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Thermal Storage Comparison for Variable Basement Kinds of a Solar Chimney Prototype in Baghdad - Iraq Weathers

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Abstract

A solar updraft tower power plant ‘solar tower’ is a solar thermal power plant utilizing a combination of solar air collector and central updraft tube to generate an induced convective flow which drives pressure staged turbines to generate electricity. The issue of this paper is to present practical results of prototype of a solar chimney with thermal mass, where the glass surface is replaced by transparence plastic cover. The study focused on chimney's basements kind effect on collected air temperatures. Three basements were used, concrete, black concrete and black pebbles basements. The study was conducted in Baghdad from August to November 2010.

The results show that the best chimney efficiency attained was 49.7% for pebbles base. The highest collected air temperature reached was 49ºC when using the black pebbles basement. Also, the maximum basement temperature measured was 59ºC for black pebbles. High increments in collected air temperatures were achieved compared to ambient air temperatures for the three basements kind. The highest temperature difference reached was 22ºC with the pebble ground.

Keywords: Solar Chimney, Basement Effect, Concrete, Pebbles, Storage Efficiency.

1. INTRODUCTION

Sun is the principal source of almost all kinds of energy, both conventional and non-conventional. The sun is approximately 1.4 million km in diameter and 150 million km from the earth. Its temperature is close to 5500℃ at its surface and emits radiation at a rate of 3.8×10^{23} kW. This power is supplied by nuclear fusion reactions near its core which are estimated to continue for several billion years [1].

The input of solar radiation to the biosphere is the source of energy which drives our weather systems and so in turn, winds, hydroelectric and biomass energy systems. Solar radiation can be used directly for photovoltaic energy conversion and for solar thermal conversion [2].
Electricity can be generated from solar radiation through the following methods:
- Photovoltaic cells
- Solar thermal power
- Solar tower / chimney [3].

A recent development in solar energy is a solar tower/chimney. It is a method used for large-scale generation of electricity from solar radiation. The principle is very simple [4]. A solar chimney is an air-heating solar collector that runs automatically, on sun power alone. It is based on the well known principle of greenhouse effect, chimney updraft effect, and wind turbine. Air is heated by

solar radiation under a low circular transparent or translucent roof opened at the periphery; the roof and the natural ground below it form a solar air collector [5]. In the middle of the roof a vertical tower is installed with large inlet at its base. The joint between the roof and the tower base is airtight. As hot air is lighter than cold air it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter [6], [14]. Due to greenhouse effect the air is warmed in the solar collector. The warm air is moving from the periphery of the solar collector towards its center, in order to ‘’escape’’ to upper layers of atmosphere through the solar chimney (fig.1). This moving stream of warm air leaves part of its thermodynamic energy to the air turbines that are geared with appropriate electric generators.
An indicative diagram for a Solar Chimney Power Plant is shown in fig.1.

In 1903, Spanish Colonel Isidoro Cabanyes first proposed a solar tower power plant in the magazine La energia electrica. One of the earliest descriptions of a solar tower power plant was written in 1931 by a German author, Hanns Gunther. Beginning in 1975, Robert E Lucier applied for patents on a solar tower electric power generator. These patents were granted in Australia, Canada, and the USA between 1978 and 1981.

The first studies on solar chimneys have been reported in 1993 by reference [17]. They present a stationary state model to describe a solar chimney, consistent by a conventional chimney linked to an air solar heater. Hirunlabh et al. report on 1999 the results of an experimental solar chimney, composed by a glass surface, air channel and a metallic black wall as collector surface. Reference [7] make a comparative study among different configurations of solar chimneys classified like; roof solar collector, modified Trombe wall, Trombe wall and metallic solar wall. On 2003 reference [8] report the experimental and theoretical results of a solar chimney similar to the Hirunlabh one.

Solar towers have a number of special features:
1. The collector can use all solar radiation, both direct and diffuse. This is crucial for tropical countries where the sky is frequently overcast [9].
2. Due to the soil under the collector working as a natural heat storage system, updraft solar towers can operate 24 hours on pure solar energy, at reduced output at night time. If desired, additional water tubes or bags placed under the collector roof absorb part of the radiated energy during the day and releases it into the collector at night [8].
3. Solar towers are particularly reliable and not liable to break down, in comparison with other power plants. Turbines and generators - subject to a steady flow of air - are the plant's only moving parts. This simple and robust structure guarantees operation that needs little maintenance and of course no combustible fuel [4].
4. Unlike conventional power stations (and also some other solar-thermal power station types), solar towers do not need cooling water. This is a key advantage in the many sunny countries that already have major problems with water supply [10].
5. The building materials needed for solar towers, mainly concrete and glass, are available everywhere in sufficient quantities. In fact, with the energy taken from the solar tower itself and the stone and sand available in the desert; they can be reproduced on site. Energy payback time is two to three years [11].
6. Solar towers can be built now, even in less industrially developed countries. The industry already available in most countries is entirely adequate for solar tower requirements. No investment in high-tech manufacturing plants is needed [12].
7. Even in poor countries it is possible to build a large plant without high foreign currency expenditure by using local resources and work-force; this creates large numbers of jobs while significantly reducing the required capital investment and thus the cost of generating electricity [2].
Nevertheless, solar towers also have features that make them less suitable for some sites:
A. They require large areas of flat land. This land should be available at low cost, which means that there should be no competing usage, like e.g. intensive agriculture, for the land [9].
B. Solar towers are not adequate for earthquake prone areas, as in this case tower costs would increase drastically [13].

C. Zones with frequent sand storms should also be avoided, as either collector performance losses or collector operation and maintenance costs would be substantial there [6].
The objective of this study was to examine the effect of basements type on the air temperatures of prototype solar chimney designed and constructed for this purpose, in Baghdad autumn days.

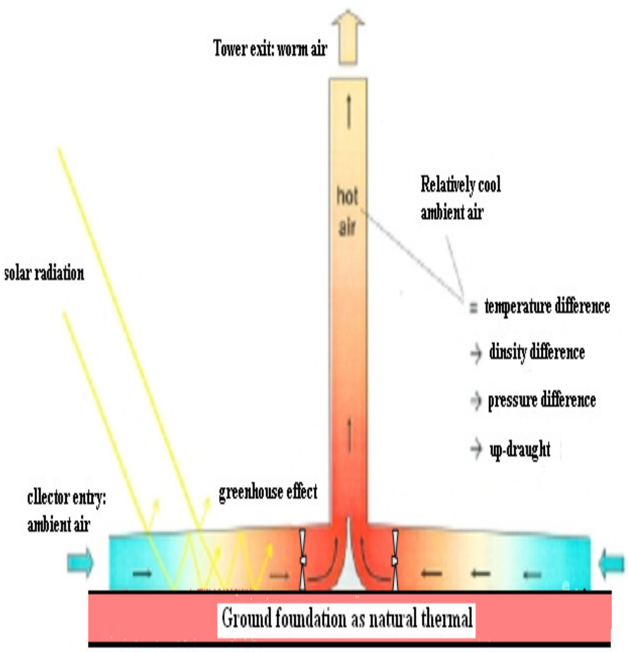

FIGURE 1: Solar tower working principles

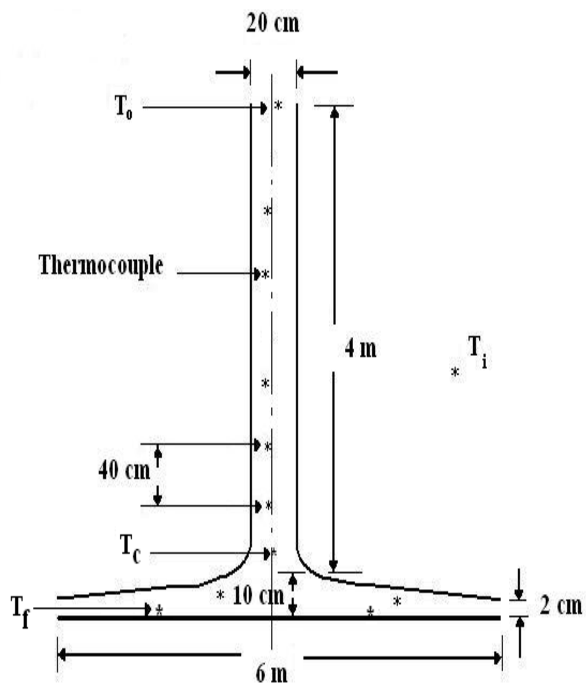

FIGURE 2: Schematic diagram of the solar chimney and thermocouples distribution

2. EXPERIMENTAL SETUP

The solar tower's prototype was build (shown in Fig. 2): Air is heated by solar radiation under a low circular transparent roof (6 meters diameter) open at the periphery (2 cm high from ground); the roof and the ground below it form a solar air collector. In the middle of the roof is a vertical (4 meters tall and 20 cm diameter) tower with large air inlets at its base (10 cm height from the ground). The joint between the roof and the tower base is airtight. As hot air is lighter than cold air it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter. Continuous 24 hours- operation can be achieved by placing a thermal collector ground. For this purpose three kinds of grounds were studied, the first was an ordinary concrete ground, which heats up during day-time and releases its heat at night. The second was selective black colored concrete ground to absorb more heat at daylight. The third basement was selective black colored pebbles which known as heat storage substance and gave efficient air mixing by increasing its turbulence. The idea was to investigate the best basement material that makes solar radiation causes a daily constant updraft in the tower.
The temperature of air under the transpierce cover was measured by (6) six calibrated copper-constantan thermocouples distributed uniformly around the vertical chimney. Also, the rising air temperature through the chimney was measured by means of calibrated thermocouples. These thermocouples were fixed in variable manner, to give accurate analysis for moving air through the chimney. The first thermocouple in the group represents collected air temperature (T_c). The temperature of the air entering the chimney (T_a) was measured by thermometer fixed away from the chimney. The basements floor temperature (T_f) was measured by means of three thrmo-couples distributed in the west, south and east directions, with a distance of 1.5 meter from the

centre of the collector; the average of these thermocouples readings was taken as (T_f). Temperatures were red by calibrated digital electronic thermometer, through a selector switch. Fig. 2 represents prototype dimensions and thermocouple distribution, while Fig. 3 shows a photographic picture for tested prototype solar chimney.

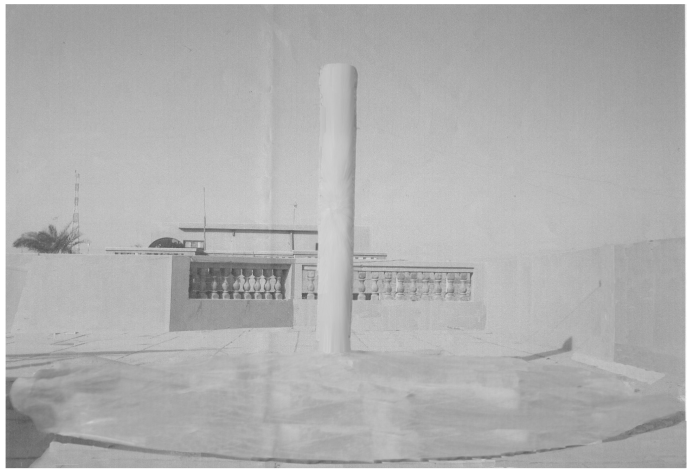

FIGURE 3: The solar tower's prototype

The experiments were conducted in Iraqi autumn days, started at the first of August and finished at the end of November 2010. The tests were conducted in Saydia city west of Baghdad. Three grounds were prepared, the first one was ordinary concrete ground, the second one was ordinary concrete ground painted with selective black color, and the third was selective black colored pebble ground. Table 1 represents the thermal properties for the used material. The prototype chimney was fixed in each ground for 10 days. Temperatures readings were taken, so for each ground there are readings for the three months, the resultant average were undertaken to compare between the three cases. Temperature readings operation began at sun shine and continued after sunset until the basement reached its starting temperature. These temperatures demonstrated the thermal storage in the basement.

3. SYSTEM EFFICIENCY CALCULATIONS

Solar tower system consists of three main parts: collector, tower and turbine. In this study there is no turbine used, and the concentration was on thermal energy gathered by solar chimney collector by its various basements.

In calculating system efficiency the procedure mentioned in (Schlaich et al, 2005) was used, for any further detail one can refer to. The basic function for solar chimney is to convert heat flow produced by the collector into kinetic energy. Then its efficiency can be calculated by:

Total system efficiency

$$= \eta_{coll} . \eta_{tower} . \eta_{turbines} \qquad (1)$$

Where: η_{coll} - Collector efficiency. η_{tower} - Tower efficiency, and $\eta_{turbine}$ - Turbine efficiency.

In this study there was no turbine to complete this conversion, and the focus was on the collector efficiency which is calculated by:

$$\eta_{coll} = \frac{P_{tot}}{\dot{Q}} \qquad (2)$$

P_{tot} - the pressure difference produced between collector outlet and ambient air, it depends on the density difference of air caused by the temperature rise in the collector area and calculated as follow:

$$P_{tot} = A_c . g . \int_0^{Hc} (\rho_a - \rho_c).dH \qquad (3)$$

With: A_c- collector area, H_c- tower hight, ρ_a- air density in ambient temperature, and ρ_c- air density in the tower. Thus P_{tot} increase with the tower hieght.

$$\dot{Q} = G_h . A_c \qquad (4)$$

where $\dot{Q}$ - The solar energy input, and G_h - Average solar intensity taken from Iraqi Meteorology organization for 24 hours of the tested period. This efficiency was used to compare between the three basements in this study.
The former equations illustrate for very important characteristic in solar chimney, which is the chimney efficiency depends mainly on chimney's tower height.

4. RESULTS AND DISCUSSION

Figures (4 to 6) represent the solar chimney behavior when concrete ground was used for the three studied months. The results show the air temperature increase with time, starting from the sun rise, this increase was associated with an increase in the collected air (T_c) and the basement (T_f) temperatures. The maximum temperatures were achieved at 2 PM. collected air was heated in this region (sun rise till 2 PM) by greenhouse effect, while the direct radiation heated the ground. In these hours the collected air was independent of the worm ground.

All temperatures reduced after 2 clock at noon, until they reached the starting temperature after sun set. In this region the collected air depends on the basement to worm up. The thermal storage for the concrete ground was very limited and achieved temperature differences for about two hours after sun set. This limited time is due to the prototype chimney dimensions. It is believed that bigger collector area will give more thermal storage heat, and will introduce more working hours to the chimney. The maximum difference between (T_c) and (T_a) was (19ºC). The maximum variation between air temperature (T_a) and ground temperature (T_f) for ordinary concrete case was about (25ºC) at 1 to 2 PM where the highest temperatures were achieved. The maximum (T_f) reached was (56ºC) in August days.

Figures (7 to 9) represent the solar chimney behavior when selective black colored concrete ground was used. The average temperatures for three months operation periods in these figures show that there were some improvements in temperature differences between ambient air and collected air, where it reached (20ºC) at peak time.

The black colored concrete ground absorbed more solar radiation, and heated more than ordinary concrete basement where (T_f) reached maximum temperature about (57.6ºC) in August days. Also at 7 AM (temperatures measurement starting point) there were differences between (T_c) and (T_f) more than other months. The effect of solar radiation is more efficient in hotter days, which means more system efficiencies will be obtained at summer months.

The thermal storage of black colored concrete basement managed to continue worming collected air for three hours after sun set, despite the limited collector size.
Figures (10 to 12) demonstrate the solar chimney behavior when black colored pebbles basement was used. The figures show that there are some improvements in temperature differences; the maximum temperature difference between (T_a) and (T_c) reached (22ºC) at the peak time. The black pebbles ground absorbed solar radiation, and heated more than ordinary concrete basement due to its higher specific heat. The maximum temperature obtained was (59ºC). This thermal storage managed to continue operating for five hours after sun set, despite the limited collector size.

These results give black pebbles priority on ordinary and black concrete basements. As well as it proves that a suitable basement combined with suitable solar chimney design manage to operate for 24 hours.

The results demonstrate that the storage capacity of black concrete improved about 50% compared with ordinary concrete, while black pebbles improved this capacity with about 250% due to its thermal properties.

Fig.13 shows the chimney's collector hourly efficiency variation for the three systems with operation time. Because the studied system depends on solar energy, then it's collecting time starts from sunrise and ends at sunset. The pebbles basement collecting efficiency surpasses the other cases. The thermal storage improved with this ground, and enables the chimney to work for more time. On the other hand, coloring the concrete ground with black upgrade the thermal storage and improve its efficiency. The results concluded that the efficiency of solar chimney depends highly on the thermal storage capacity of its basement material.

5. CONCLUSIONS

The practical prototype model of the solar chimney power plant was designed and constructed to investigate the influence of basement kinds on chimney's air temperatures, in the region of Baghdad city- Iraq. The effects of storage parameter, such as the solar radiation, the ambient temperature, and the heat storage capacity for ground materials on the power plant operation time are also investigated. According to the results obtained from the proposed model, the following conclusions can be drawn:

1- The solar chimney power plant have a suitable basement (black colored pebble ground in this work) can achieve air heating for many hours operation after sun set. With suitable design the solar chimney power plant will manage to act 24 hours / day.

2- The results show that black pebbles basement had better thermal storage quality than ordinary concrete or black concrete ground.

3- Although the chimney prototype size was limited, it gave high temperature difference between T_c and T_a reached 22°C. Maximum T_f reached was 59 °C when using black pebbles. This indicates the convenient of Iraqi weathers for this type of plants.

4- Painting the basement with selective black color increase absorbed solar radiation, thereby improved the system efficiency.

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material	Density (ρ) kg/m3	Conductivity (k) W/m ºC	Conductance W/m2 ºC	Specific heat kJ/kg ºC
Concrete	2020-2180	-	3.0-3.5	0.92
Pebble	2080	0.92-1.12	-	5.28

TABLE 1: Typical thermal properties for tested materials (McQuiston et al).

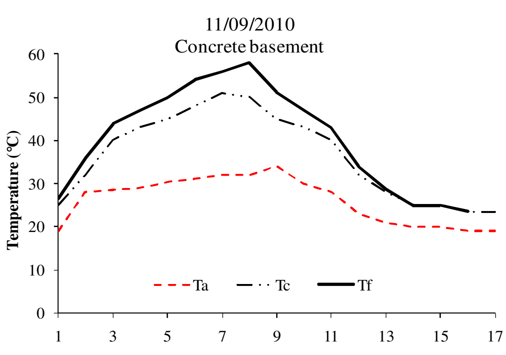

FIGURE 4: Concrete basement and air temperatures at 11/9/2010.

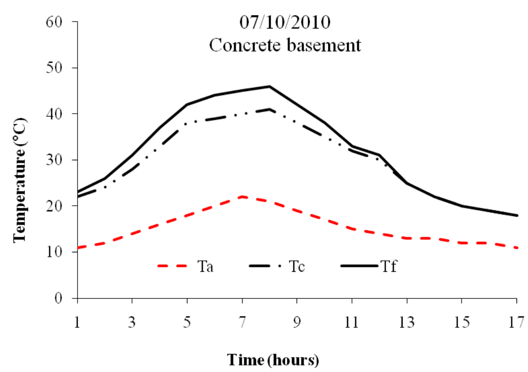

FIGURE 5: Concrete basement and air temperatures at 7/10/2010**.**

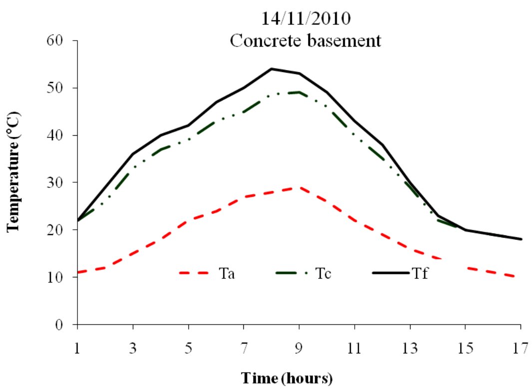

FIGURE 6: Concrete basement and air temperatures at 14/11/2010.

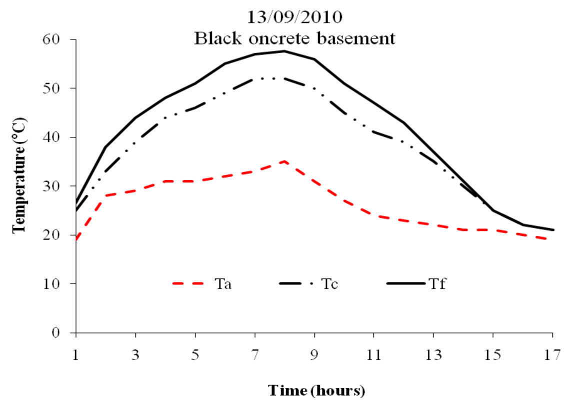

FIGURE 7: Black concrete basement and air temperatures at 13/9/2010**.**

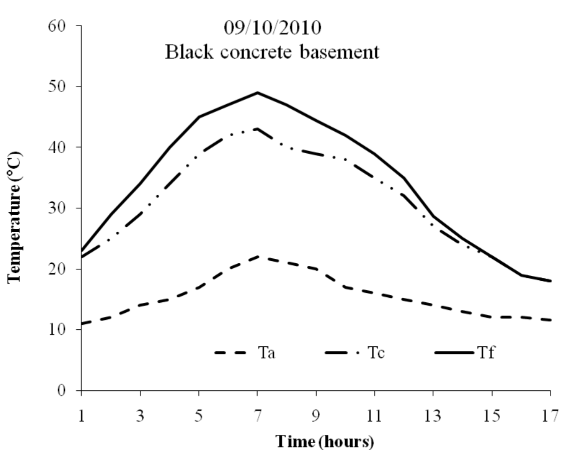

FIGURE 8: Black concrete basement and air temperatures at 9/10/2010.

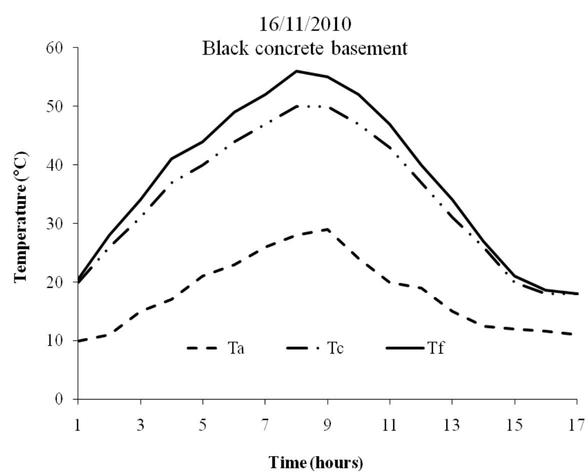

FIGURE 9: Black concrete basement and air temperatures at 16/11/2010.

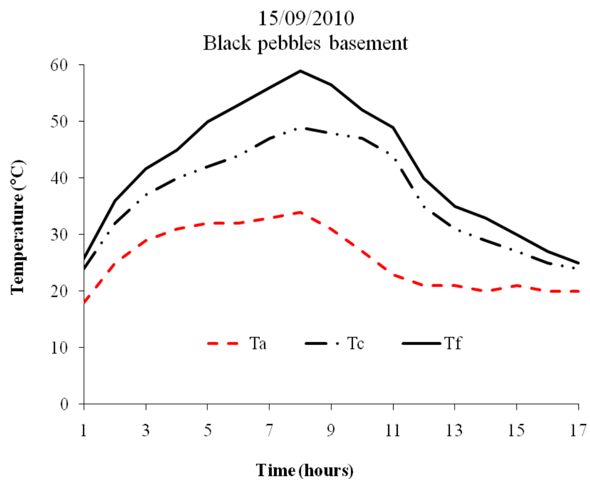

FIGURE 10: Black pebbles basement and air temperatures at 15/9/2010.

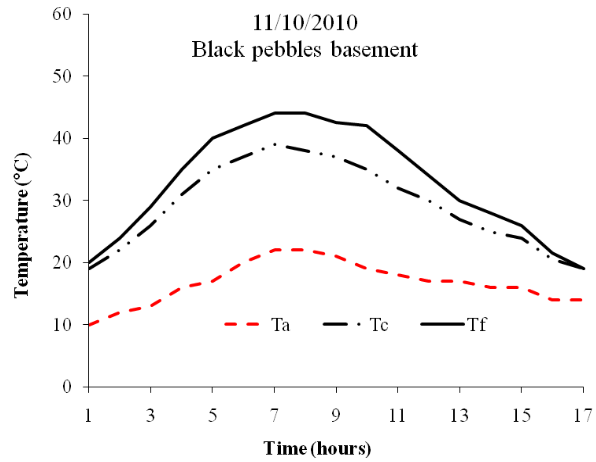

FIGURE 11: Black pebbles basement and air temperatures at 11/10/2010.

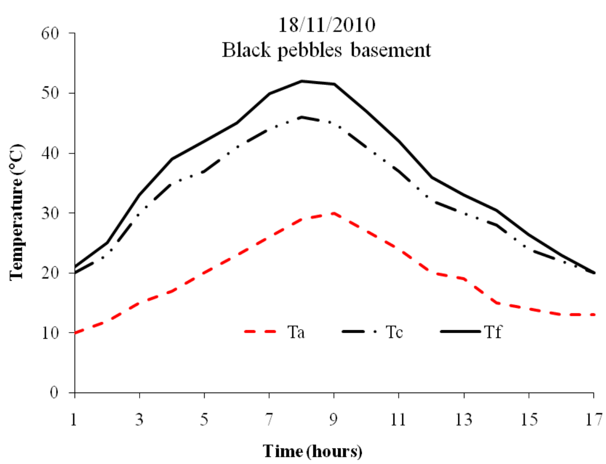

FIGURE 12: Black pebbles basement and air temperatures at 18/11/2010.

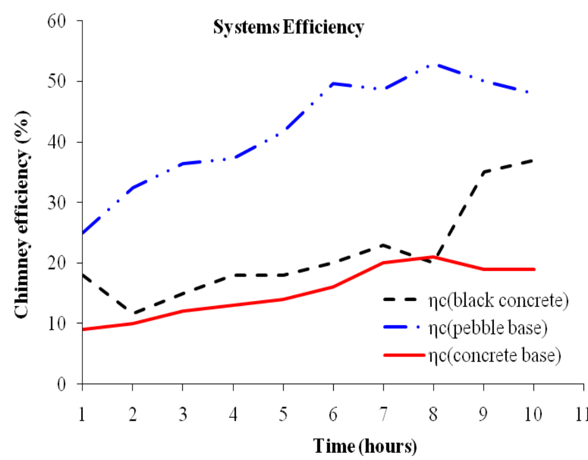

FIGURE 13: Average efficiency differences for day hour for basement systems.

Method for Estimation of Total Nitrogen and Fiber Contents in Tealeaves with Ground Based Network Cameras

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Abstract

Methods for estimation of total nitrogen and fiber contents in tealeaves with ground based network cameras are proposed. Due to a fact that Near Infrared: NIR camera data is proportional to total nitrogen while that shows negative correlation to fiber contents, it is possible to estimate nitrogen and fiber contents in tealeaves with ground based NIR camera data and remote sensing satellite data. Through regressive analysis between measured total nitrogen and fiber contents and NIR reflectance of tealeaves in tea estates, it is found that there is a good correlation between both then regressive equations are created. Also it is found that monitoring of total nitrogen and fiber contents in tealeaves measured with networks cameras is valid. Thus it is concluded that a monitoring of tea estates with network cameras of visible and NIR is appropriate.

Keywords: Nitrogen and Fiber Content, Tealeaf, Sensor Network, Visible and Near Infrared Network cameras, Tea Estate Monitoring

1. INTRODUCTION

Vitality monitoring of vegetation is attempted with photographic cameras [1]. Grow rate monitoring is also attempted with spectral reflectance measurements [2]. Total nitrogen content corresponds to amid acid which is highly correlated to Theanine: 2-Amino-4-(ethylcarbamoyl) butyric acid so that total nitrogen can be used for a measure of the quality of tealeaves. It is well known that Theanine rich tealeaves taste good while fiber content in tealeaves is highly correlated to the grow rate of tealeaves. Both total nitrogen and fiber content in tealeaves are highly correlated to the reflectance in the visible and near infrared wavelength regions and vegetation index derived from visible and near infrared data so that it is possible to determine most appropriate tealeaf harvest date using the total nitrogen and fiber content in the tealeaves which are monitored with ground based visible and near infrared cameras and with visible and near infrared radiometers onboard remote sensing satellites. Namely the most appropriate time for harvesting tealeaves is whenever total nitrogen shows the maximum and fiber content shows the minimum. It, however, is not so easy because no one knows the minimum and maximum and because grow rate cannot be estimates with fiber content which is monitored with just cameras and radiometers perfectly. Therefore, it is required to monitor grow rate with the other method with a much precise manner.

Tea estate monitoring system with network cameras together with remote sensing satellite data is proposed in the following section followed by proposed estimation methods for total nitrogen and fiber contents with network camera data together with some experimental results. Finally, concluding remarks is followed with some discussions.

2. PROPOSED METHOD

1. Tea Estate Monitoring System With Network Cameras

The proposed tea estate monitoring system is illustrated in Figure 1. Visible and NIR network cameras are equipped on the pole in order to look down with -5-95 degrees of incident angle which depends on the location as is shown in Figure 1. The pole is used for frosty damage avoidance to the tealeaves using fan (convection of boundary layer of the air) mounted on the pole. With these network cameras, reflectance in the wavelength region of 550nm (red color) and 870nm (NIR) are measured together with BRDF assuming that vegetated areas are homogeneous and flat. BRDF is used for estimation of Grow Index (GI) and BRDF correction from the measured reflectance of the tealeaves.

The proposed system of tea estate monitoring consists of wireless connected network cameras, weather station and its controller of mobile phone and internet terminals. Visible Pan-Tilt-Zoom: PTZ network camera and NIR filter (IR840) attached one is equipped on the pole. PTZ cameras are controlled by mobile phone with “mobile2PC” or Internet terminal with “LogMeIn” of VNC services [3] through wireless LAN connected Internet. Acquired camera data are used for estimation of total nitrogen and fiber contents for monitoring grow index. Figure 2 shows examples of the acquired visible and near infrared camera data. From the acquired camera images, flatly situated leaf is extracted then mean and variance of the pixels value is estimated. After that, reflectance of the tealeaf is calculated with the mean value of the leaf with the reference to the pixel value of Spectralon for each visible and near infrared wavelength. Figure 3 shows histograms of flatly situated tealeaf (normal direction is almost identical to zenith direction) extracted from the Figure 2 of images. Reflectance of the flatly situated tealeaf can be calculated with pixels value of Spectralon.

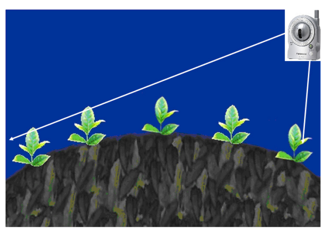


FIGURE 1: Illustrative view of the proposed vegetation monitoring system with two network cameras, visible and NIR.

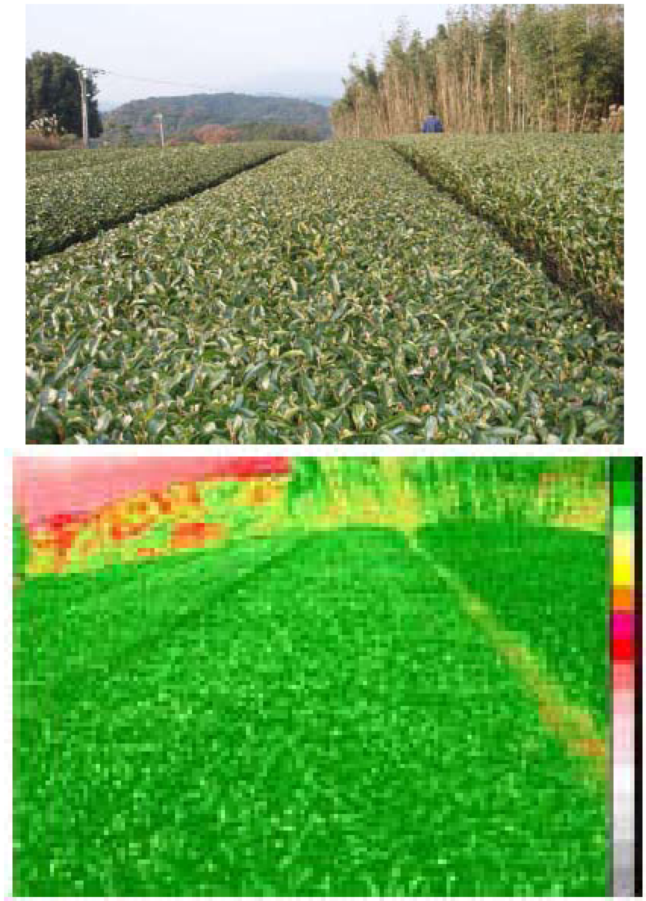
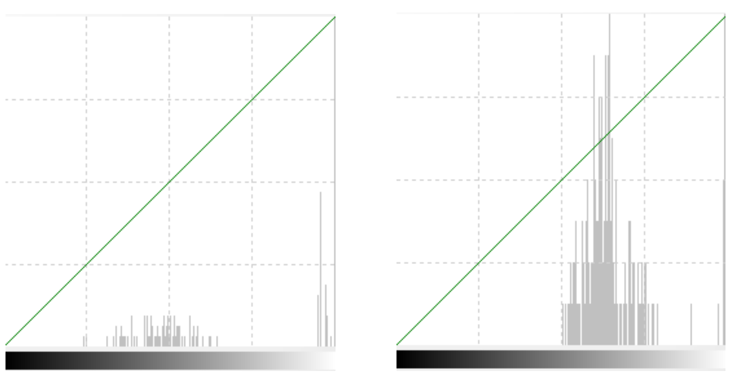


FIGURE 2: Examples of the acquired visible (left) and near infrared (right) camera data of September 27 2007.



(a) Visible (550nm) (b) Near infrared (870nm)

FIGURE 3: Histograms for visible and near infrared camera image of flatly situated tealeaf extracted from the whole scene of tea estate which was acquired on September 27 2007.

2. Regressive Analysis

In general, nitrogen content (Total Nitrogen: TN) in the tealeaves is proportional to the near infrared radiance from the tealeaves while fiber content (Fiber measured with Near Infrared: F-NIR) in the tealeaves is negatively proportional to the near infrared radiance from the tealeaves.

$TN = a\ Ref_{870} + b$ (1)
$F\text{-}NIR = -c\ Ref_{870} + d$ (2)

where a,b,c,d are regressive coefficients while Ref_{870} denotes reflectance at 870nm of wavelength. *TN* is measured by NIR method of measuring instrument, RT-85 manufactured by Shizuoka Seiki Co., Ltd. In order to check the measured *TN*, Kjeldahl method of chemical method is also used. Meanwhile *F-NIR* is Neutral Detergent Fiber: NDF which is also measured by NIR method of RT-85 for dried tealeaves. The date measured is as follows,
7/2,8/18,10/23,11/26,12/24 in 2007,
1/4,1/15,2/10,2/27,2/28,3.29,4/14,5/2, 5/16,6/1,7/1.7/3,8/4,8/20,9/5,10/8,11/7,12/10,12/26 in 2008,
1/11,2/12,2/28,3/16,4/17,6/20,7/6,8/7,8/23, 9/24,10/10,10/14,11/27,12/29 in 2009, and
1/30,2/17,3/3,3/19,4/4 in 2010, respectively.
Total nitrogen, fiber contents are measured together with harvested amount for the following dates,
5/4,5/3,5/12,5/8,5/3&5/6&5/7 in 2008 for E1Yabukita, S5Oiwase, N12Benifuki, N3Okumidori, and N3Yabukita, respectively.
4/24,4/23,5/7,5/4,4/18&4/30 in 2009 for E1Yabukita, S5Oiwase, N12Benifuki, N3Okumidori, and N3Yabukita, respectively.
4/30,5/6,5/11,5/7,5/3 in 2010 for E1Yabukita, S5Oiwase, N12Benifuki, N3Okumidori, and N3Yabukita, respectively. Where E,S,N,W denote tea estate name while attached words are species of tealeaf.

Usually, new tealeaves are harvested firstly in the late of April or in the begging of May. Also new tealeaves are harvested secondly in the middle of June, usually followed by the third harvesting in September. In terms of tea taste of the first harvested new tealeaves is the best followed by the secondly and thirdly harvested new tealeaves so that TN and F-NIR of the firstly harvested new tealeaves is mainly focused in this paper.

Through regressive analysis between nitrogen and fiber contents in the tealeaves and the radiance from the corresponding tealeaves measured with visible and near infrared cameras, regressive coefficients of linear equation are estimated.

3. EXPERIMENTS

1. Experimental Conditions

The monitor systems are equipped at four test sites of tea estates of the Saga Prefectural Institute of Tea: SPIT which is situated at 1870-5 Shimojuku, Ureshino city in Saga prefecture Japan. There are four tea estates at the institute, East, South, West and North tea fields. Species and ages are different each other among the four tea fields. Yabukita is situated at the eastern tea field, Oiwase for southern tea field, Benifuki for western tea field and Yabukita and Okumidori for northern tea field, respectively, as are shown in Figure 4.

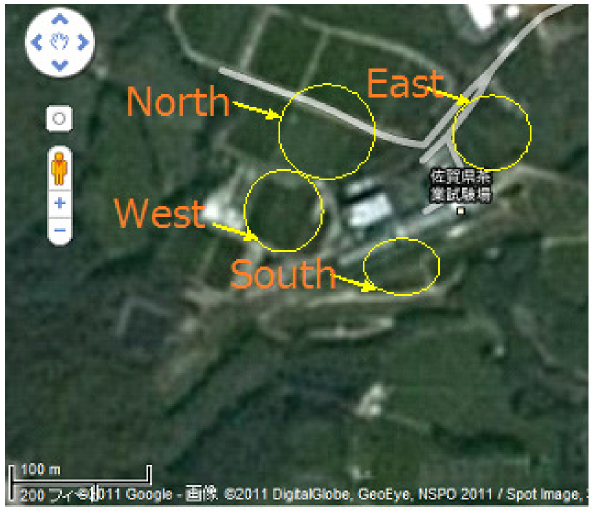


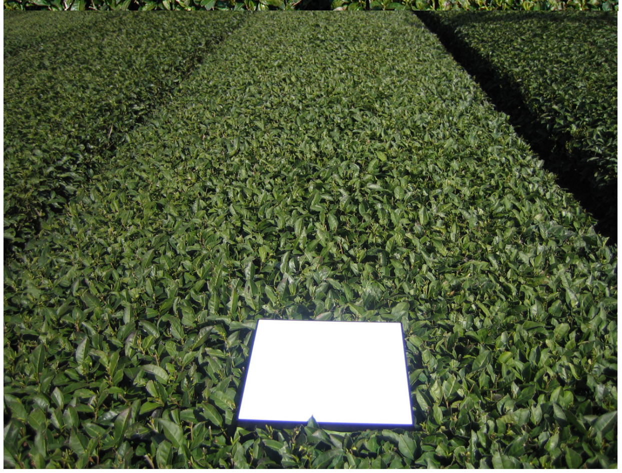
FIGURE 4: Test sites of four tea estates (East, South, West, and North) situated at Saga Prefectural Institute for Tea: SPIT (E129°59′22.3″N33°05′50.7″).

Look angle of the cameras with wide viewing angle (90 degree) of lens are fixed 45 degree of elevation angle so that the camera acquire the field from 0 to 90 degree of elevation angle. Sky condition is monitored pyrometer (hemispherical radiometer). If the sky condition is not good enough, then I omit such unreliable data. I used to measure spectral optical depth. Also I used to estimate absorption due to water vapor, ozone and Rayleigh scattering and aerosol scattering. If the atmospheric condition is varied too much, then I also omit such unreliable data.Figure 5 shows one of the examples of the photos which show how does tea estate look like (a) and also show Spectralon which is manufactured by Labsphere in U.S.A. on the tealeaves (b). Both are taken on September 27 2007 and April 4 2010, respectively. (a) shows how the surface reflectance of tealeaves is measured while (b) shows Spectralon, standard plaque for reflectance measurement looks like. Reflectance measuring instrument is MS-720 manufactured by Eiko Co. Ltd. in Japan. The specification of MS-720 is in the Table 1.

Wavelength coverage	350～1,050nm
Number of channels/Wavelength interval	256ch/3.3nm(interpolated with 1nm）
Wavelength accuracy	<0.3nm
Wavelength resolution (Half power width)	10nm
Temperature Dependency	±5% (－10～＋40℃)
Unit of the measurements	W/m^2・μm
Full aperture(deg.)	10

TABLE 1: Specification of spectral radiometer of MS-720 manufactured by Eiko Co. Ltd.

It also shows outlook of the tea estate on June 4 2009 (c).In comparison to (c) and (a),(b), it is easily found that color of the tealeaves are different each other. Because new tealeaves appear in the early April, May and September so that new tealeaves for both (a) and (b) are just began to appear. On the other hand, new tealeaves well grow-up in June so that almost all the surface is covered with new tealeaves.



(a)September 27 2007

(b) April 4 2010

(c)June 4 2009

FIGURE 5: Example of the photos which show how does tea estate look like and also show Spectralon which is set-up on the tealeaves.

2. Estimation Method for Total Nitrogen and Fiber Contents in Tealeaves

Figure 6 shows typical new tealeaves grow process from the top view of tea estate. Typically, new tealeaves appear in the early April and are harvested in the late April or the early May. Then new tealeaves grow up again in June and are harvested in July. After that new tealeaves grow up again and are harvested in September or October. After all, old tealeaves are cut a little bit for preparation of cold winter season. The idea proposed here is to evaluate vitality of the tea trees through evaluation of total nitrogen and fiber contents by using network cameras monitored in the winter season after harvesting new tealeaves. Such method that allows estimation of vitality of the tea trees is to use measured reflectance at 870nm acquired with NIR network cameras.

Reflectance at 550nm and 870nm together with GM: Green Meter value [4], Grow index, total nitrogen content, fiber content as well as water content are measured at the Prefectural tea research institute of Saga which is situated in Ureshino-city in April.

(a) New tealeaves appear (Mixed with old and new tealeaves)

(b) New tealeaves all over the old tea leaves

FIGURE 6: Typical photos of new tealeaves grow process taken with network camera at tea estate of the prefectural tea research institute of Saga in the begging of April (a) and the late of April (b).

Through a comparison between measured total nitrogen and fiber content and estimated reflectance derived from the NIR camera data, Figure 7 of relationship is obtained. From this relation, the following equations are derived through linear regressive analysis,

$$TN=16.247Ref_{870} - 6.73 \quad (3)$$
$$F\text{-}NIR= - 220.47Ref_{870} + 165.63 \quad (4)$$

where *TN* and *F-NIR* denote Total Nitrogen and Fiber content in tealeaves. R square value for *TN* is 0.7453 while that for *F-NIR* is 0.7989 so that it may say that *TN* and *F-NIR* can be estimated with reflectance at 870nm derived from NIR network camera.

3. Estimation of Grow Index With Measured Reflectance at 870nm

On the other hand, grow index is also highly correlated to reflectance measured at 870nm. Grow index is defined as the ratio of the number of new tealeaves to the total number of tealeaves. In accordance with new tealeaves grow up, grow index is getting large. The grow index, essentially, highly correlated to Normalized Deviation of Vegetation Index: NDVI,

$$NDVI=(Ref_{870}-Ref_{550})/(Ref_{550}+Ref_{870}) \quad (5)$$

and GM. Figure 8 shows the relation between GI and NDVI where GI_{old}=56 and Ref_{870}=0.55518 as well as $NDVI$=0.562677.

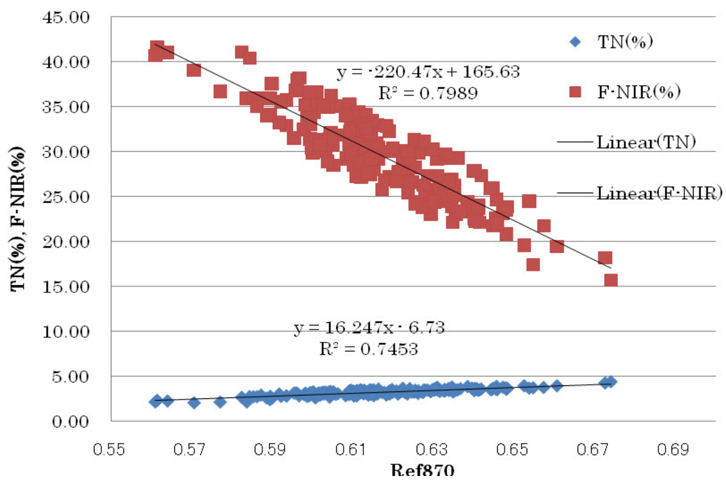


FIGURE 7: Relation between total nitrogen and fiber contents in tealeaves and reflectance at 870nm measured with NIR camera.

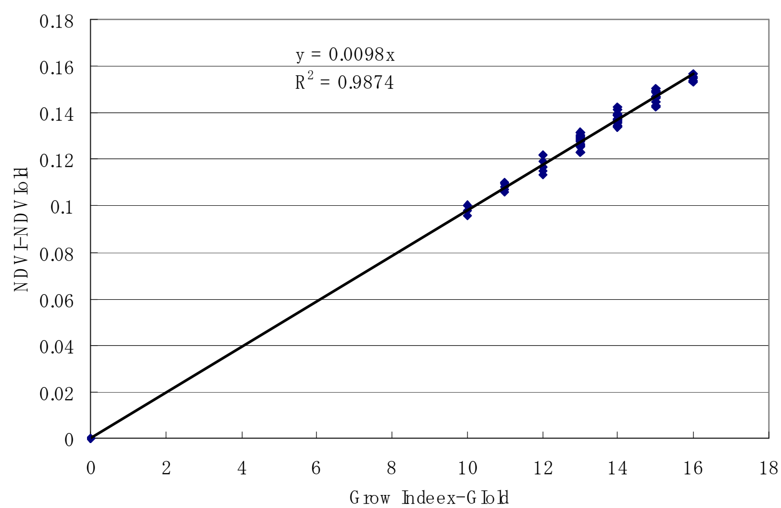


FIGURE 8: Relation between Grow index and NDVI

In the figure, the horizontal axis shows $GI\text{-}GI_{old}$ while the vertical axis shows $NDVI\text{-}NDVI_{old}$. Suffix of old denotes that the tea estate covers with old tealeaves only. In accordance with growing tealeaves, the number of new tealeaves is getting large results in increasing of *GI* as well as *NDVI.* Grow Index: *GI* is expressed with the equation (6) through a linear regressive analysis.

$$GI=102.041 NDVI \quad (6)$$

Thus *TN*, *F-NIR* and *GI* can be estimated with Visible and NIR of network cameras data.

4. Total Nitrogen Content Trend

Figure 9 shows seasonal changes of total nitrogen content in the tealeaves situated in the tea estates of SPIT. E1Yabukita denotes total nitrogen of tealeaves of Yabukita tea trees which are situated in the eastern tea estate while N12 Benifuki denotes that of Benifuki which are situated in Western tea estate. Meanwhile, N3 Okumidori is that of Okumidori tealeaves which are situated in Northern tea estate while N3 Yabukita denotes that of Yabukita tealeaves which are situated in Northern tea estate. Furthermore, S5Oiwase means that of Oiwase tealeaves which are situated in Southern tea estate.

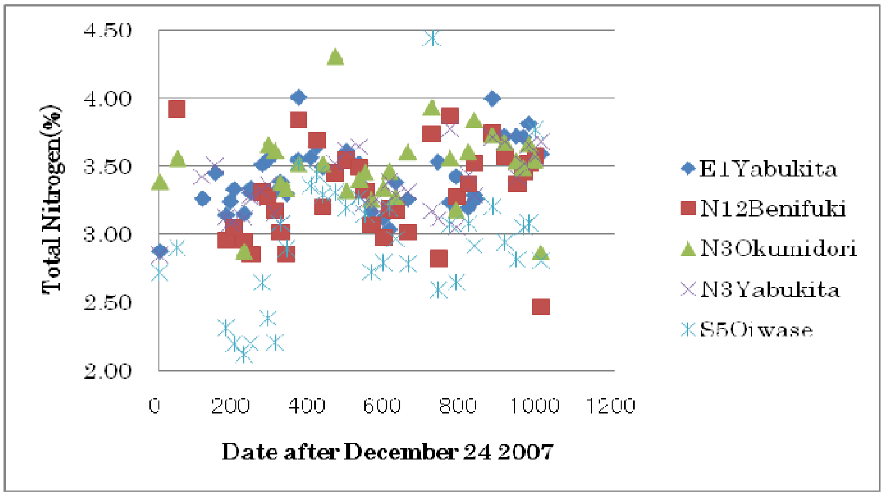


FIGURE 9: Total nitrogen content trend for three years from 2007 to 2010

In general, new tealeaves appears from the old tealeaves in March and grow-up during about four weeks. Then new tealeaves are harvested in the late of April and the begging of May. New tealeaves appear again after that and are harvested in July. After all, new tealeaves appear again after the harvesting then new tealeaves are harvested in September. Namely new tealeaves are harvested three times a year. During from September to the next March, old tealeaves spend cold weather season to maintain their vitality of the tea trees. Total nitrogen is increased three times a year as is shown in Figure 9. Vitality of the tea trees depends on the total nitrogen content during from September to March.

4. CONCLUSIONS

It is possible to estimate mass and quality of new tealeaves based on monitored camera imagery data and satellite imagery data derived total nitrogen and fiber contents in the new tealeaves. It is obvious that nitrogen rich tealeaves tastes good while fiber rich tealeaves tastes bad. Theanine: 2-Amino-4-(ethylcarbamoyl) butyric acid that is highly correlated to nitrogen contents in new tealeaves are changed to catechin [5],[6],[7] due to sun light. In accordance with sun light, new tealeaves grow up so that there is a most appropriate time for harvest in order to maximize amount and taste of new tealeaves simultaneously.

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