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Araştırma Makalesi/*Research Article (Orjinal Paper)*

Evaluation of Conservation and Conventional Tillage Systems Using Thermal Infrared Imagery in Dryland Cold Region of Iran

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Abstract: Conservation tillage has been proposed as a promising strategy to improve soil and water conservation in dryland areas. A 2-year experiment was conducted to determine the influence of crop residue remained on soil surface in conservation and conventional tillage systems on soil surface temperature, canopy temperature [using Infrared thermal imaging on a clay loam soil (Vertic Calcixerepts)] and wheat grain yield in the northwest region of Iran. Tillage treatments were conventional tillage (MD: mouldboard plough + disk harrow), reduced tillage (CD: chisel plough + disk harrow), minimum till (MT: Stubble cultivator), and no-till (NT_1 and NT_2: with standing stubble and total residue, respectively). Rresidues in NT_1 and NT_2 lowered the averaged canopy temperature by 3.70 °C over the other treatments (MD and CD) and there was a positive and significant correlation between soil surface temperature and wheat canopy temperature. Results indicated that for a dryland vetch (*Vicia panonica*)-winter wheat cropping system, NT_2 had higher grain yield than that obtained with MD system probably owning to greater rain fall efficiency and lower canopy temperature.

Key words: Conservation tillage, Crop residue, Canopy temperature, Soil surface temperature, Dryland, Wheat.

İran'ın Kurak Soğuk Bölgesi'nde Termal Kızılötesi Görüntüleri Kullanılarak Koruyucu ve Geleneksel Toprak İşleme Sistemlerinin Değerlendirilmesi

Özet: Koruyucu toprak işleme, kurak alanlarda toprak ve su tasarrufunu artırmak amacı ile umut verici bir strateji olarak öne sürülmüştür. İran'ın kuzeybatı bölgesinde iki yıllık bir deneme, koruyucu ve geleneksel toprak işleme sistemlerinde toprak yüzeyinde kalan bitki artıklarının, toprak yüzey sıcaklığı, bitki taç sıcaklığı [killi tın toprakta (Vertic Calcixerepts) kızılötesi termal görüntüleme kullanılarak] ve buğday dane verimine etkisini belirlemek amacı ile yürütülmüştür. Toprak işleme yöntemleri: Geleneksel (KD: kulaklı pulluk + diskaro), azaltılmış toprak işleme (ÇD: Çizel pulluğu + diskaro), minimum toprak işleme (AK: Anız kültivatörü) ve toprak işlemesiz ($Tİ_1$ ve $Tİ_2$, sırasıyla anızlı ve toplam kalıntılı) olarak belirlenmiştir. $Tİ_1$ ve $Tİ_2$ uygulamalarındaki kalıntılar, diğer uygulamalar göre (KD ve ÇD) bitki taç sıcaklığını ortalama 3.7 C° düşürmüştür ve toprak yüzey sıcaklığı ve buğday bitki taç sıcaklığı arasında pozitif ve anlamlı bir korelasyon gözlemlenmiştir. Sonuçlar, kurak fiğ (*Vicia panonica*)- kışlık buğday ürün sistemi için, yağış verimliliği ve düşük bitki taç sıcaklığına sahip $Tİ_2$ uygulamasında KD uygulamasına göre daha yüksek tane verimi elde edildiğini göstermektedir.

Anahtar kelimeler: Geleneksel toprak işleme, Bitki kalıntısı, Bitki taç sıcaklığı, Toprak yüzey sıcaklığı, Kurak, Buğday.

Introduction

Conservation tillage (CT) methods, which include reduced and no-till methods, leave substantial quantities of crop residues on the soil surface. These crop residues act as a barrier to wind and water to reduce soil erosion and evaporation (Truman et al. 2003). On the other hand, conservation tillage reduces C emission, while decreasing soil disturbance and retaining at least 30% of soil surface covered with crop residue. (Daughtry 2001; Jarecki and Lal 2003). Several researchers have effectively applied remote sensing to discriminate the spectral signatures of conventional and conservation tillage practices (South et al. 2004; Daughtry et al. 2006).

Measuring the effects of tillage system on plant response in a large scale is difficult. However, remotely sensed thermal infrared data show great potential as an indicator of plant response to environmental stresses. Water stresses, nutrient availability, pests, disease, and temperature impact the ability of a plant to efficiently cool itself via evapotranspiration (Pinter et al. 2003; Sullivan et al. 2007). Plants regulate temperature in one of two ways: 1) heat up and emit increased amounts of radiation or 2) dissipate energy via evapotranspiration and minimize radiated heat. Thus, healthy plants with plenty of available water remain cool, radiating away less energy.

The effect of management factors, such as tillage systems, crop residue management, and crop rotation on crop growth and development during the crop cycle has not been studied intensively. Until now, most of the knowledge on plant growth especially for measuring canopy temperature has been developed for conventional management practices, including heavy tillage and common crop residue removal (Verhulst et al. 2011). Hache et al. (2005) demonstrated the applicability of wheat canopy multispectral airborne images to discriminate conventional and conservation tillage practices interacting with two nutrient sources. Infrared canopy temperature measurements indicated that stress onset was almost 14d earlier in the conventionally tilled ley plots, compared to the direct drill (Bell et al. 1996).

Thermal remote sensing exploits the fact that everything above absolute zero (0 K or −273.15˚C or −459˚F) emits radiation in the infrared range of the electromagnetic spectrum hence approximately 80% of the energy thermal sensors received in the thermal wavelength region is emitted by land surface, making surface temperature as the easiest variable to extract from the thermal infrared signal (Ishimwe et al., 2014). Sullivan et al.(2008) evaluated the sensitivity of a remotely derived crop residue cover index for depicting conventional tillage, strip tillage and no-tillage systems in a cotton-corn-peanut rotation using a handheld rnultispectral radiometer (485 to 1,650 nm) and thermal imager (7,000 to 14,000 nm). The crop residue cover index outperformed the thermal infrared, accurately separating conventional from conservation tillage treatments. Cooler soil temperatures are usually associated with high residue cropping systems. Crop residue will have two major impacts on heat energy. The first is the reflection of incoming solar energy from a relatively lighter colored material, and the second is the insulating effect the residue provides. Potter et al. (1985) noted that thermal conductivity was about 20% greater in a no-till soil because of a more continuous arrangement of the soil matrix when compared to the plowed system. Hatfield (1996) noted that no-till fields have a smaller difference between their daily minimum and maximum temperature, because of the insulating effect of the residue. No-till fields also cool more slowly in the fall. He suggests that the fall temperatures be measured in no-till fields to insure that soil temperature is below 50 °F where the fall application of anhydrous ammonia is planned.

Kozak et al. (2007) studied the effects of residue architecture on soil temperature and water and found that temperature difference between soil surface and ambient air frequently exceeded 17 °C under reduced tillage and no-till conditions. Likewise Afzalinia et al. (2011) reported that No-till decreased soil surface temperature by 39% compared to conventional tillage system. Sun_et al.(2009) studied the effects of tillage systems on respiration, canopy temperature and soil moisture and found that soil respiration rate had a significant linear relationship with the canopy temperature of both spring wheat and pea, the correlation coefficient being the highest at booting stage of spring wheat and at flowering and pod formation stages of pea.

The objectives of this study were threefold: (1) evaluating thermal infrared (TIR) spectra as a tool for differentiating among tillage regimes (2) evaluating effect of tillage systems on the yield of dryland wheat and (3) evaluate relationship between soil surface and canopy temperature in different tillage systems.

Materials and Methods

Site and Soil

The field experiment was conducted in 2011–2012 at the Dryland Agricultural Research Station (latitude 37◦12_N; longitude 46◦20_E; 1730m a.s.l.), 25 km of East of Maragheh, province of East Azerbaijan, Iran, located in a cold semi-arid region. Location map of study area are shown in Fig.1. The soil (Typic Calcixerept) at the study site had a clay loam texture in the 0-15 cm surface layer (300, 390 and 310 g kg^{-1} sand, silt, and clay, respectively) and a clay texture in the 15-60 cm depth (240, 290 and 470 g kg^{-1} sand, silt and clay, respectively). The climate of the region is temperate continental with warm summers under the Koeppen's classification system. The long-term average precipitation, temperature and relative humidity of the station are 354 mm, 12.5^{0}C and 50.2%, respectively.

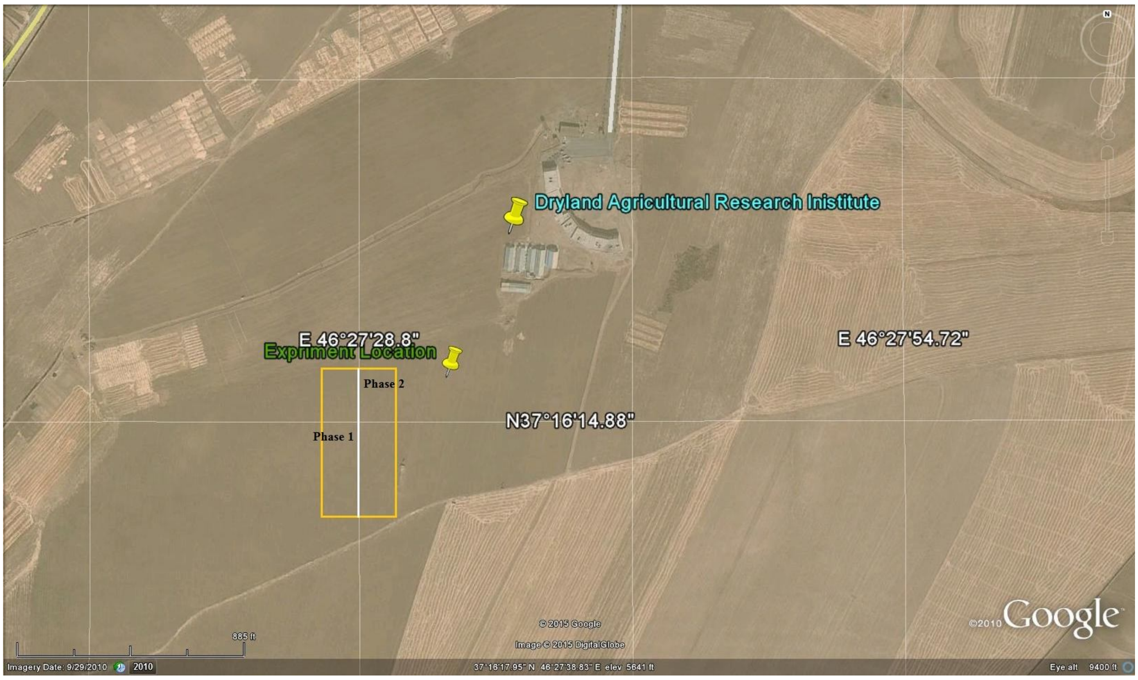

Figure.1. Location map of study area

Tillage Treatments

Two sites adjacent to each other and separated by a 5 m wide boarder were established to produce a wheat crop every year in a winter wheat–vetch (Vicia panonica) rotation from 2011–2012 to 2012–2013. Both the vetch and winter wheat phases were present each year Fig.1. The study was laid out as a randomized complete block design (RCBD) with five tillage treatments and four replications. The tillage treatments consisted of (1) conventional tillage: moldboard plowing followed by one pass of tandem disk (MD); (2) reduced tillage: chisel plowing followed by one pass of tandem disk (CD); (3) minimum tillage: stubble cultivator (MT); (4) no-till with only standing stubble (NT_1) and (5) with total previous crop residue (NT_2). On NT_2 plots, the shredded vetch residue, collected after harvesting and threshing of the plants from the same plots, was distributed uniformly before wheat planting. Primary tillage depths for MD, CD and MT were 20, 25 and 15 cm, respectively. Tandem disk was used at 8–10 cm. Experimental plots were 6 m wide 30 m long with borders 2 m wide and a main border 7 m wide between each two blocks.

Wheat Sowing

A winter wheat (Homa) was seeded with 178 kg ha^{-1} rate and 17 cm row spacing. The planting depth was about 6 cm. Fertilizers (P&N) were applied at 10 and 40 kg ha^{-1} rate, respectively, as a band 3 cm below the seed in one pass. Additional 20 kg N ha^{-1} as urea was applied as top dressing on April. Wheat was planted on first of October and harvested on mid-July.

Soil Surface and Wheat Canopy Temperature

Thermal infrared data (TIR) were collected using a hand-held IVN770-P thermal infrared imager (Impac Mikron Group). The IVN770-P measures emittance (W m^{-2}) in one broad band (8,000 to 14,000 nm) with a 27° horizontal and 20° vertical field of view. Imagery was acquired at nadir from a distance of 10.0 m. At this height, the ground resolution was 4.8m × 3.53 m. All data were taken between 10 am and 12 am, looking over the center of the same target.

Because TIR data were acquired over approximately 2 h, it was necessary to verify all output for changes in ambient air temperature. Ambient air temperatures were recorded every 2 min throughout each RS acquisition and used to calibrate TIR data. Each IVN770-P measurement was adjusted using adding or subtracting the change in ambient air temperature from initial conditions (Sadler et al., 2002). Thermal images data were analysed by IVN specific software and seeing of temperature of any point in each plot and calculating average temperature of any plot were possible. The SAS (SAS Institute1990, Cary, North Carolina, USA) was used to analysis of variance. We used Xlstal 2011 software for Regression analyses of data, too.

Results and discussion

Tillage Effects on Soil Surface Temperature

Soil surface temperature in NT_1 and NT_2 treatments was significantly lower than other treatments especially MD (Table 1). In conventional tillage system, the average temperature of surface was 27.2°C. It was 3.5 and 4.3 °C higher than MT and No-till treatments respectively. Figures 2 to 4 show the thermal images in different treatment. Increasing of the amount of red points in thermal image shows of the increasing of temperature in treatment. This was likely a function of heat capacity, where the lower heat capacities of organic materials (crop residue) in No-till treatments resulted in higher emittance and cooled the surface compared to a mineral surface (bare soil) with a greater affinity to absorb incoming radiation (Campbell 1996). Soil temperatures in surface layers can be significantly lower (often 2 to 8 °C) during daytime (in summer) in zero tilled soils with residue retention compared to conventional tillage (Oliveira et al. 2001). In these same studies, during night the insulation effect of the residues led to higher temperatures so there was lower amplitude of soil temperature variation with zero tillage.

In first year of study, rain fall amount (351 mm) and distribution was normally close to long term rainfall. Therefore wheat and vetch growth were in optimal conditions and after harvesting the residue of them was high. Since chisel plough mix less than 25% of total previous crop residue with soil comparison to moldboard plough which mix all the residue with soil, in second year exiting of greater residue of previous year (first year) reduced soil surface temperature in chisel plough plots comparison to moldboard plots (Table 1).

Table 1. Effect of tillage system on soil surface temperature (2011–2013)

Tillage systems	Average Surface Temperature °C		
	2011-2012	2012-2013	Treatment mean
Moldboard plowing + disking (MD)	31.63±0.4a	31.12±0.3a	27.18± 0.2a
Chisel plowing + disking (CD)	32.63±0.8b	28.62±0.9b	25.66±0.9b
Stubble Cultivator (MT)	30.73±0.1b	26.72±0.1bc	24.67±0.1bc
No-till with standing crop residue (NT_1)	28.00±0.4c	26.81±0.2bc	24.07±0.3c
No-till with total crop residue (NT_2)	26.52±0.5c	25.60±0.4c	23.46±.04c
Year mean	29.90	27.77	–
Statistical analysis			
Source			
Tillage	**	**	**
Year	–	–	**
Tillage × year	–	–	**

** Significant at $P > 0.01$.

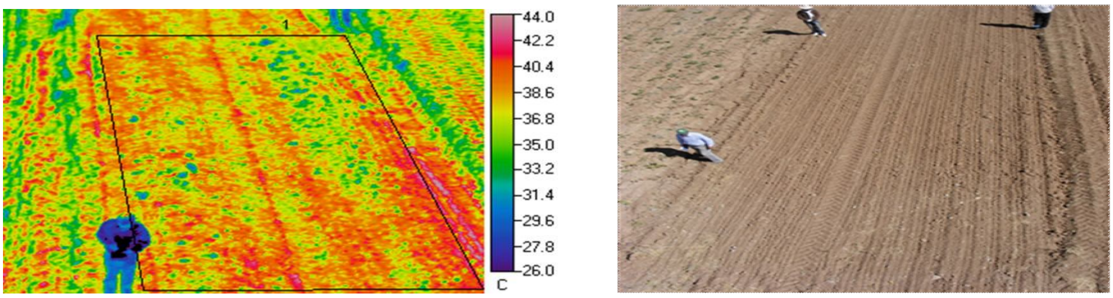

Fig.2. Thermal and digital images of conventional tillage system (Mould board plow plus disk harrow)

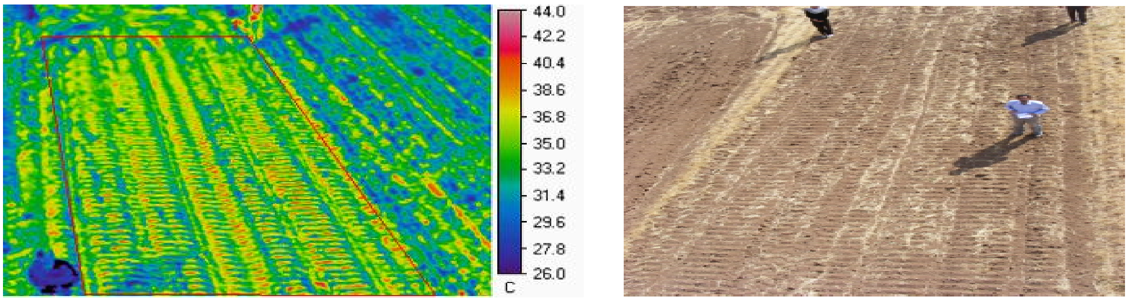

Fig.3. Thermal and digital images of minimum tillage (Stubble Cultivator)

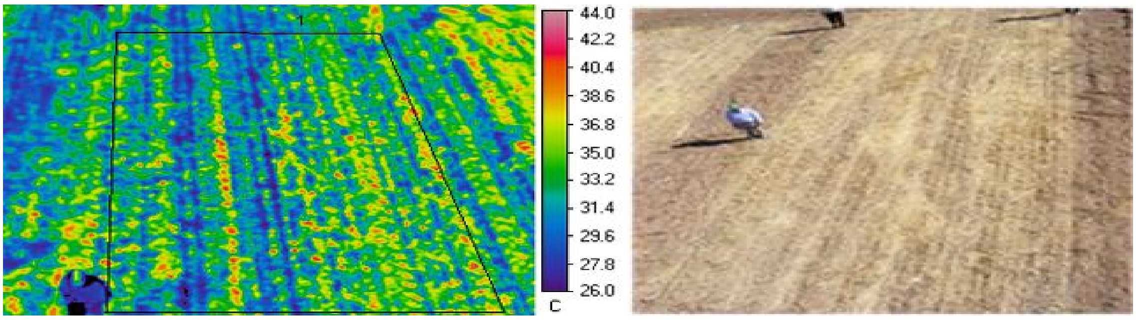

Fig.4. Thermal and digital images No-till with total crop residue (NT2)

Tillage Effects on Wheat Canopy Temperature and Crop Water Stress Index

Wheat canopy temperature was higher in second year (2012-2013) compared to first year in all treatments. (Table 2). This differences related to lower precipitation (273 mm and decreasing about 23% that's of long term) in second year. In addition wheat growth in traditional tillage systems (MD and CD) more affected by drought than conservation tillage systems.

During the flowering and grain filling stages, residues in NT_1 and NT_2 lowered the canopy temperature by 3-9 °C than the other treatments (MD and CD) (Table 2). The average canopy temperature at grain filling stage of wheat in conventional tillage system was 37.4°C, which was 4.4 and 7.1 °C higher than MT and No-till treatments, respectively. According to results of this experiment increasing the tillage intensity and reducing crop residue on soil surface, wheat canopy temperature increased by 1 to 7°C (Table2 and Fig. 5-7). Sun et al. (2009) reported that tillage–straw treatments with straw retention showed cooler canopy temperatures than treatments with straw removal. The results from this experiment also agree with Moraru and Rusu (2012) results which reported that reduced and no tillage decrease the soil temperature at 15 layer of soil. According to Jackson et al. (1988) the higher Canopy Temperature Depression (CTD) in the tillage–straw treatments with straw removal suggests that the transpiration rate was less due to lower soil water content than in treatments with straw retention.

Table 2. Effect of tillage system on wheat canopy temperature (2011–2013)

Tillage systems	Average Canopy Temperature ^{o}C			Crop Water Stress Index (CWSI)[a]
	2011-2012	2012-2013	mean	
Moldboard plowing + disking (MD)	35.57±0.3a	39.40±0.4a	37.40±0.4a	0.929±0.07a
Chisel plowing + disking (CD)	28.55±0.8 b	39.55±0.8ab	34.06±0.8b	0.816±0.11ab
Stubble Cultivator (MT)	27.67±0.4bc	38.37±0.6b	33.00±0.7b	0.729±0.09b
No-till with standing crop residue (NT_1)	26.27±0.4cd	37.40±0.5c	31.84±0.4c	0.581±0.08c
No-till with total crop residue (NT_2)	25.45±0.5d	35.27±0.7d	30.30±0.6d	0.484±0.10c
Year mean	28.85	43.15	–	–
Statistical analysis				
Source				
Tillage	**	**	**	**
Year	–	–		–
Tillage × year	–	–	ns	–

[a]: Crop Water Stress Index was calculated according to Idso definition (Idso et al., 1981).

** Significant at $P > 0.01$. ns:Non-significant at $P > 0.05$.

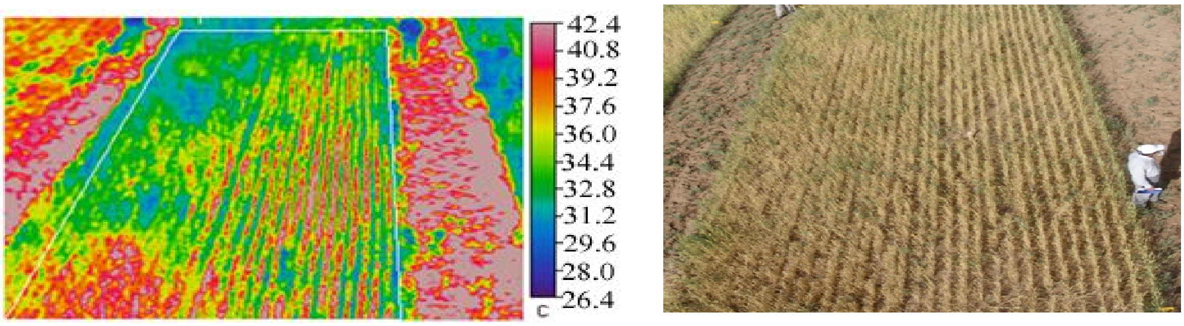

Fig.5. Thermal and digital images of wheat at grain filling stage in conventional tillage

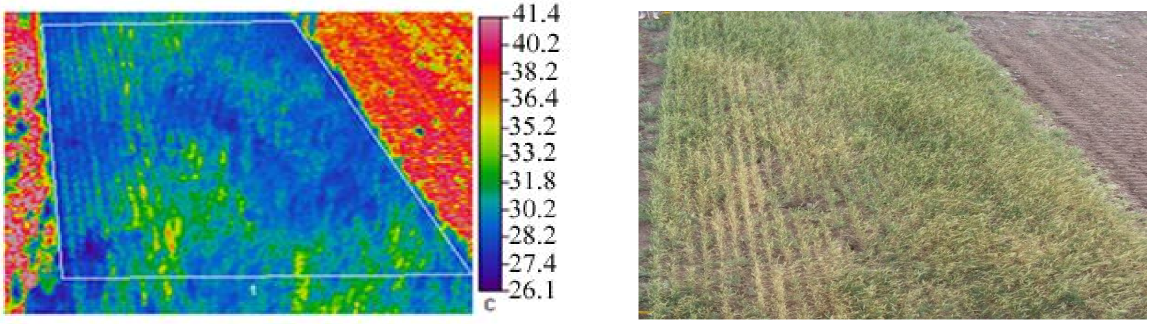

Fig.6. Thermal and digital images wheat at grain filling stage in minimum tillage

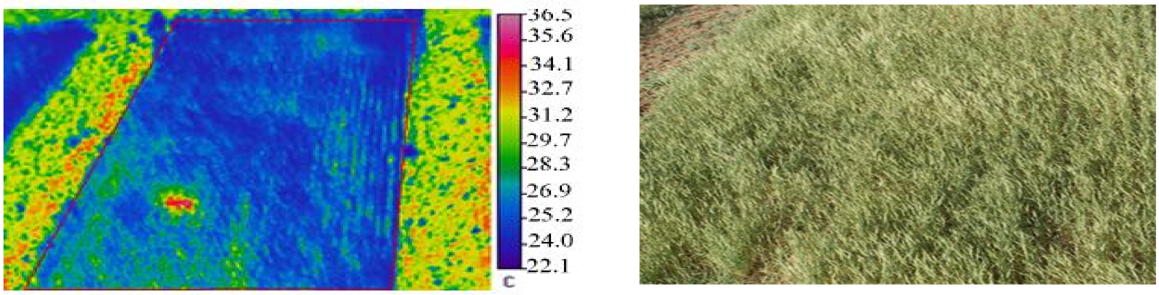

Fig.7. Thermal and digital images wheat at grain filling stage in No-till with total crop residue

The crop water stress index (CWSI) is the most often used index which is based on canopy temperature to detect crop water stress. Results of this study showed that no tillage treatments had lower CWSI. This index was 48, 40 and 33% higher in conventional, reduced and minimum tillage than no-tillage system respectively (Table 2).

Tillage Effects on Wheat Grain Yield

Response of wheat grain yield to tillage methods varied depending on the amount and distribution of precipitation in each growing season. Tillage effect on average wheat yield in 2-year period was significant. Although, for conventional tillage, yield was consistently the lowest (Table 3), the average grain yields for No-till treatments (NT_1 and NT_2) were significantly higher than others. Pala et al. (2007) reported similar results for spring wheat. Although, previous crop residue was a little greater in NT2, there were no differences in grain yield between in NT2 and NT1. Even though grain yield at CD treatment was 13% high compared to MD, the difference wasn’t significant. Grain yields ranking from highest to lowest respectively were CD > MT > MD (Table 3).

Table 3. Grain yield and rain use efficiency of winter wheat as affected by five tillage systems for 2 years (2011–2013) at the Dryland Agricultural Research Station near Maragheh, Iran

Tillage Systems	Wheat Grain yield (kg ha^{-1})			PUE[a]
	2011–2012	2012–2013	Treatment mean	(kg mm^{-1} ha^{-1})
Moldboard plowing + disking (MD)	973±138c	2165±111b	1569±125b	5.02±0.68
Chisel plowing + disking (CD)	1274±169bc	2285±123ab	1780±150b	5.79±0.55
Stubble Cultivator (MT)	1289±133bc	2195±142b	1742±138b	5.69±0.50
No-till with standing crop residue (NT_1)	1686±151ab	2415±145ab	2051±140a	6.80±0.45
No-till with total crop residue (NT_2)	1735±144a	2720±144a	2228±138a	7..33±0.72
Year mean	1391	2356	–	–
Statistical analysis				
Source				
Tillage	**	**	**	**
Year	–	–	**	*
Tillage × year	–	–	ns	*

[a] : Precipitation Use Efficiency

Within years, values followed by the same letter or with no letters in each column are not significantly different according to Duncan’s new multiple range test at the 1% level of probability.

**Significant at the 0.01 probability level.

*Significant at the 0.05 probability level.

ns Non-significant at P > 0.05.

The results from this study agree with Lafond et al. (1992) reported that zero or minimum tillage can increase available soil moisture for uptake of plant under stubble mulch cropping conditions. Carter (1991) indicated that at very dry growing seasons direct drilling improve grain yield in fine sandy loams. In addition, Pala et al. (2007) showed that wheat grain yield can be increased by reduced and no tillage under dryland condition. Our findings suggest that under different tillage systems, (Table 3) minimum and no tillage practices may increase precipitation use efficiency and wheat grain yields.

Tillage Effects on Wheat Precipitation Use Efficiency

Wheat precipitation use efficiency at no-till with total residue was significantly higher than conventional tillage (Table3). Similarly, Li et al. (2005) suggested that conservation tillage can increase precipitation use efficiency and soil moisture storage. According to Nielsen, et al. (2005) PUE by residue management practices can increases water availability and water use efficiency, reduces evaporation, erosion. Residual management increases shading of the soil surface, reduces soil temperature, wind speed at the soil surface leading to increased water use efficiency (Hatfield et al. 2001).

Relationship Between Soil Surface and Wheat Canopy Temperature

According to results of first year (2011-2012) there was a positive and significant correlation between soil surface and wheat canopy temperature (Fig.8). At the range of soil surface temperatures, results showed that by increasing 1 degree surface temperature, the canopy temperature increase by average of 1.27 C^{o}. While this increase for five first step (25- 30 C^{o}) was 1.6 C^{o} and for second five step (30-35 C^{o}) this value decreased to 0.76 C^{o}. Effects of crop residue on decreasing soil surface and canopy temperature may be confined at specified values as the slop of curve confirms this issue.

Relationship Between Wheat Canopy Temperature, Crop Water Stress and Grain Yield

The results of study showed that grain yield and mean canopy temperature were correlated negatively (R^2 = 0.77). This agrees with other reports indicating that the correlation between grain yield and wheat canopy temperature is negative (Guendouz et al., 2012; Mohammadi and Karimizadeh, 2012). According to results of our study increasing 1 degree of canopy temperature cased in decreasing 97 kg grain yield per hectare. Yield decreasing was between 26 and 33 C^{o} of canopy temperature (Fig.9). Results of correlation between canopy temperature (CT) and grain yield suggest that it can be possible use of CT to differentiate tillage systems.

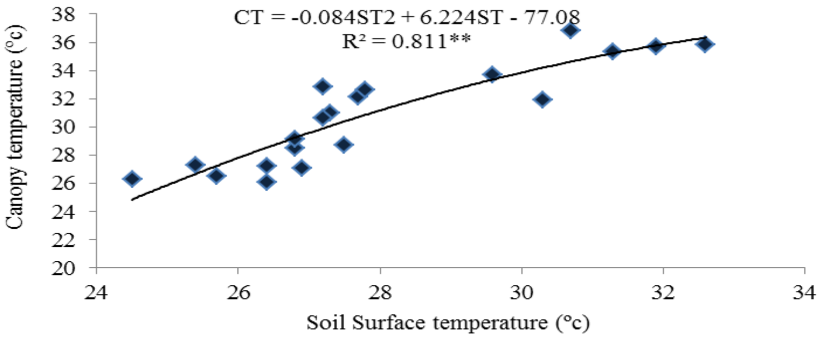

Fig. 8. Relationship between soil surface and wheat canopy temperature

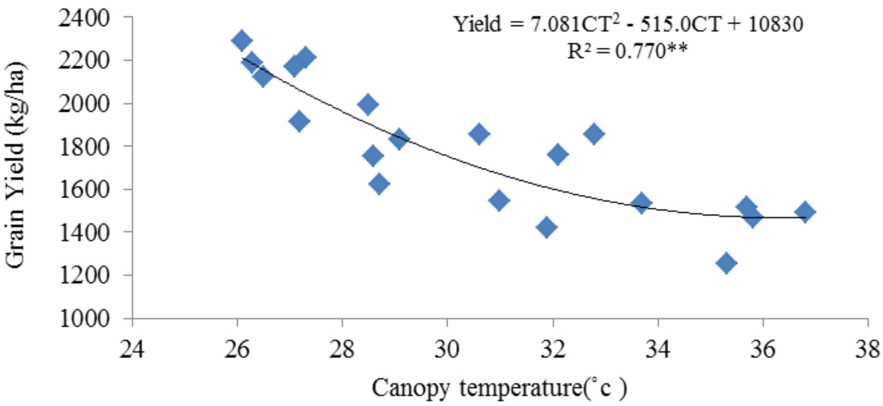

Fig.9. Relationship between canopy temperature wheat grain yields

A liner relation between Crop Water Stress Index (CWSI) and wheat grain yield was found Fig. 10. All of the CWSI values were greater than 0.4 which indicated that treatments were not completely under optimum moisture and temperature condition. The reason of this state is because of planting wheat in dryland condition. In this case by increasing CWSI, wheat grain yield significantly decreased.

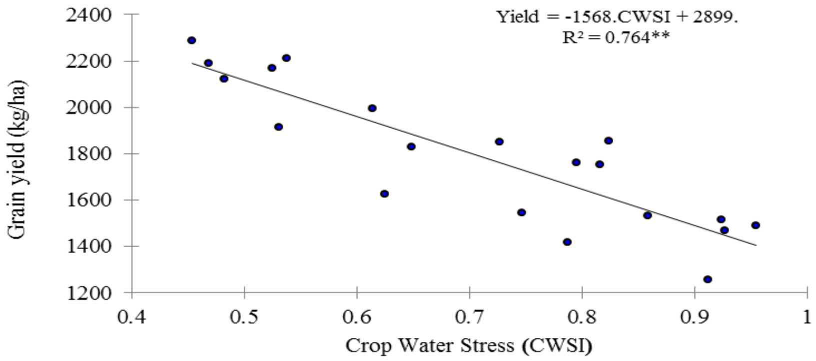

Fig. 10. Grain yield and crop water stress index of winter wheat

Conclusions

Results showed that TIR emittance approach (based on surface and canopy temperature) accurately differentiated between conventional and conservation tillage systems. In conventional tillage system the average surface temperature was 3.5 and 4.3 °C higher than stubble cultivator and No-till treatments respectively.Straw retention in No-tillage system showed cooler canopy temperatures than treatments with straw removal and conventional tillage system. The wheat grain yield of conventional tillage was consistently the lowest. The average grain yield for No-till treatments (NT_1 and NT_2) was significantly higher than for other treatments. According to the results of this study, in a vetch–wheat rotation system that managed by NT_2 (No-till with total residue) can improve wheat productivity by improving rain fall use efficiency and regulating canopy and soil surface temperature in semi-arid zones of Iran.

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