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Measurement of Personal PM10, PM2.5 and PM1 Exposures in Tractor and Combine Operations and Evaluation of Health Disturbances of Operators

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ABSTRACT

The objective of this study was to determine personal PM10, PM2.5, and PM1 exposure levels of tractor and combine harvester operators in rotary tilling, disc-harrowing, soil packing, planting, fertilizing, harvesting, hay making, and bale making, and to determine health status of the operators. The gravimetric method was used to determine particulate matters (PM) concentrations. PM10 concentrations were higher than the threshold limit value (15000 $\mu g\ m^{-3}$) determined by Occupational Safety and Health Organization (OSHA) in rotary tilling (25770 $\mu g\ m^{-3}$), wheat harvesting (29300 $\mu g\ m^{-3}$), and hay making (24640 $\mu g\ m^{-3}$). Similarly, PM2.5 concentrations were also greater than the threshold limit (5000 $\mu g\ m^{-3}$) in these operations (respectively with 5888, 10560, 8470 $\mu g\ m^{-3}$). PM1 concentration was considerably high, especially in wheat harvest and hay making (respectively with 3130 and 6026 $\mu g\ m^{-3}$), and was even greater than the PM2.5 threshold limit during hay making. It is probable for such high PM concentrations of fine particles to increase the respiratory system nuisances. PM10 and PM2.5 concentrations were measured to be lower than the thresholds in all other field applications. A respiratory questionnaire survey was administered to 40 operators for determination of upper and lowers respiratory disturbances and smoking habits. Sixty three percent of operators were smokers, and complained about coughing with 60% and phlegm with 83%. Health complaint about chest tightness is 31% and breathlessness is about 29%. Nevertheless, when smokers and non-smokers are evaluated separately, coughing rate decreases to 47% and chest tightness reduces to 13%. Although personal exposure to particulate matters is important in its effect on respiratory system disturbances, smoking habit aggravates the complaints. Operators need to use personal preventions to avoid such adverse health effects when operating tractors and combine harvesters without cabins. Operators are unlikely to work in the comfort zone due to high ambient temperature and low relative humidity in vehicles without cabins.

Keywords: PM10; PM2.5; PM1; Personal exposure; Tractor; Combine harvester

Traktör ve Biçerdöver İşlemlerinde Kişisel PM10, PM2.5 ve PM1 Maruziyetinin Ölçümü ve Operatörlerin Sağlık Sorunlarının Değerlendirilmesi

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ÖZET

Bu araştırmanın amacı, traktör ve biçerdöver operatörlerinin rotovatör, diskli tırmık, tapan çekme, ekim, gübreleme, hasat, saman yapma ve balyalama işlemleri sırasında maruz kaldığı PM10, PM2.5 ve PM1 konsantrasyonlarının belirlenmesi ve operatörlerin sağlık durumlarının belirlenmesidir. Partikül madde konsantrasyonunu belirlemek için gravimetrik yöntem kullanılmıştır. PM10 konsantrasyonları rotovatör ile toprak işlemede (25770 µg m^{-3}), buğday hasadında (29300 µg m^{-3}) ve saman yapma işleminde (24640 µg m^{-3}) Mesleki Güvenlik ve Sağlık Örgütü OSHA (Occupational Safety and Health Assosiciation) tarafından belirlenen sınır değerin (15000 µg m^{-3}) üzerinde bulunmuştur. Benzer şekilde, PM2.5 yoğunlukları da bu işlemlerde (sırasıyla 5888, 10560, 8470 µg m^{-3}) sınır değerin (5000 µg m^{-3}) üzerinde ölçülmüştür. PM1 konsantrasyonu özellikle buğday hasadında ve saman yapmada oldukça yüksek düzeylerde (sırasıyla 3130 ve 6026 µg m^{-3}) olup saman yapma işleminde PM2.5 sınır değerini de aşmıştır. Bu konsantrasyondaki çok ince tozların alt solunum yolları rahatsızlıklarını artırması olasıdır. Diğer bütün işlemlerde PM10 ve PM2.5 konsantrasyonları sınır değerlerin altında ölçülmüştür. Bir anket kırk operatöre, üst ve alt solunum yolları rahatsızlıkları ve sigara alışkanlıkları belirlemek için uygulanmıştır. Anket yapılan tüm operatörlerin %63'ü sigara içmektedir; %60'ı öksürükten, %83'ü ise balgamdan şikâyetçidir. Göğüste daralma %31 ve nefes darlığı ise %29 düzeyinde şikâyet konusu olmuştur. Ancak, sigara içen ve içmeyenler ayrı değerlendirildiğinde sigara içmeyenlerde öksürme oranı %47'ye düşerken, göğüste sıkışma şikâyeti %13 düzeyine gerilemiştir. Solunum yolları ile ilgili rahatsızlıklarda kişisel partikül madde maruziyeti önemli ise de sigara alışkanlığı tüm şikayetlerini önemli ölçüde arttırmaktadır. Operatörlerin bu olumsuz sağlık etkilerinden korunmak için kabinsiz traktör ve biçerdöver kullanırken kişisel önlem almaları gerekmektedir. Ortam sıcaklığının yüksek ve bağıl nem oranının düşük olması nedeniyle, operatörlerin kabinsiz araçlarda konfor bölgesi içinde çalışması mümkün görünmemektedir.

Anahtar Sözcükler: PM10; PM2.5; PM1; Kişisel maruziyet; Traktör; Biçerdöver

1. Introduction

Farmers and tractor operators are exposed to various levels of particulate matter (PM) during agricultural field operations. The concentration level (µg m^{-3}) as well as the PM particle size distribution might vary depending on working conditions. PM, in terms of human health, might be classified as respirable, thoracic or inhalable. Particles less than 10 microns (PM10) in aerodynamic diameter might access the upper respiratory system and these are called inhalable PM and also called course particulates. Thoracic PM has a diameter of 3-5 µg m^{-3}, which can reach the lower respiratory system. Fine particles, smaller than 2.5 µg m^{-3} (PM2.5), are respirable PM which can reach the alveoli at the lung (Reilly 1981).

Particulate matter might cause a variety of disturbances and illnesses when threshold PM concentration level is exceeded over prolonged periods. Particulate matter may result in poisoning and allergy in the respiratory system (Witney 1988). Inflammation of the eyes, lungs, and the skin are other adverse effects of personal PM exposure (Matthews & Knight 1971). Numerous researchers, as cited by Baker et al (2005), linked diseases such as asthma, pulmonary fibrosis, and lung cancer to dust inhalation. Bronchitis and chronic obstructive airways disease are non-allergic and are associated with inorganic PM generated in agricultural field applications (Baker et al 2005). Maynard & Howard (1999) cited several literatures regarding PM effect on human health. According to Maynard & Howard (1999), "PM10 is currently regarded as the size fraction best representing those particles most likely to cause ill health (DoE 1995). PM10 is not as long-lived as PM2.5, with a life-time of some 7±30 days, as the latter is less subject to efficient removal by gravitational settling or scavenging by rain (DoE 1993). However, particles have to be < 2.5 mm (mean aerodynamic diameter) in order to penetrate into the gas exchange regions of the lungs. Numerous epidemiological studies have found a relationship between particulate air pollution and increased cardiorespiratory morbidity and mortality (Pope et al 1995), and hospital admissions for asthma and chronic obstructive pulmonary disease (Schwartz 1994, Schwartz et al 1993)".

In agricultural operations, particularly in soil tillage, particulate matters can contain both mineral and organic components. It may be more likely to encounter more organic matter in soils with abundant stubble mixed in the soil. In hay making, on the other hand, the particulate matter is basically composed of organic materials. Nonetheless, there is no specified threshold size segregated PM limits set for mineral and organic pollutants found in such operations. Different threshold limit values apply for personal PM exposure, set by different health organizations. Most standards define limit values for 24 hours while OSHA in the United States determines the limit values for personal exposure duration of 8 hours, which may be used to draw conclusions for agricultural operations as well. Therefore, the limit PM concentration values, set by OSHA, were used to determine whether the personal PM exposure level exceeds the limits for agricultural tractor operators (Table 1).

Particulate matter measurements in agricultural sector basically serve for two purposes. One purpose is to determine the personal PM measurements of workers. The second objective is to assess the effect of PM emissions generated by agricultural activities on air quality. Agricultural crop production may generate different levels of PM causing poor air quality in regions where the agricultural activities are intensive (Nieuwenhuijsen et al 1999). Determination of personal PM exposure levels during agricultural field work is necessary to determine whether there is a need to take personal protection to minimize potential health hazards.

Agricultural activities causing dust emissions and personal PM exposure include soil tillage, seedbed preparation, planting, fertilizing, harvesting, baling, compost spreading, residue burning, and herbicide use (Nordstroma & Hottab 2004). Nevertheless, the adverse effects of personal PM exposure are not limited to agricultural operators working in the field. For instance, personal PM exposure of women in family farms in Poland was also studied, resulting in high levels of PM concentrations (Molocznik & Zagórski 1998).

Nieuwenhuijsen & Schenker (1998) states that the presence of an enclosed cabin, relative humidity, type of field operation, and tractor speeds are the determinants of personal dust exposure during field operations. In this study, tractors with no cabins were used to determine the level of risks encountered by operators. Most tractors are not equipped with an original cabin in the study area.

There is no publication reporting size segregated personal PM exposure for agricultural field work in Turkey. The first objective of this study was to determine the personal PM10, PM2.5, and PM1 exposure levels of tractor and combine harvester operators during field applications, including rotary tilling, disc harrowing, soil packing, fertilizing, wheat seeding, hay making, baling, and harvesting of wheat and corn. The second objective of the study was to determine the health complaints of workers through an abbreviated respiratory questionnaire (OSHA 2010). The final objective was to measure ambient climate conditions to determine whether agricultural operators worked in the comfort zone

2. Materials and Methods

2.1. Materials

Sioutas personal PM sampler and Leland Legacy pump was used to collect the PM samples. Personal Sioutas Cascade Impactor has four impactor stages and after-filter that are responsible for separating and collecting particles in different size fractions. Particles in each cut-point are collected on a 25-mm filter. The impactor is clipped onto an operator's collar in the breathing zone while the pump is clipped onto the operator's belt. Teflon filters were used to collect the PM samples and a controlled laboratory at a temperature of 20±1 °C and relative humidity of 50±5% was used to condition the samples. The filter weights were determined using a microbalance (Mettler-Toledo UMX2) with a precision of ±0.1 µg. A thermo-hygro-anemometer (Delta OHM DO 9847) was used to determine the ambient conditions during data collection. Some features of the tractors and the implements used in the study are given in Table 2. The soils in this study had sandy clay loam texture.

2.2. Methods

The personal PM exposure measurements were done in 2008 and 2009 in the Eastern Mediterranean region of Turkey. Operators were randomly selected in the Province of Kahramanmaraş. The thermo-hygro-anemometer

Table 1-Exposure limits for PM10 and PM2.5 (OSHA)
Çizelge 1-PM10 ve PM2.5'e maruz kalma limitleri (OSHA)

Feature	*Limit values (µg m⁻³)*	*Particle size*
Lower respiratory system nuisance limit	5000	PM2.5
Total nuisance limit	15000	PM10
Granular materials dust (wheat, oat, barley)	15000	PM10
Granular materials dust (wheat, oat, barley)	5000	PM2.5

Table 2-Some features of the combines, tractors and implements used in the study
Çizelge 2-Araştırmada kullanılan biçerdöverler, traktörler ve ekipmanların bazı özellikleri

Operation	*Tractor or combine brand*	*Equipment property*
Combine harvesting (wheat)	New Holland 8030	4.2 m swath width
Combine harvesting (corn)	New Holland TC 156	4-row
Baling	MF 188	Rectangular baler, 36x46 cm
Hay making	Fiat 70-56	Automatic pick up, 1.7 m swath width
Rotary tilling	MF 266 G	Rotary tiller + roller, 260 cm working width
Disc harrowing	Ford 6610	2.1 m
Soil packing	FI 70-56	3 m
Planting	MF 285 S	Gaspardo SP4, 4-row, pneumatic precision planter
Fertilizing	*MF 266 G*	Broadcast spreader, 250 kg capacity, single disc

was held near the personal sampler by a second person on the tractor or combine harvester to continuously record the ambient temperature, relative humidity, and the air speed during sampling.

The reference measurement method (gravimetric method) was used to calculate PM10, PM2.5, and PM1 concentrations. The sampling filters were conditioned for 48 hours in the laboratory and then the filters were weighed using the microbalance. Particles with diameters greater than 2.5 µm, with diameters between 1.0 and 2.5 µm, and particles with diameters less than 1.0 microns were collected using the Sioutas impactor during sampling in the field. The filters were taken out of the filter cassette and were reconditioned in the laboratory for another 48 hours. The filters with PM samples were then reweighted and the amount of PM (µg) on each filter was determined. The pump was operated at an air flow rate of 9 L min^{-1} and was calibrated before each use by using the air flow calibrator (Bios Defender 510-H). The air volume (m^3) was calculated by using the pump flow rate and the sampling time, allowing the calculation of the concentration of each PM fraction. Sampling time varied from 1 to 5 hours depending on working conditions that caused overload in the cascade impactor. Although field conditions may vary during field work throughout the day, the field conditions during sampling were assumed to be the same for an 8-hour work to make a comparison with the threshold limit values.

The calculated PM concentration level for each operation was compared to OSHA standards to assess the health hazard of the operators exposed to the particulate matters.

The nuisance felt by an operator might be affected by ambient climatic conditions. Measurement of ambient temperature, relative humidity and air speed may be helpful in making better assessment on the effect of all measured parameters. The comfort zone for human was defined as a temperature range of 18-24 °C and relative humidity range of 30-70% (Suggs 1991). The working conditions of operators were compared to these criteria to determine whether these parameters have made any contributions to operators' nuisance in addition to disturbances caused by personal PM exposure.

Since the histories of operators were not known it was not likely to accurately relate personal PM exposures to health complaints of operators.

Extensive health examinations and follow up tests and questionnaires are required over long periods to properly determine the effect of working environment on workers' health. In this study, an attempt was made to evaluate the effect of personal PM exposure on operator's health through a respiratory questionnaire that was administered by the researchers. The survey was administered to forty operators randomly selected to determine whether tractor and combine operators had health complaints in terms of coughing, phlegm, chest tightness, and breathlessness.

3. Results and Discussion

This study reports tractor and combine operators' personal exposure concentrations of particulate matter during different field operations. Three meteorological variables (temperature, relative humidity, and wind speed) were also measured during operations. A health status questionnaire survey was administered to 40 operators. Prevalence of several respiratory symptoms was determined.

3.1. Personal PM exposure levels

The PM sources may be organic and/or inorganic in agricultural field operations. The source of personal PM exposure during tillage, for instance, is mainly inorganic with some organic particulate matters mixed in the soil while PM source during harvest, bale making, and hay making is basically organic. In cereal grain and forage crop areas, measured average organic fractions of airborne particles were 4.5 and 28%, respectively. The rest of the particles were mineral particles from suspension of soils, consisting mainly of silicate minerals, with a small amount (1– 17%) of free silica (Gehr & Heyder 2000).

The PM concentrations were evaluated separately for organic and inorganic PM sources of agricultural operations. Average personal PM10, PM2.5, and PM1 exposure levels of tractor operators in field applications that are predominantly inorganic PM sources are shown in Figure 1. PM10 concentration was quite low in disc harrowing and fertilizing compared to other applications. The greatest level of personal PM10 exposure occurred during rotary tilling (25000 µg m^{-3}) followed by planting (11000 µg m^{-3}). No field application, except soil tillage with rotary tiller, caused personal exposure greater than the limit for PM10 (15000 µg m^{-3}). Personal PM2.5 exposures followed the same pattern as PM10 with the highest concentrations in rotary tilling (6000 µg m^{-3}) and planting (4000 µg m^{-3}), followed by soil packing, disc harrowing, and fertilizing. The greatest PM10 and PM2.5 concentrations in rotary tilling should have been caused by aggressive manipulation and mixing of the soil by the tiller.

Harvesting (wheat and corn), hay making and baling generate organic particulate matters. Average PM concentrations that the operators are exposed to during these field applications are shown in Figure 2. Both PM10 and PM2.5 personal exposure levels were greater than the threshold limits during wheat harvest and hay making. Personal PM1 exposures were also noticeable with 3500 µg m^{-3} and 6000 µg m^{-3} for wheat harvest and hay making, respectively. Fine particle concentration level therefore is profound with the addition of PM1 fraction to the PM2.5. Measured PM1 concentrations were very low during operations from seedbed preparation to fertilizing (Figure 1).

PM2.5/PM10, PM1/PM10, and PM1/PM2.5 ratios were calculated to assess whether there were differences between dominantly inorganic and organic PM operations. No significant differences were found in the nature of groups of operations producing inorganic and organic particle emissions. It should be noted, however, that all three ratios were found to be statistically higher ($P < 0.05$) in broadcast fertilizing. This behavior might be due to the centrifugal effect in spreading the fertilizer, the physical properties of the granular material used, and the higher forward speed of the tractor during fertilizing.

It appears that during soil cultivation with rotary tiller and planting operations, operators of tractors without cabins need to use personal preventions to avoid dust-induced disturbances during field operations. Likewise, combine operators should use personal preventions during wheat harvest and tractor operators during hay making. Most farmers neglect or avoid using dust masks, but some prefer using a fabric, which is wrapped around the head so

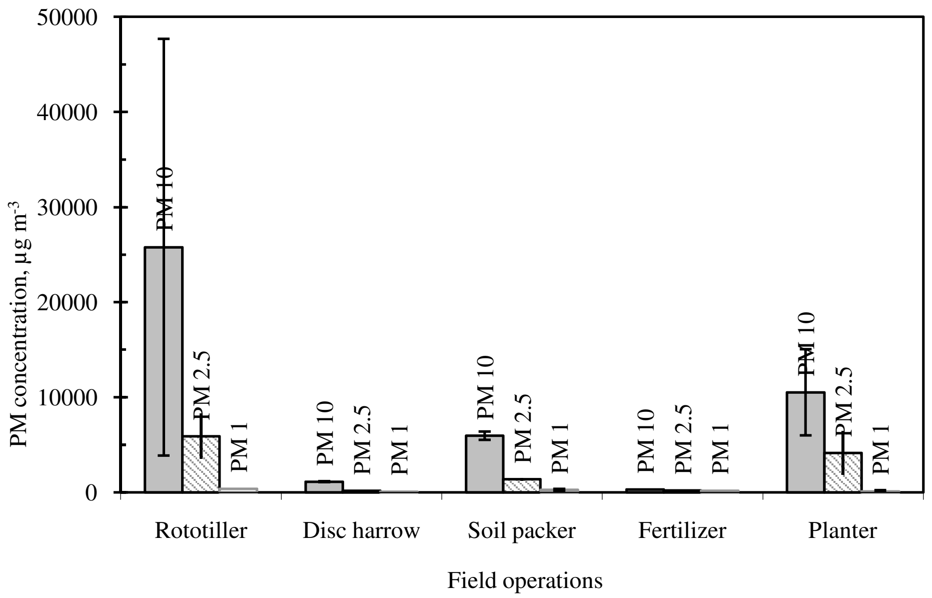

Figure 1-Average personal particulate matter exposure in agricultural operations – predominantly inorganic PM sources
Şekil 1-Tarımsal işlemlerde ortalama kişisel partikül madde maruziyeti – ağırlıklı olarak inorganik PM kaynakları

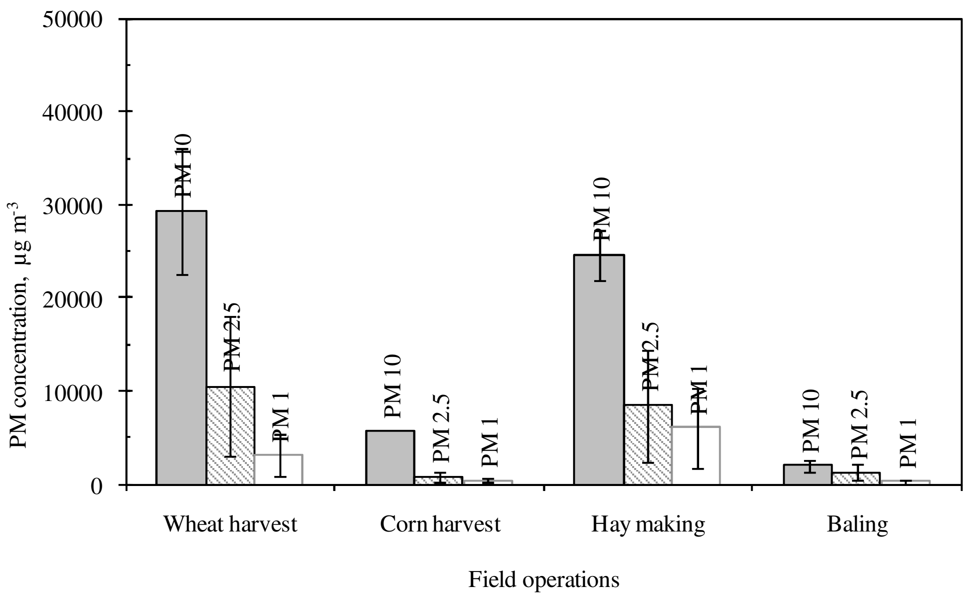

Figure 2-Average personal particulate matter exposure in agricultural operations – predominantly organic PM sources
Şekil 2-Tarımsal işlemlerde ortalama kişisel partikül madde maruziyeti – ağırlıklı olarak organik PM kaynakları

as to cover the mouth and nose. The use of such methods should also be effective in diminishing adverse effects of particulate matter since the mouth and nose are covered to some extent, but the performance of such protection is not known compared to professional prevention tools.

As a result, PM10 and PM2.5 concentrations were greater than the personal exposure limits during rotary tilling, wheat harvesting and haymaking. Also, PM1 concentrations were noticeably high during wheat harvest and hay making.

The demarcation concentration for dangerous conditions in Air Quality Index (EPA, 2003), a classification and communication tool for ambient air quality, is 500 µg m^{-3} (24-hr average). Concentrations measured in this study were higher than the demarcation level; however, the difference in averaging times should be noted. European Directives 1999/30/EC and 96/62/EC impose that in phase 2, referring to the stage after January 1st 2010, annual average PM10 concentration should not exceed 20 µg m^{-3}, whereas personal exposure level may be over 50 µg m^{-3} only seven days in a year. Thus, standards are much strict for general public and industrial areas. However, there is no standard that specifies a threshold limit for mineral or organic particulate matter concentrations for size segregated particulate matter. It is particularly difficult to characterize the particulate matters found in the soil and in agricultural products since they are made up of different sources. Due to these complexities, PM10 and PM2.5 concentration limits for soil-implement interactions are not known. Most literature deals with personal PM10 while PM2.5 exposure levels have rarely been published yet. PM1 threshold levels are not known either, and literature is difficult to find reporting personal PM1 exposure levels in agricultural operations yet.

Previous studies investigated personal PM exposures in some agricultural operations. Gustafsson & Noren (1979) reported a dust concentration of 300000 µg m^{-3} in studies conducted in Germany and Netherlands and 22000 – 72 000 µg m^{-3} in Sweden. They found dust concentrations ranging from 2100 to 577000 µg m^{-3} in soil tilling operations with no cabins. This wide range was attributed to a wide variety of tilling equipments tested and changing wind direction during data collection.

Aybek & Arslan (2007) found that soil packing, furrowing, straw making, and baling had a significant effect on measured dust concentrations ($P<0.01$) and each operation had higher concentration than 80000 µg m^{-3}, which was much higher than tolerable PM concentrations. It should be noted that these studies did not attempt to differentiate between PM10 and PM2.5, but represents total PM concentration found in the work environment. Although the results may not be directly comparable to the findings of studies reporting PM10 or PM.2.5, these findings showed that the operators faced health hazards during agricultural field applications.

Molocznik & Zagórski (1998) measured 1350 to 57500 µg m^{-3} dust exposure for women workers in Polish family run farms. Measured dust concentrations were 5100 to 23600 in soil tilling, 3000 to 7500 µg m^{-3} in seeding, 3300 to 19300 µg m^{-3} in harvesting, and 1300 to 3900 µg m^{-3} in household working. In our study, the measured concentrations were about 30000, 5000, 5000, and 25000 µg m^{-3} in wheat harvesting, corn harvesting, soil packing, and rotary tilling, respectively. The results of both studies may be considered similar.

Madden et al (2008) found 85% and 86% reduction in PM generation in conservation tillage in the first year and 52% and 93% in the second year of a two-year study in two farms, respectively. The reduction in emission was due to reduced number of field operations and the ability of working in wetter soil conditions in conservation tillage. Conventional method required 3-6 operations whereas only one operation was sufficient in conservation tillage. In another study, total suspended PM (<100 µm aerodynamic diameter) and respirable PM4 concentrations generated in conservation tillage in a two year cotton-tomatoes rotation was one third of standard soil tillage (Baker et al 2005). The reduction in PM concentrations in the latter study was also related to the reduced number of field operations. Thus, there are ways to reduce the PM emission during agricultural field work. Although the problems continue in many regions, reduction in dust generations in some areas demonstrates that the results of adapting advanced management techniques could be effective (Nordstroma et al 2004).

Atiemo et al (1980) found a range from 410 to 490 µg m^{-3} in unit-manufactured cabins during straw making. Nieuwenhuijsen et al (1999) state that personal PM exposure considerably reduces with the use of tractors and combine harvesters equipped with cabins. Greater dust concentrations (70000 to 180000 µg m^{-3}) were sampled outside of agricultural tractors during seeding, fallowing, spraying, and baling operations (Gehr & Heyder 2000). However, inside the cabins of tractors, dust concentration was reduced to 0.03– 2.5 µg m^{-3} by filtering air and by pressurizing the cab. Aybek and Arslan (2007) found mean dust concentrations from 1100 to 3200 µg m^{-3} in tractor operations with original cabins and 1400 µg m^{-3} in combine harvesters. A new tractor with an original cabin may filter the air and reduce personal PM exposure from 2.000-20.000 µg m^{-3} to 100-1.100 µg m^{-3} (Kirkhorn & Garry 2000). Thus, the earlier studies demonstrated that the use of a cabin is a very effective way of eliminating potential health hazards caused by personal PM exposures during field work.

As a result, tractors and combines with cabins seem to be the primary solution for personal protection from dust inhalation and respiration for Turkish farmers. Use of personal protection, such as dust masks, could be the secondary protection method. Kirkhorn & Garry (2000) exclaimed that the use of personal protection was limited in agriculture and that the dust masks feel hot and uncomfortable. Furthermore, dust masks may hinder breathing, and hence are not routinely used in agriculture. People with lung diseases are suggested to use sophisticated equipment (Kirkhorn & Garry 2000). The third method is to incorporate conservation tillage practices minimizing the use of machinery, which has been gaining acceptance in many parts of the world in recent decades.

3.2. Meteorological factors during field operations

Ambient conditions are more stable in enclosed working areas while they may be quite variable in field applications during the day. In addition to particulate matter inhalation, varying environmental conditions (temperature, relative humidity, wind speed) might also increase the total disturbance felt by a tractor operator. The wind speed and direction is important and have a direct effect on the personal PM exposure of the operators. The effect of PM exposure cannot be isolated or differentiated from other factors in the machine operations.

The accuracy of wind speed measurements may be low since the person holding the thermo-hygro-anemometer could not have followed the changes in wind direction promptly. Another reason for increased wind speed measurement error could be the vibration of the tractor, causing the person to move around during operations. Since the climatic factors were measured continuously, relating a single PM concentration value to average wind speed may not serve for practical purposes.

The temperature ranged from 25 to 39 °C during the measurements in different field operations, suggesting discomfort to operators due to high temperatures (Table 3). The relative humidity and the air speed were low in general. It is almost unlikely for the operators to work in comfort zone during field work unless the tractor is equipped with an air-conditioned cabin since temperature was high and relative humidity was low compared to the comfort zone (18-24 °C and 30-70%, respectively) defined by Suggs (1991). The bearable zones that apply to humans for temperature range from -1 to 38 °C and the relative humidity from 10% to 90% (Liljedahl et al 1996). The measured relative humidity did not exceed the limits of bearable zones whereas temperature was occasionally higher than the upper limit. The climate in the province may not be conducive to working in bearable environmental zone since the temperature may be over the upper temperature limit during late spring and summer field operations. The use of a cabin, however, might further decrease the relative humidity while adjusting the temperature. Also, agricultural operations might be carried out at different seasons in the year, especially in double-cropping systems that are common in the region, resulting in wide ranges in variations.

3.3. Health status of operators

Based on the questionnaire conducted in this study,

Table 3-Descriptive statistics for measured climatic parameters in agricultural operations
Çizelge 3-Tarımsal işlemlerde ölçülen iklimsel parametrelerin tanımlayıcı istatistikleri

Operation	*Climatic parameter*	*Number of samples*	*Average*	*Std. dev.*
Combine harvesting (wheat)	Temperature (°C)	158	36.90	1.99
	Relative humidity (%)	158	16.53	1.33
	Wind speed (m s^{-1})	158	0.85	0.69
Combine harvesting (corn)	Temperature (°C)	62	33.67	1.07
	Relative humidity (%)	62	31.62	1.90
	Wind speed (m s^{-1})	62	0.96	0.97
Baling	Temperature (°C)	276	26.09	1.25
	Relative humidity (%)	276	31.20	2.89
	Wind speed (m s^{-1})	276	1.35	1.14
Hay making	Temperature (°C)	286	37.77	2.13
	Relative humidity (%)	286	15.79	2.61
	Wind speed (m s^{-1})	286	0.83	0.84
Rotary tilling	Temperature (°C)	187	38.29	3.27
	Relative humidity (%)	187	20.27	5.80
	Wind speed (m s^{-1})	187	0.63	0.66
Disc harrowing	Temperature (°C)	105	25.39	0.89
	Relative humidity (%)	105	35.40	1.53
	Wind speed (m s^{-1})	105	1.08	0.99
Soil packing	Temperature (°C)	182	31.75	2.21
	Relative humidity (%)	182	24.91	4.09
	Wind speed (m s^{-1})	182	0.71	0.74
Planting	Temperature (°C)	295	36.14	2.09
	Relative humidity (%)	295	19.51	3.12
	Wind speed (m s^{-1})	295	0.73	0.72
Fertilizing	Temperature (°C)	87	25.36	1.43
	Relative humidity (%)	87	17.85	1.38
	Wind speed (m s^{-1})	87	0.61	0.58

some descriptive information was obtained on tractor and combine harvester operators and the health complaints of operators were determined. It is difficult to relate the information from the questionnaire to particle concentrations since the health history of operators was not known. Additionally, operators might have been exposed to different level of particle concentrations in applications other than field operations such as animal production.

The descriptive information on operators is given in Table 4. The age, height, weight, and work experience of operators vary significantly among the operators. Not all operators work both in tractor and combine applications. Most deals with bale making (49%) while a small percentage (8%) is involved in hay making (Table 5).

Nuisances relevant to upper and lower respiratory systems are coughing, phlegm, chest tightness, and breathlessness. The majority of the

Table 4-Descriptive information of tractor and combine harvester operators
Çizelge 4-Traktör ve biçerdöver operatörleri tanımlayıcı bilgileri

	Minimum	*Maximum*	*Average ± SEM*
Age, year	20	65	35±1.74
Height, cm	165	186	176±0.84
Weight, kg	64	115	79±1.80
Work experience, year	2	30	13±1.34

Table 5-Percentage of operators dealing with different agricultural field operations
Çizelge-Farklı tarla işlemlerinde görevli operatörlerin yüzdesi

Operation	*%*
All tractor operations	26
Bale making	49
Hay making	8
Combine harvesting	17

operators had complaints about coughing (60%) and phlegm (83%) while chest tightness (31%) and breathlessness (29%) were not the major nuisances reported by operators (Figure 3).

The adverse effect of smoking on human health is well known and the majority (63%) had a smoking habit but the severity of their addiction was not sought in the study. Figure 3 does not necessarily explain the effect of smoking on operator health complaints. As shown in Figure 4, smoking increased the rate of complaints in all nuisances. For instance, 60% of operators expressed that they had coughing problem (Figure 3) whereas this rate reduced to 47% for nonsmokers (Figure 4). Similarly, while 31% of all operators had chest tightness (Figure 3), only 13% of non-smokers suffered from the same nuisance (Figure 4).

It is apparent that the nuisances experienced by operators may not be explained only by PM inhalation and respiration. Non-smokers also expressed complaints particularly on upper respiratory system with high rates of coughing (%47) and phlegm (%67), which might be related to course particle inhalation.

The measured concentrations of PM fractions in this study do not represent all field applications carried out by farmers. There is a wide variety of operations as well as varying soil, plant, climate, and working conditions in agricultural operations. It should also be mentioned that the personal exposure time of operators was quite variable from 2 years to 30 years (Table 4). Thus, conclusions on the effect of PM exposure on operators' health may be accurately drawn only with extensive medical investigations on health history of each operator. The upper and lower respiratory system nuisances, however, are apparent both for smokers and non-smokers as shown in Figure 4.

Although the operators were not exposed to PM levels greater than the PM exposure limits in some of the field applications in this study, it would be better if operators used personal protections in all operations, especially during soil tillage with rotary tillers, harvesting, and hay making to avoid adverse health effects due to particulate matter personal exposure during prolonged working hours.

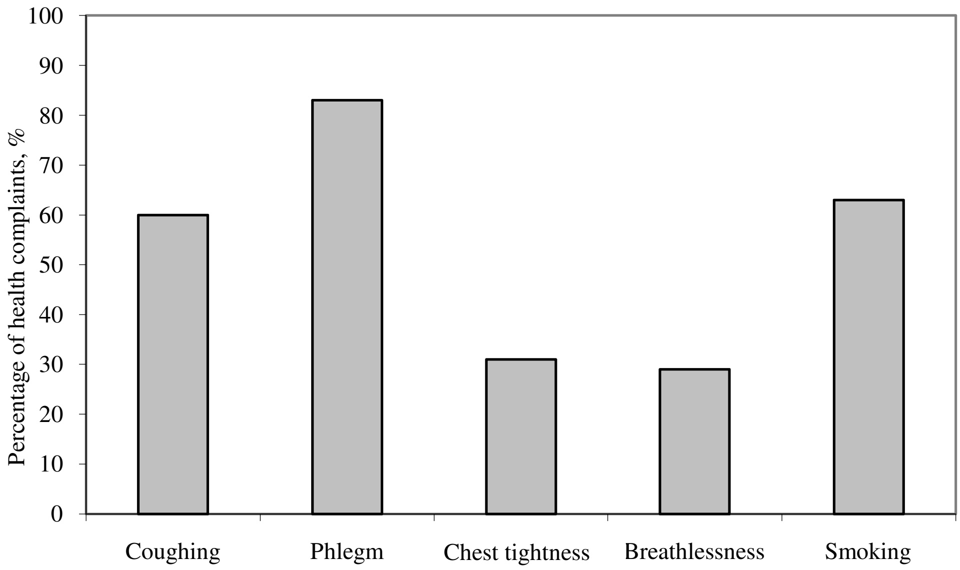

Figure 3-Percentage of operators complaining about specific health nuisances
Şekil 3-Belirli sağlık rahatsızlıklarından şikayetçi olan operatörlerin yüzdesi

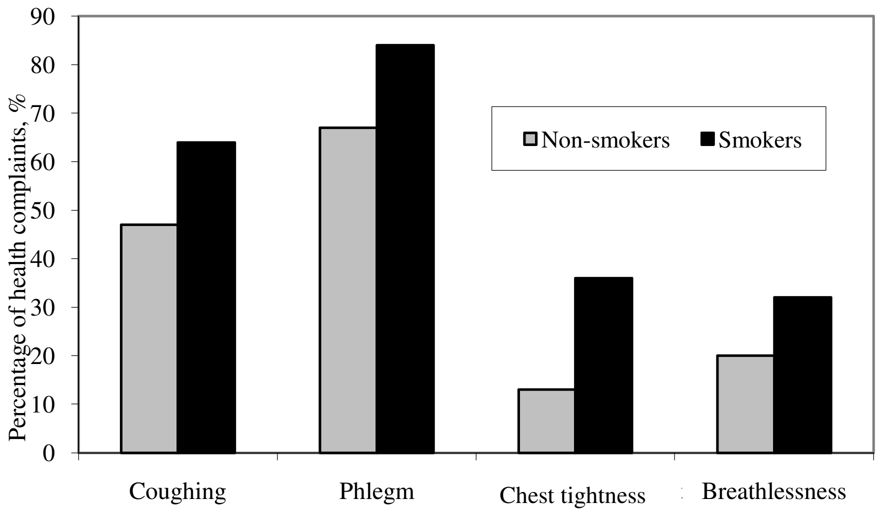

Figure 4-Effect of smoking on health complaints of operators
Şekil 4-Sigara içmenin operatörlerin sağlık şikayetlerine etkisi

Conclusion

The followings could be concluded as a result of this study:

- Measured PM10 and PM2.5 concentration levels were higher than the threshold limit values of 15000 µg m^{-3} and 5000 µg m^{-3} in rotary tilling, wheat harvesting and hay making. Concentration of PM1 was notably high during wheat harvest and haymaking.
- The survey on operators showed that there were health complaints in terms of coughing, phlegm, chest tightness, and breathlessness at varying levels. Smoking habit increased the health complaints of operators.
- The operators should use personal preventions to minimize the potential adverse health effects of personal PM exposure while working on tractors and combines without cabins.
- Tractors and combines should be equipped with cabins since the use of a cabin is a very effective way of protecting the operators from personal PM exposure.

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