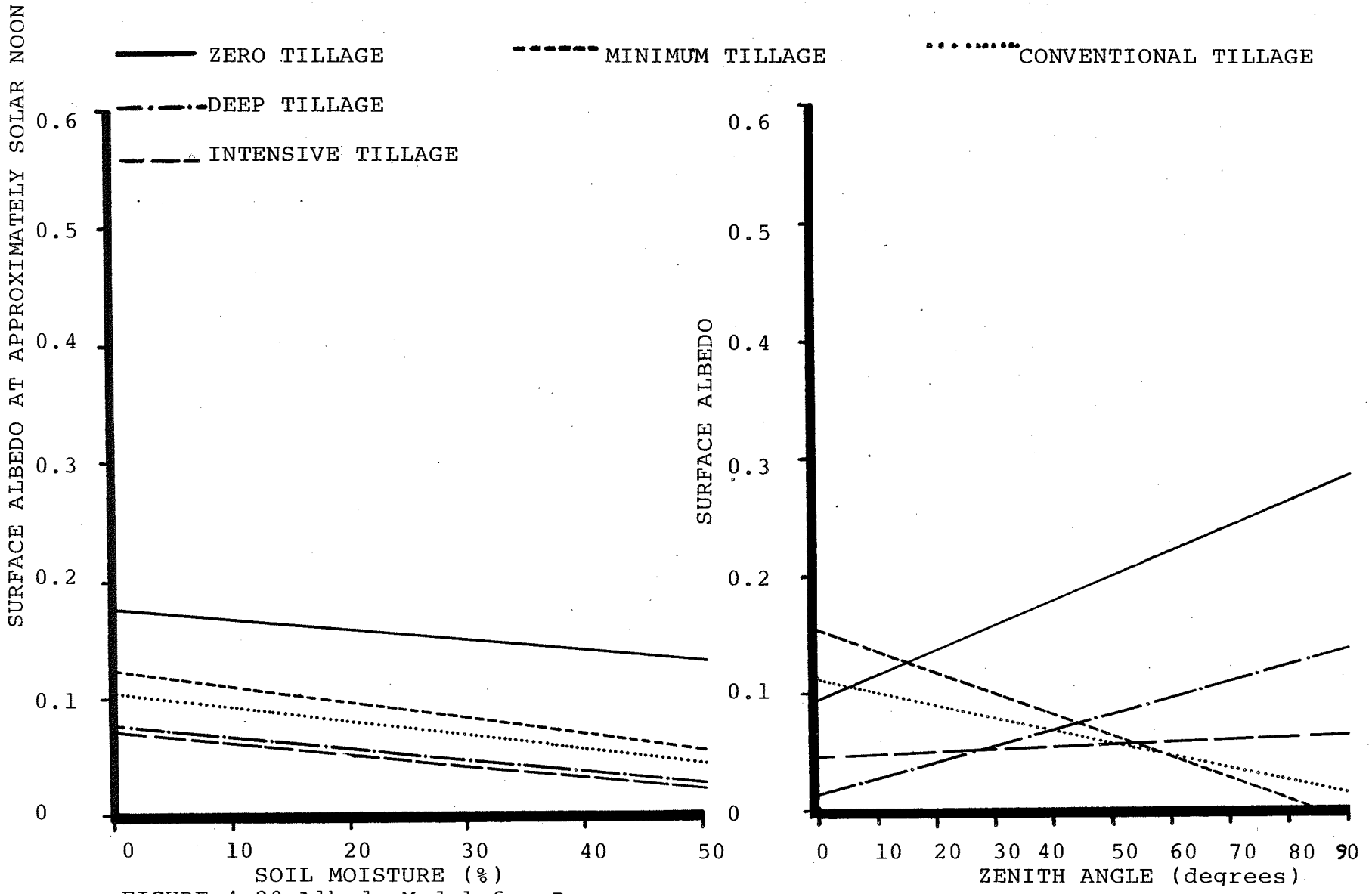


FIGURE 4-20 Albedo Model for June p.m.

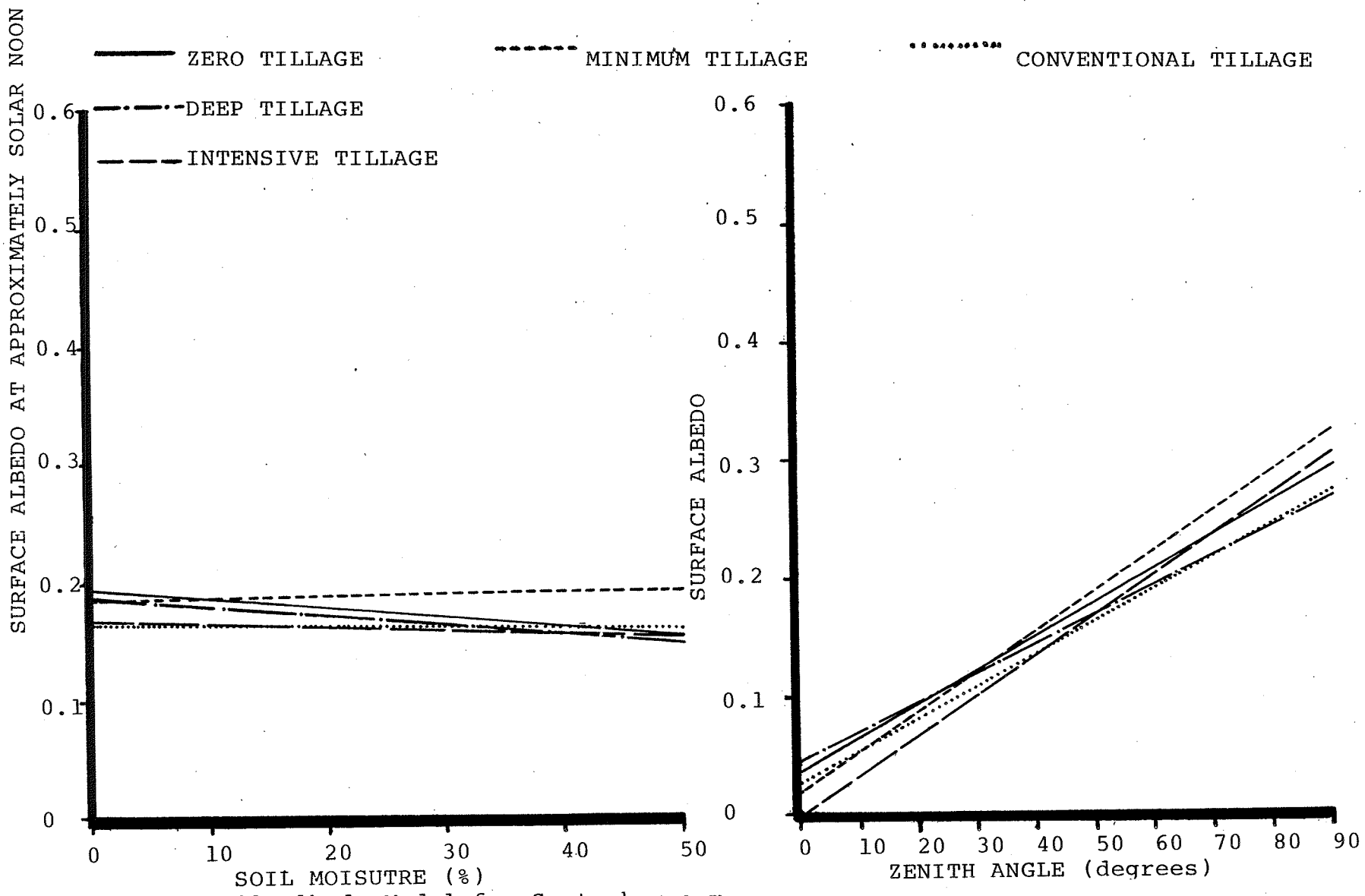


FIGURE 4-21 Albedo Model for September a.m.

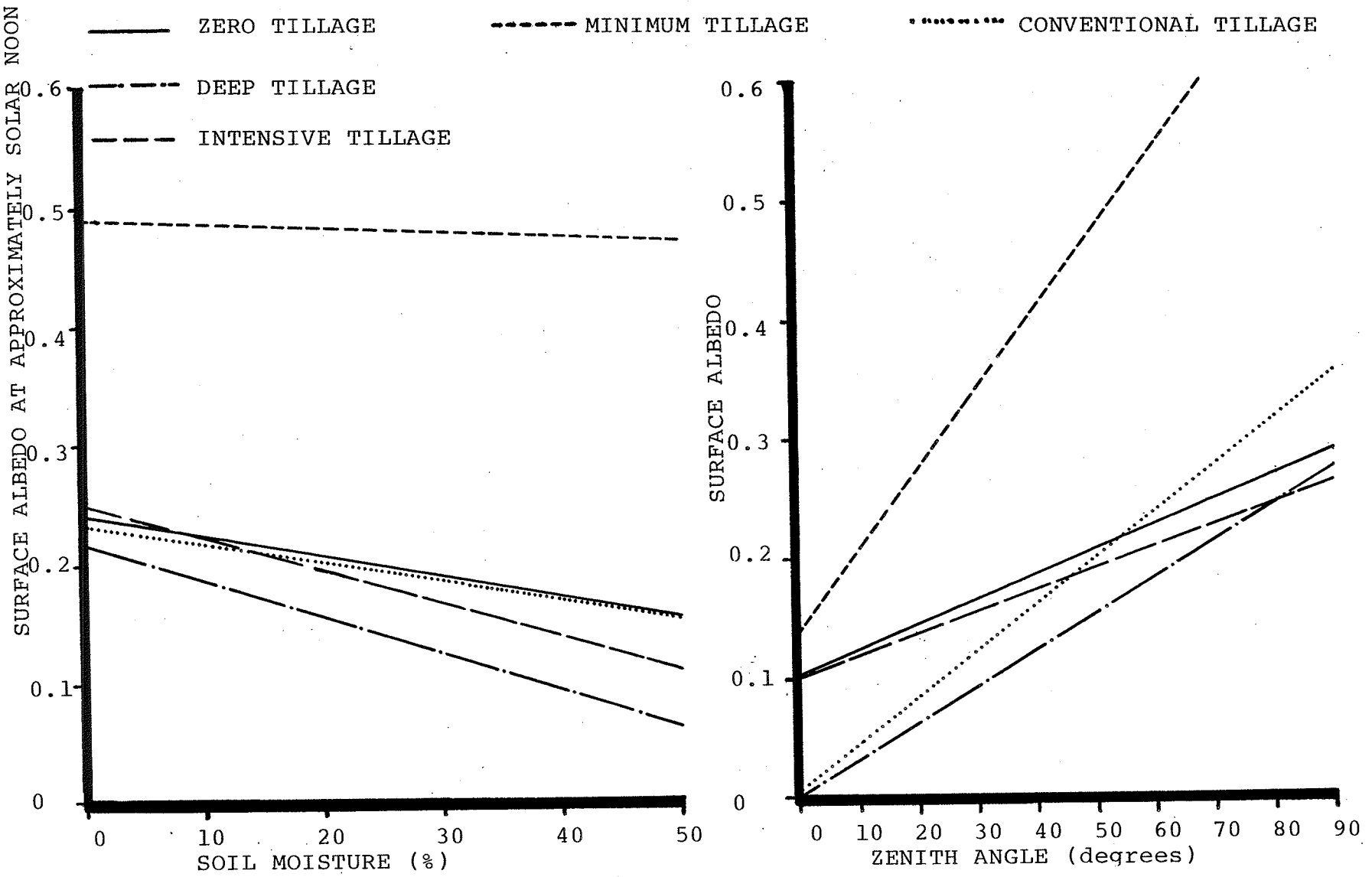


FIGURE 4-22 Albedo Model for September p.m.

The exception was for the month of September when the computed F value was 3.06 and the tabulated F was 3.5. The albedos for the different tillage systems became more alike as the season progressed. This is to be expected since as the crop grows it blocks out more and more of the soil characteristics.

4.7 Soil and Surface Temperatures: After Planting

The average soil and surface temperatures for the five different tillage systems after planting are shown in Table 4-11. In the month of June (Germination and Crop Emergence) the zero tillage system had the highest soil temperature and the lowest surface temperature. This means the lowest temperature difference between the soil and surface. From this it can be stated that the zero tillage system had the highest thermal diffusivity. In the month of July (Crop Growth and Development) the zero tillage system had the lowest soil to surface temperature difference. This indicates that the thermal diffusivity is again the highest of the five tillage systems. This trend does not follow for the rest of the growing season.

For every month except September the intensive tillage system had the highest temperature difference between the soil and surface. This indicates that the thermal diffusivity of the intensive tillage system was the lowest of the five tillage systems.

An analysis of variance was performed on the collected soil and surface temperatures for each month. From the analysis it was concluded that there was no significant

TABLE 4-11: Soil and Surface Temperatures: After Planting

Tillage System	Month	Average Soil 1/ Temperature T1(°C)	Average Surface Temperature T2(°C)	T2-T1 (°C)
Zeroo Tillage	June	21.22	39.88	18.66
Minimum Tillage		20.17	39.59	19.42
Conventional Tillage		20.33	40.52	20.19
Deep Tillage		20.63	40.11	19.48
Intensive Tillage		20.75	41.30	20.55
Zero Tillage	July	24.79	36.94	12.15
Minimum Tillage		24.87	38.86	13.99
Conventional Tillage		24.82	38.98	14.16
Deep Tillage		25.01	39.53	14.52
Intensive Tillage		25.38	40.45	15.07
Zero Tillage	Aug.	20.99	26.21	5.22
Minimum Tillage		21.36	26.26	4.90
Conventional Tillage		21.23	26.21	4.98
Deep Tillage		21.59	26.72	5.13
Intensive Tillage		21.98	27.68	5.70
Zero Tillage	Sept.	16.49	22.38	5.89
Minimum Tillage		17.35	22.33	4.98
Conventional Tillage		17.36	22.75	5.39
Deep Tillage		17.19	23.35	6.16
Intensive Tillage		17.58	23.68	6.10

1/ measured at 11.5 cm. depth

difference in the soil or surface temperatures at the 5 percent level.

It should be noted from the average temperature differences that the zero tillage system had the highest thermal diffusivity and the intensive tillage treatment had the lowest thermal diffusivity.

4.8 Conclusion

From the previous discussions it can be predicted that the intensive tillage system would have the highest yield. This is due to the fact that it reflected the least amount of solar radiation every month. This means more energy was available to the plant for photosynthesis and other important processes.

The yields for the various tillage systems are shown in Table 4-12. From Table 4-12 it should be noted that the excessive tillage system reflected the least amount of solar radiation and had the highest yield. Also, the zero tillage system reflected the most amount of solar radiation and had the lowest yield. It can therefore be concluded that the yield is inversely related to the albedo of the tillage system.

An economic analysis was not considered in this study. However, it should be noted from Table 4-10, that the minimum tillage system had the same yield as the conventional tillage system. The albedos of these two tillage systems were very close. The minimum tillage system had one less tillage operation than the conventional tillage system. From this it is obvious that the minimum tillage

TABLE 4-12: Average Wheat Yield and Minimum Average Albedos for the Five Tillage Systems

Tillage System	Average Yield (t/ha)	Minimum Average Monthly Albedo(%)
Zero Tillage	1.5	14.88
Minimum Tillage	1.8	9.82
Conventional Tillage	1.8	8.50
Deep Tillage	2.0	6.24
Intensive Tillage	2.3	5.82

system would be recommended over the conventional tillage system since the net return for the minimum tillage system would be higher. The deep tillage system and the intensive tillage system both had higher yields than the minimum tillage system but these systems had two and three more tillage operations, respectively. In order to determine the feasibility of these two tillage systems over the minimum tillage system a detailed economic analysis would have to be performed.

CHAPTER V

CONCLUSIONS

The radiation characteristics of five different tillage systems were investigated. The following conclusions can be made:

1. The measured albedo of the various tillage systems in order from highest to lowest were: zero tillage, minimum tillage, conventional tillage, deep tillage, intensive tillage. This order was maintained throughout the growing season for the average albedo. Predicted albedo using a model by Monteith (1959) did not follow this trend.
2. In the spring, before seeding, the albedo was related to the amount of stubble left on the field. The zero tillage system had the maximum albedo and the most stubble. The excessive tillage system had no evidence of stubble and the smallest albedo. This was true for both the average albedo and the albedo derived by equations.
3. The daily variation of albedo for each tillage system was much greater at the beginning of the growing season than at the end of the growing season.
4. The range of albedos between the different tillage systems was very high in the spring but as the growing season progressed the range decreased. The tillage systems with a high albedo in the spring had a decreasing albedo when the crops emerged. The tillage systems with a low albedo in the spring had an increasing albedo when the crops emerged.
5. Heating coefficients were minimum in the spring and maximum in the fall for zero tillage, deep tillage and intensive

tillage. Minimum tillage and conventional tillage did not follow this trend.

6. As the moisture of the soil increased the albedo decreased.

7. As the solar zenith angle increased the albedo tended to increase.

8. The albedo of the soil surface and crop surface was not symmetric about solar noon.

9. The albedo of a soil surface was more dependent on the solar zenith angle than on the soil moisture content.

10. The minimum tillage system had the same yield as the conventional tillage system. Since the minimum tillage system has one less tillage operation, this tillage system would be recommended over the conventional tillage system in the Red River Valley.

11. The thermal diffusivity of the zero tillage system was the highest in the early part of the growing season and the thermal diffusivity was the lowest for the intensive tillage treatment.

CHAPTER VI

SUGGESTED FURTHER STUDY

It should be noted that this study was conducted during one growing season, and that temperature and percipitation varies from year to year. Results from this study are specifically related to one particular year. Results from one year may not always be the same as another year. For these reasons the following points should be studied further.

1. Due to fluctuating commodity prices and fuel costs, a feasibility study to determine break even points for each tillage system, should be determined.
2. Further albedo measurements and soil moisture contents should be taken for various growing seasons to validate the albedo equations for various growing seasons.

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APPENDIX - A

CALIBRATION EQUATIONS - AMPLIFIER #1

Date of Calibration	Equation	Number of Points	Correlation Coefficient
May 17, 1979	E1 = 0.9902E0+0.4533	8	0.996
June 28, 1979	E1 = 0.10102E0+0.3887	7	0.999
Aug. 8, 1979	E1 = 0.09843E0+0.46501	8	0.999
Sept. 19, 1979	E1 = 0.9915E0+0.4123	8	0.998

CALIBRATION EQUATIONS - AMPLIFIER#2

Date of Calibration	Equation	Number of Points	Correlation Coefficient
May 17, 1979	E1 = 0.09572E0 - 9.134	28	1.00
June 28, 1979	E1 = 0.09595E0 - 0.88921	15	0.999
Aug. 8, 1979	E1 = 0.09680E0 - 0.68115	9	0.998
Sept. 19, 1979	E1 = 0.09695E0 - 0.6188	9	0.993

Where,

E1 is the input voltage into the amplifier - This is the output from the radiometer.

E0 is the amplifier output voltage. this is the voltage in the raw date.

APPENDIX B

BEFORE PLANTING - MAY 18 - JUNE 13

ALBEDO

Tillage System	Average Surface Albedo(%)
Zero Tillage	17.19
Minimum Tillage	16.68
Conventional Tillage	14.73
Deep Tillage	10.39
Intensive Tillage	8.95

ANALYSIS OF VARIANCE FOR ALBEDO

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	47.36	15.79	0.7148	3.78	2.60
Treatments	4	3874.89	968.72	43.8500	3.32	2.37
Experimental Error	12	178.45	14.87	0.6732	2.18	1.75
Sampling Error	340	7512.03	22.09			
Total	359	11612.73				

Comparing the computed F to the tabulated F, it can be concluded that the difference in albedo is due to the different tillage treatments.

DUNCAN'S MULTIPLE-RANGE TEST

To calculate the shortest significant ranges

$Rp = rp(S_{\bar{x}})$ where, rp is obtained from Tables and

$S_{\bar{x}} = \sqrt{\frac{S^2}{n}}$

$Rp = rp\sqrt{\frac{22.09}{18}} = 1.108(rp)$

p	rp(0.01)			
2	2.643	4.036	2.772	3.071
3	3.796	4.206	2.918	3.233
4	3.900	4.321	3.017	3.343
5	3.978	4.408	3.089	3.423

17.19	16.68	14.73	10.39	8.98	Level
					0.01
					0.05

Any two means not underscored by the same line are significantly different at the levels indicated

SURFACE TEMPERATURE

Tillage System	Average Surface Temperature ^{o}C
Zero Tillage	27.97
Minimum Tillage	28.21
Conventional Tillage	28.82
Deep tillage	28.35
Intensive Tillage	28.96

ANALYSIS OF VARIANCE TABLE FOR SURFACE TEMPERATURES

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	30.31	10.10	0.1826	3.78	2.60
Treatments	4	47.52	11.88	0.2147	3.32	2.37
Experimental Error	12	184.79	15.40	0.2783	2.18	1.75
Sampling Error	320	17706.66	55.33			
Total	339	17969.29				

Comparing the computed F to the tabulated F, it can be concluded that the difference in surface temperatures is not due to the different tillage systems. The difference in surface temperatures are not significantly different at the levels indicated, because in all cases the computed F is less than the tabulated F.

Soil Temperature

Tillage System	Average Soil Temperature ^{o}C
Zero Tillage	14.78
Minimum Tillage	14.70
Conventional Tillage	14.69
Deep Tillage	14.84
Intensive Tillage	14.66

ANALYSIS OF VARIANCE TABLE FOR SOIL TEMPERATURE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean of Squares	Computed F	Tabulated F 0.01	0.05
Blocks	3	22.59	7.53	0.04596	3.78	2.60
Treatments	4	1.59	0.40	0.0243	3.32	2.37
Experimental Error	12	57.26	4.77	0.291	2.18	1.75
Sampling Error	320	5243.10	16.39			
Total	339	5324.53				

Comparing the computed F to the tabulated F, it can be concluded that the difference in soil temperatures is not due to the different tillage systems. The difference in soil temperatures are not significantly different at the level indicated because in all cases the computed F is less than the tabulated F.

GERMINATION AND CROP EMERGENCE JUNE 13 - JUNE 30

SURFACE ALBEDO

TILLAGE SYSTEM	AVERAGE SURFACE ALBEDO %
Zero Tillage	15.72
Minimum Tillage	9.82
Conventional Tillage	8.50
Deep Tillage	6.24
Intensive Tillage	5.82

ANALYSIS OF VARIANCE TABLE FOR ALBEDO

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	24.92	8.31	2.8169	4.01	2.71
Treatments	4	1548.78	387.19	131.2508	3.54	2.48
Experimental Error	12	31.71	2.64	0.8949	2.39	1.86
Sampling Error	100	295.38	2.95			
Total	119	1900.79				

Comparing the computed F to the tabulated F it can be concluded that the difference in albedo is due to the different tillage treatments.

DUNCAN'S MULTIPLE-RANGE TEST

To calculate the shortest significant ranges

$Rp = rp\ (S_{\bar{x}})$ where, rp is obtained from Tables and $S_{\bar{x}} = \sqrt{\frac{s^2}{n}}$

$Rp = rp\sqrt{\frac{2.95}{6}} = 0.701\ rp$

p	rp(0.01)	Rp	rp(0.05)	Rp
2	3.722	2.609	2.810	1.970
3	3.879	2.719	2.957	2.073
4	3.987	2.795	3.054	2.141
5	4.066	2.850	3.125	2.191

15.72	9.82	8.50	6.24	5.82	Level
					0.01
					0.05

Any two means not underscored by the same line are significantly different at the levels indicated

SURFACE TEMPERATURE

TILLAGE SYSTEM	AVERAGE SURFACE TEMPERATURE ^{o}C
Zero Tillage	39.88
Minimum Tillage	39.59
Conventional Tillage	40.52
Deep Tillage	40.11
Intensive Tillage	41.3

ANALYSIS OF VARIANCE TABLE FOR SURFACE TEMPERATURES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	6.58	2.19	0.0823	3.95	2.68
Treatments	4	49.71	12.43	0.4671	3.40	2.45
Experimental Error	12	133.99	11.17	0.4198	2.34	1.83
Sampling Error	120	3192.86	26.61			
Total	139	3383.14				

Comparing the computed F to the tabulated F it can be concluded that the difference in the surface temperatures is not due to the different tillage systems. The difference in the surface temperatures are not significantly different at the levels indicated, because in all cases the computed F is less than the tabulated F.

SOIL TEMPERATURES

TILLAGE SYSTEM	AVERAGE SOIL TEMPERATURES ^{o}C
Zero Tillage	21.22
Minimum Tillage	20.17
Conventional Tillage	20.33
Deep Tillage	20.63
Intensive Tillage	20.75

ANALYSIS OF VARIANCE TABLE FOR SOIL TEMPERATURES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	Computed F	Tabulated F 0.01	0.05
Blocks	3	50.79	16.93	3.2558	3.95	2.68
Treatments	4	18.79	4.70	0.9038	3.48	2.45
Experimental Error	12	85.93	7.16	1.3769	2.34	1.83
Sampling Error	120	623.96	5.20			
Total	139	779.46				

Comparing the computed F to the tabulated F, it can be concluded that the difference in the soil temperatures is not due to the different tillage systems. The difference in soil temperatures are not significantly different at the levels indicated because in all cases the computed F is less than the tabulated F.

CROP GROWTH AND DEVELOPMENT JULY 1 - JULY 31

SURFACE ALBEDO

TILLAGE SYSTEM	AVERAGE SURFACE ALBEDO %
Zero Tillage	16.54
Minimum Tillage	14.27
Conventional Tillage	14.00
Deep Tillage	12.45
Intensive Tillage	11.89

ANALYSIS OF VARIANCE TABLE FOR ALBEDO

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	Tabulated F 0.05
Blocks	3	100.16	33.39	2.3415	3.78	2.60
Treatments	4	1062.05	265.51	18.6192	3.32	2.37
Experimental Error	12	41.85	3.49	0.2447	2.18	1.75
Sampling Error	380	5419.33	14.26			
Total	399	6623.39				

Coparing the computed F to the tabulated F it can be concluded that the difference in albedo is due to the different tillage treatments.

DUNCAN'S MULTIPLE - RANGE TEST

To calculate the shortest significant ranges

$Rp = rp\ (S_{\bar{x}})$ where, rp is obtained from Tables and

$$S_{\bar{x}} = \sqrt{\frac{S^2}{n}}$$

$$Rp = rp\sqrt{\frac{14.26}{20}} = 0.844\ rp$$

p	rp(0.01)	Rp	rp(0.05)	Rp
2	3.643	3.075	2.772	2.340
3	3.796	3.204	2.918	2.463
4	3.900	3.292	3.017	2.546
5	3.978	3.357	3.089	2.607

16.54	14.27	14.00	12.40	11.89	Level
					0.01
					0.05

Any two means not underscored by the same line are significantly different at the levels indicated.

SURFACE TEMPERATURES

TRLLAGE SYSTEM	AVERAGE SURFACE TEMPERATURE ^{o}C
Zero Tillage	36.94
Minimum Tillage	38.86
Conventional Tillage	38.98
Deep Tillage	39.53
Intensive Tillage	40.450

ANALYSIS OF VARIANCE TABLE FOR SURFACE TEMPERATURES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	179.68	59.89	0.9584	3.78	2.60
Treatments	4	531.82	132.96	2.1277	3.32	2.37
Experimental Error	12	841.09	70.09	1.1216	2.18	1.75
Sampling Error	380	23744.21	62.49			
Total	399	25296.80				

Comparing the computed F to the tabulated F it can be concluded that the difference in surface temperature is not due to the different tillage systems. The difference in the surface temperatures are not significantly different at the levels indicated, because in all cases the computed F is less than the tabulated F.

SOIL TEMPERATURES

TILLAGE SYSTEM	AVERAGE SOIL TEMPERATURE ^{o}C
Zero Tillage	24.79
Minimum Tillage	24.87
Conventional Tillage	24.82
Deep Tillage	25.01
Intensive Tillage	25.38

ANALYSIS OF VARIANCE TABLE FOR SOIL TEMPERATURES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	48.65	16.22	1.3642	3.78	2.60
Treatments	4	19.03	4.76	0.4003	3.32	2.37
Experimental Error	12	98.94	8.25	0.6939	2.18	1.75
Sampling Error	380	4520.00	11.89			
Total	399	4686.62				

Comparing the computed F to the tabulated F, it can be concluded that the difference in the soil temperatures is not due to the different tillage systems. The difference in soil temperatures are not significantly different at the levels indicate because in all cases the computed F is less than the tabulated F.

HEADING AND FILLING OF HEADS - AUGUST 1 - AUGUST 31

SURFACE ALBEDO

TILLAGE SYSTEM	AVERAGE SURFACE ALBEDO %
Zero Tillage	14.88
Minimum Tillage	14.73
Conventional Tillage	14.72
Deep Tillage	13.54
Intensive Tillage	12.56

ANALYSIS OF VARIANCE TABLE FOR ALBEDO

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	Tabulated F 0.05
Blocks	3	13.00	4.33	0.5964	3.76	2.60
Treatments	4	174.29	43.57	6.0014	3.32	2.37
Experimental Error	12	25.92	2.16	0.2975	2.18	1.75
Sampling Error	180	1306.22	7.26			
Total	199	1519.46				

Comparing the computed F to the tabulated F, it can be concluded that the difference in the albedo is due to the different tillage treatments.

DUNCAN'S MULTIPLE - RANGE TEST

To calculate the shortest significant ranges

$Rp = rp\ (S_{\bar{x}})$ shere, rp is obtained from Tables and

$$S_{\bar{x}} = \sqrt{\frac{S^2}{n}}$$

$$Rp = rp\sqrt{\frac{7.26}{10}} = 0.852\ rp$$

p	rp(0.01)	Rp	rp(0.05)	Rp
2	3.643	3.104	2.772	2.362
3	3.796	3.234	2.918	2.486
4	3.900	3.323	3.017	2.571
5	3.978	3.389	3.089	2.632

14.88	14.73	14.72	13.54	12.56	Level
					0.01
					0.05

There is no significant difference between any two means at the two levels shown.

SURFACE TEMPERATURES

TILLAGE SYSTEM	AVERAGE SURFACE TEMPERATURE ^{o}C
Zero Tillage	26.21
Minimum Tillage	26.26
Conventional Tillage	26.21
Deep Tillage	26.72
Intensive Tillage	27.68

ANALYSIS OF VARIANCE TABLE FOR SURFACE TEMPERATURES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	33.05	11.02	1.1862	3.78	2.60
Treatments	4	57.63	14.41	1.5511	3.32	2.37
Experimental Error	12	112.44	9.37	1.0086	2.18	1.75
Sampling Error	160	1486.43	9.29			
Total	179	1689.55				

Comparing the computed F to the tabulated F, it can be concluded that the difference in surface temperatures is not due to the different tillage systems. The difference in the surface temperares are not significantly different at the levels indicated, because in all cases the computed F is less than the tabulated F.

SOIL TEMPERATURES

TILLAGE SYSTEM	AVERAGE SOIL TEMPERATURE ^{o}C
Zero Tillage	20.99
Minimum Tillage	21.36
Conventional Tillage	21.23
Deep tillage	21.59
Intensive Tillage	21.98

ANALYSIS OF VARIANCE TABLE FOR SOIL TEMPERATURES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	4.72	1.57	0.1057	3.78	2.60
Treatments	4	20.34	5.09	0.3413	3.32	2.37
Experimental Error	12	39.33	3.28	0.2468	2.18	1.75
Sampling Error	160	2384.33	14.90			
Total	179	2448.73				

Comparing the computed F to the tabulated F, it can be concluded that the difference in the soil temperatures is not due to the different tillage systems. The difference in soil temperatures are not significantly different at the levels indicated because in all cases the computed F is less than the tabulated F.

RIPENING AND DRYING OF CROP - SEPTEMBER 1 - HARVEST

SURFACE ALBEDO

TILLAGE SYSTEM	AVERAGE SURFACE ALBEDO - %
Zero Tillage	17.68
Minimum Tillage	17.03
Conventional Tillage	16.68
Deep Tillage	16.28
Intensive Tillage	16.24

ANALYSIS OF VARIANCE TABLE FOR ALBEDO

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	Tabulated F 0.05
Blocks	3	8.64	2.88	0.5035	4.07	2.73
Treatments	4	70.03	17.51	3.0612	3.59	2.50
Experimental Error	12	19.59	1.63	0.2850	2.45	1.89
Sampling Error	80	457.56	5.72			
Total	99	555.82				

Comparing the computed F to the tabulated F it can be concluded that there is no significant difference in the albedo at the 1 percent level. At the 5 percent level the computed F is larger than the tabulated F. Therefore we will proceed with Duncan's Multiple Range Test at the 5 percent level only.

DUNCAN'S MULTIPLE - RANGE TEST

To calculate the shortest significant ranges

$Rp = rp\ (S_{\bar{x}})$ where, rp is obtained from Tables and

$$S_{\bar{x}} = \sqrt{\frac{s^2}{n}}$$

$$Rp = rp \sqrt{\frac{5.72}{5}} = 1.070\ rp$$

p	rp - 0.05	Rp
2	2.819	3.015
3	2.966	3.172
4	2.064	3.277
5	3.134	3.352

17.68	17.03	16.68	16.28	16.24	Level
					0.05

There is no significant difference between any two means at the 5 percent level as indicated.

SURFACE TEMPERATURES

TILLAGE SYSTEM	AVERAGE SURFACE TEMPERATURE ^{o}C
Zero Tillage	22.38
Minimum Tillage	23.33
Conventional Tillage	22.75
Deep Tillage	23.35
Intensive Tillage	23.68

ANALYSIS OF VARIANCE TABLE FOR SURFACE TEMPERATURES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	0.05
Blocks	3	21.93	7.31	0.5530	4.07	2.73
Treatments	4	21.84	5.46	0.4130	3.59	2.50
Experimental Error	12	78.95	6.58	0.4977	2.45	1.89
Sampling Error	80	1057.64	13.22			
Total	99	1180.36				

Comparing the computed F to the tabulated F it can be concluded that the difference in surface temperatures is not due to the different tillage systems. The difference in the surface temperatures are not significantly different at the levels indicated because in all cases, the computed F is less than the tabulated F.

SOIL TEMPERATURES

TILLAGE SYSTEM	AVERAGE SOIL TEMPERATURES ^{o}C
Zero Tillage	16.49
Minimum Tillage	17.35
Conventional Tillage	17.36
Deep Tillage	17.19
Intensive Tillage	17.58

ANALYSIS OF VARIANCE TABLE FOR SOIL TEMPERATURES

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabulated F 0.01	Tabulated F 0.05
Blocks	3	11.95	3.98	0.5958	4.07	2.73
Treatments	4	13.10	3.27	0.4895	3.59	2.50
Experimental Error	12	40.45	3.37	0.5045	2.45	1.89
Sampling Error	80	534.59	6.68			
Total	99	600.09				

Comparing the computed F to the tabulated F it can be concluded that the difference in the soil temperatures is not due to the different tillage systems. The difference in soil temperatures are not significantly different at the levels indicated because in all cases the computed F is less than the tabulated F.