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CO_2-equivalent Greenhouse Gas Emissions from Agricultural Production Over Turkey

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ABSTRACT

Though inevitable for the sustenance of life, energy resources must be used to meet human needs so as to comply with how biogeochemical cycles work. Agricultural production is one of the energy-intensive sectors that rely on fossil fuels, thus contributing a great deal to the enhancement of greenhouse gas (GHG) emissions and greenhouse effect. The present study aims to quantify the minimum and maximum range of CO_2-equivalent ($CO_{2\text{-}eq}$) GHG emissions per hectare from 12 agricultural inputs (from human labor to irrigation) used in the production of 31 crops over Turkey. Konya and Şanlıurfa out of 81 provinces, and wheat, barley, cotton, and apple out of 31 crops had the highest $CO_{2\text{-}eq}$ GHG emissions. There is great potential to develop and implement practices and technologies to reduce GHG emissions from energy consumption in agricultural production.

Keywords: Energy policy, Greenhouse gases, Best management practices, Sustainable agriculture

INTRODUCTION

Since the second half of the 20th century, global agricultural production has kept up with the growth rates of human population and consumption owing to advances in agricultural technology, crop genetics, and expansion of arable land. For example, between 1961 and 2005, the global human population and agricultural production grew by 111% and 162%, respectively (Burney et al. 2010). As with other economic sectors, sustainable management of energy supply type (e.g., renewable versus non-renewable), energy demand, energy use efficiency, and energy-related environmental issues plays an important role in securing environmental quality as well as in mitigating adverse impacts of environmental issues such as global climate change.

As there exist two sides to the issue of energy management; that is, supply- and demand-side management, the management of both agricultural sinks and sources must be considered through best available practices and eco-friendly technologies. This in turn necessitates the quantification and prediction of spatiotemporal dynamics of agricultural emissions and sequestration of greenhouse gas (GHG) emissions. Agricultural activities such as irrigation, fertilizers, pesticides, and machinery all involve the consumption of fossil fuels, and thus, the release of GHG emissions to the atmosphere (Disbudak, 2008). Agricultural GHG emissions account for 10 to 12% of total global GHG emissions (IPCC, 2007), while forestry GHG emissions are responsible for 17.4% (FAO, 2007). According to the Turkey's 2008 GHG inventory data, agricultural activities account for approximately 7% (25.04 Mt CO_2 equivalent—$CO_{2\text{-}eq}$) of the total GHG emissions in 2008 (TUIK, 2010).

There exists a knowledge gap about the spatiotemporal quantification of energy consumption in every stage of agricultural production from human labor to machinery on a national scale. Therefore, the objective of this study is to quantify CO_{2-eq} GHG emissions from energy consumption in the agricultural production of 31 crops over Turkey.

MATERIALS AND METHODS

Agricultural production depends on human labor, farm machineries, fertilization through chemicals and farmyard manure, biocides, diesel fuel, electricity and irrigation which all, in turn, requires energy consumption. In the present study, minimum (best-case scenario) and maximum (worst-case scenario) values of energy consumption per hectare (ha) by the 12 basic agricultural inputs used in the production of 31 crops in 2015 were derived from related literature and presented in Tables 1 and 2.

All the consumption values were converted to CO_{2-eq} GHG emissions based on coefficients derived from related literature in Table 3. All the related statistics about the agricultural production of 31 crops in 2015 from 81 provinces across Turkey were obtained from Turkish Statistics Institution (TUIK) database (TUIK 2015). Human labor data expressed in $h.ha^{-1}$ were converted to $MJ.ha^{-1}$ using 1.96 $MJ.h^{-1}$ (Houshyar et al. 2015a; 2015b). These converted values for each crop were multiplied by the total production areas for each province (Houshyar et al. 2017; Gezer et al. 2003). The interpolation method of the empirical Bayesian kriging was used to generate estimate surfaces of total CO_{2-eq} GHG emissions at the national scale.

Table 1. Minimum (best-case scenario) and maximum (worst-case scenario) values of energy consumptions per hectare by six agricultural inputs used in the agricultural production of 31 crops in related literature.

Product	Human (MJ/ha)		Machinery (MJ/ha)		Diesel (L/ha)		Electricity (kWh/ha)		Irrigation (MJ/ha)		Farmyard Manure (ton/ha)		References
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Wheat	3.2	618.2	437.0	1519.5	21.9	283.1	-	-	-	3780.0	-	-	(Marakoglu et al.2017; Yaldiz et al. 1993; Karaagaç et al. 2012; Gokdogan et al. 2011; Gozubuyuk et al. 2012; Ertekin et al. 2017)
Barley	19.4	1428.8	1080.2	1608	29.5	60.5	-	-	-	3145.0	-	-	(Yaldiz et al. 1993; Ertekin et al. 2009; Baran et al. 2014; Koral et al. 1998)
Maize	29.2	1578.8	100.2	1459.8	23.2	134.8	-	-	1665.4	15960.0	-	-	(Karaagac et al. 2011; Yaldiz et al. 1993; Ertekin et al. 2009; Ozturk et al. 2006; Canakci et al. 2005)
Maize (for silage)	14.2	65.7	16.3	975.75	23.0	79.9	-	-	1400.0	2750.0	-	-	(Barut et al. 2011; Baran et al. 2016)
Sugar beet	601.3	2760.1	869.1	4068.0	41.4	170.0	1136.2	1136.2	1883.7	23763.6	-	9.1	(Yaldiz et al 1993; Toprak et al. 2010; Erdal et al.2005; Baran et al. 2016; Koral et al. 1998)
Sunflower	13.0	1426.4	555.1	1761.0	10.9	124.7	-	-	1033.2	4725.0	-	-	(Gozubuyuk et al. 2015; Yaldiz et al. 1993; Bilgili et al. 2014; Uzunoz et al. 2008; Baran et al. 2014)
Cotton	469.6	2162.4	1027.0	1418.5	44.8	337.2	-	-	2520.0	7245.0	-	-	(Şehri, 2012; Koral et al. 1998; Oren et al.2006; Canakci et al. 2005; Yaldiz et al 1993; Gokdogan et al. 2016; Polat et al. 2006)
Rose	1197.5	6654.5	65.1	1903.0	16.0	113.8	-	-	60.6	1472.3	-	75.0	(Koral et al. 1998; Gökdoğan 2011; Akbolat et al. 2006; Gökdoğan et al. 2013)
Sesame	698.9	698.9	512	512	87.8	87.8	-	-	-	-	-	-	(Canakci et al. 2005.)
Colza	17.1	29.0	1142.7	1212.8	76.6	77.9	-	-	-	-	-	-	(Arikan, 2011; Baran et al. 2014)
Sorghum	15.3	15.3	441.6	441.6	92.6	92.6	-	-	2856.0	2856.0	-	-	(Eren et al. 2011)
Haricot Bean	496.6	1275.0	430.9	971.9	62.6	120.9	-	-	-	5679.7	-	30.0	(Ertekin et al. 2010; Koral et al. 1998)
Chickpea	3.1	731.7	307.6	1380.6	17.2	94.5	-	-	-	3883.7	-	-	(Marakoglu et al. 2010; Yaldız et al. 1993; Ertekin et al. 2010)
Lentil	226.7	588.0	279.2	627.5	32.9	104.5	-	-	-	3596.4	-	-	(Koral et al. 1998; Ertekin et al. 2010; Gokdogan et al. 2016.)
Soybean	21.2	576.0	576.2	1467.4	48.3	105.5	-	-	-	8041.7	-	-	(Yaldiz et al. 1993; Koral et al. 1998; Ertekin et al. 2010; Bilgili et al. 2015)
Potato	758.0	4086.5	425.5	1880.8	22.6	300.2	1297.0	1297.0	1580.7	3325.1	-	17.0	(Yavuz et al. 2015; Yaldiz et al. 1993; Ertekin et al.2011; Koral et al. 1998)
Onion	1099.7	3604.0	262.6	922.4	48.6	116.6	-	-	-	2777.0	-	38.6	(Koral et al. 1998; Ertekin et al.2011)
Garlic	1527.6	4374.7	263.4	263.4	50.2	50.2	-	-	1994.8	1994.8	-	25.0	(Ertekin et al.2011; Koral et al. 1998; Yaldız et al. 1993)
Tomato	1739.9	12531.5	1976.6	11791.	169.8	723.8	-	-	1883.7	3982.7	-	28.6	(Çetin et al. 2008; Esengun et al. 2007; Canakci et al. 2005; Dellal et al. 2007; Erdal et al. 2009; Koral et al. 1998)
Watermelon	439.2	1160.1	538.81	1659.4	72.4	172.7	-	-	-	-	-	-	(Koral et al. 1998; Baran et al. 2014; Canakci et al. 2005)
Melon	316.5	1058.0	883.1	1598.0	91.7	169.2	-	-	-	-	-	-	(Koral et al. 1998; Baran et al. 2014; Canakci et al. 2005)
Green bean	1217.3	3443.7	524.2	1303.7	27.1	43.6	-	-	1994.8	1994.8	-	5.9	(Yaldiz et al. 1993; Koral et al. 1998)
Apple	417.2	6300.0	4300.0	4351.5	14.8	8730.0	40.6	542.2	72.3	3116.7	-	32.5	(Koral et al. 1998; Dilay et al. 2010; Ekinci et al. 2015; Yilmaz et al. 2010; Gokdogan et al. 2016)
Apricot	145.2	2614.3	1350.7	1350.7	48.8	187.1	30.5	81.0	181.4	340.2	-	33.2	(Koral et al. 1998; Gezer et al. 2003; Esengun et al. 2007; Gundogmus2006)
Cherry	464.7	4834.7	1124.4	1124.4	91.0	183.8	3013.0	3013.0	2523.8	3051.0	-	49.1	(Koral et al. 1998; Demircan et al. 2006; Kizilaslan, 2009)
Peach	354.6	4814.5	3816.1	3816.1	168.6	245.7	33.9	2960.5	1134.7	2726.8	-	86.5	(Koral et al. 1998; Gokdoğan, 2011; Goktolga et al. 2006)
Mandarin	416.0	4669.5	793.1	793.1	254.7	254.7	622.2	622.2	189	189	-	66.0	(Koral et al. 1998; Ozkan et al. 2004)
Orange	1615.4	2993.7	787.5	787.5	248.4	337.5	852.7	852.7	215.2	215.2	2.5	16.3	(Koral et al. 1998; Ozkan et al. 2004; Dellal et al. 2007)
Lemon	1376.1	3578.3	541.7	541.7	234.4	344.4	624.9	624.9	207.9	4167.1	3.3	18.5	(Ozkan et al. 2004; Bilgili 2012; Koral et al. 1998)
Pomegranate	1084.5	4293.0	664.6	1403.8	26.9	85.6	364.8	364.8	135.5	4365.9	-	10.0	(Koral et al. 1998; Canakci, 2010; Akcaoz et al. 2009)
Pistachio	80.1	1332.5	538.2	538.2	41.8	68.8	25.9	30.4	1.21	1.9	-	8.9	(Koral et al. 1998; Kulekci et al. 2013; Saglam et al. 2012)

Table 2. Minimum (best-case scenario) and maximum (worst-case scenario) values of energy consumptions per hectare by six agricultural inputs used in for the agricultural production of 31 crops.

Product	N (kg/ha)		P_2O_5 (kg/ha)		K_2O (kg/ha)		Insecticide (kg/ha)		Fungicide (kg/ha)		Herbicide (kg/ha)		References
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Wheat	25.6	250.0	-	116.0	-	52.5	-	0.56	-	1.7	-	4.8	(Koral et al. 1998; Canakci et al. 2005; Degerli et al. 2015)
Barley	30.0	164.5	-	78.0	-	-	-	-	-	-	-	2.0	(Koral et al. 1998; Baran et al. 2014)
Maize	66.0	260.0	11.0	180.0	-	75.0	-	2.0	-	-	-	2.0	(Koral et al. 1998; Karaagaç et al. 2016; Ozturk et al. 2006; Canakci et al. 2005)
Maize (for silage)	211.0	211.0	69.0	69.0	-	-	-	-	-	-	1.3	1.3	(Baran et al. 2016)
Sugar beet	130.0	270.0	80.0	246.0	-	64.2	-	3	-	0.3	-	5.0	(Koral et al. 1998; Toprak et al. 2010; Erdal et al 2005; Baran et al. 2016)
Sunflower	-	201.5	-	126.6	-	100.0	-	1.5	-	-	-	2.6	(Gozubuyuk et al. 2016; Koral et al. 1998; Bilgili et al. 2014; Uzunoz et al. 2008; Baran et al. 2014)
Cotton	80.0	270.0	24.0	90.0	-	75.0	-	41.0	-	0.3	-	1.0	(Koral et al. 1998; Canakci et al. 2005; Baran 2016; Polat et al. 2006; Oren et al. 2006; Şehri 2012; Gokduman et al. 2016)
Rose	41.0	205.0	41.0	460.0	-	1.8	-	5	-	-	-	7.0	(Koral et al. 1998; Gokduman 2011; Gökduman et al. 2013; Akbolat et al. 2006)
Sesame	60.0	60.0	15.0	15.0	15.0	15.0	-	-	-	-	-	-	(Canakci et al. 2005)
Colza	15.2	53.1	10.6	67.7	-	-	-	1.3	-	-	-	1.4	(Baran et al. 2014; Ertekin et al. 2009)
Sorghum	172.0	172.0	40.0	40.0	-	-	-	-	-	-	-	-	(Eren et al. 2011)
Haricot Bean	30.0	74.5	-	100.0	-	-	-	-	-	-	-	6.8	(Koral et al. 1998)
Chickpea	-	96.0	-	69.0	-	-	-	-	-	-	-	-	(Koral et al. 1998; Marakoglu et al. 2010)
Lentil	-	38.0	-	66.5	-	-	-	-	-	-	-	-	(Koral et al. 1998; Gokduman, 2016)
Soybean	32.5	140.0	47.9	100.0	-	-	-	3	-	-	-	-	(Koral et al. 1998; Bilgili et al. 2015)
Potato	35.0	332.5	63.0	204.9	-	75.0	-	7	-	4.0	-	4.0	(Koral et al. 1998; Yavuz et al. 2015)
Onion	60.0	178.1	69.0	156.0	-	-	-	-	-	-	-	4.9	(Koral et al. 1998)
Garlic	197.0	210.0	68.0	174.0	-	-	-	-	-	-	-	-	(Koral et al. 1998)
Tomato	97.8	2777.0	-	295.6	-	107.8	-	27.3	-	7.8	-	65.2	(Koral et al. 1998; Erdal et al. 2009; Esengun et al. 2007)
Watermelon	50.3	261.0	58.2	193.6	-	144.0	-	1.9	-	1.7	-	5.7	(Koral et al. 1998; Canakci et al. 2005)
Melon	-	261.0	-	131.4	-	144.0	-	7.0	-	7.6	-	135.4	(Koral et al. 1998; Canakci et al. 2005)
Green bean	123.8	252.7	69.4	158.0	-	43.8	-	4.7	-	-	-	3.0	(Koral et al. 1998)
Apple	-	257.7	-	141.3	-	201.9	-	22.7	-	31.7	-	155.0	(Koral et al. 1998; Yilmaz et al. 2010; Dilay et al. 2007; Gokduman et al.2016; Ekinci et al. 2015)
Apricot	-	138.7	-	109.5	-	160.0	-	30.0	-	38.3	-	50.0	(Gundogmus 2006; Koral et al. 1998; Gezer et al. 2003)
Cherry	50.0	192.1	40.0	182.7	-	166.1	-	32.0	-	2.6	-	12.2	(Koral et al. 1998; Kizilaslan 2009; Demircan et al. 2006)
Peach	30.0	202.8	24.3	198.0	-	429.0	-	4.5	-	29.5	-	105.6	(Koral et al. 1998; Goktolga et al. 2006; Gokdogan 2011)
Mandarin	179.7	338.7	-	142.0	-	180.0	-	15.0	-	16.8	-	110.2	(Koral et al. 1998; Ozkan et al. 2004)
Orange	247.0	406.8	114.1	134.0	172.3	202.0	1.5	16.5	-	10.6	-	0.2	(Koral et al. 1998; Ozkan et al. 2004)
Lemon	245.0	473.2	113.3	188.0	202.6	247.0	3.5	15.0	-	13.0	-	0.2	(Ozkan et al. 2004; Bilgili 20012; Koral et al. 1998)
Pomegranate	-	288.9	-	258.5	-	185.8	4.0	22.5	-	50.2	-	-	(Koral et al. 1998; Akcaoz et al. 2009)
Pistachio	-	112.0	-	100.0	-	29.2	-	1.2	-	36.2	-	29	(Koral et al. 1998; Saglam et al. 2012; Kulekci et al 2013)

Table 3. Coefficients used to convert to carbon dioxide equivalent (CO_{2-eq}) GHG emissions

Energy Type	Coefficient	Unit	References
Human labor	0.36	kg $CO_2.MJ^{-1}$	(Houshyar et al. 2015a; Houshyar et al. 2015b; Houshyar et al. 2017)
Farm machinery	0.071	kg $CO_2.MJ^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Yousefi et al. 2013; Sefeedpari et al. 2014; Nabavi-Pelesaraei et al. 2014; Rassam et al. 2015; Moghimi et al. 2014; Mardani and Taghavifar, 2016)
Nitrogen (N)	1.3	kg $CO_2.kg^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Yousefi et al. 2013; Sefeedpari et al. 2014; Nabavi-Pelesaraei et al. 2014; Lal, 2004; Rassam et al. 2015; Moghimi et al. 2014)
Phosphorus (P_2O_5)	0.2	kg $CO_2.kg^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Yousefi et al. 2013; Sefeedpari et al. 2014; Nabavi-Pelesaraei et al. 2014; Lal, 2004; Rassam et al. 2015; Moghimi et al. 2014)
Potassium (K_2O)	0.2	kg $CO_2.kg^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Yousefi et al. 2013; Nabavi-Pelesaraei et al. 2014; Rassam et al. 2015; Moghimi et al. 2014; Mardani and Taghavifar 2016)
Farmyard manure	0.005	kg $CO_2.ton^{-1}$	(Mohammadi et al. 2014.)
Insecticide	5.1	kg $CO_2.kg^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Lal, 2004; Rassam et al. 2015; Moghimi et al. 2014; Mardani and Taghavifar 2016)
Herbicide	6.3	kg $CO_2.kg^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Sefeedpari et al. 2014; Lal, 2004; Rassam et al. 2015; Moghimi et al. 2014; Mardani and Taghavifar, 2016)
Fungicide	3.9	kg $CO_2.kg^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Nabavi-Pelesaraei et al. 2014; Lal, 2004; Rassam et al. 2015; Moghimi et al. 2014)
Fuel (diesel)	2.76	kg $CO_2.L^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Yousefi et al. 2013; Sefeedpari et al. 2014; Nabavi-Pelesaraei et al. 2014; Rassam et al. 2015; Moghimi et al. 2014; Mardani and Taghavifar, 2016)
Electricity	0.608	kg $CO_2.kWh^{-1}$	(Khoshnevisan et al. 2013a; Khoshnevisan et al. 2013b; Khoshnevisan et al. 2013c; Yousefi et al. 2013; Nabavi-Pelesaraei et al. 2014; Mardani and Taghavifar, 2016.)
Irrigation	0.27	kg $CO_2.MJ^{-1}$	(Houshyar et al. 2015a; Houshyar et al. 2015b; Houshyar et al. 2017)

RESULTS AND DISCUSSIONS

Annually CO_{2-eq} GHG emissions per ha varied between 192.4 and 1578.4 kg for lentil, 429.7 and 2274.2 kg for melon, 473.2 and 1471.5 kg for water melon, 1269.9 and 2403.1 kg for green bean, and 1871.1 and 12692.8 kg for tomato. According to the best-case (minimum emissions) scenario, diesel-related CO_2 emissions were highest for lentil (82.1%), melon (58.9%), irrigation for green bean (42.6%), watermelon (42.2%), and labor for tomato (33.5%). In the worst-case (maximum emissions) scenario, herbicide consumption accounted for the highest share in irrigation for lentil (71.1%), melon (37.5%), diesel in watermelon (32.4%), and labor for green bean (51.6%) and tomato (35.5%) (Fig. 1). The minimum and maximum CO_{2-eq} GHG emissions were estimated at 24.79, 33.97, 44.26, 63.35 and 350.20 Gg (10^6 kg = Gg) in lettuce, melon, watermelon, green bean and tomato productions and 120.45, 137.65, 179.78, 305.95 and 2375.62 Gg in green bean, watermelon, melon, lettuce and tomato productions, respectively.

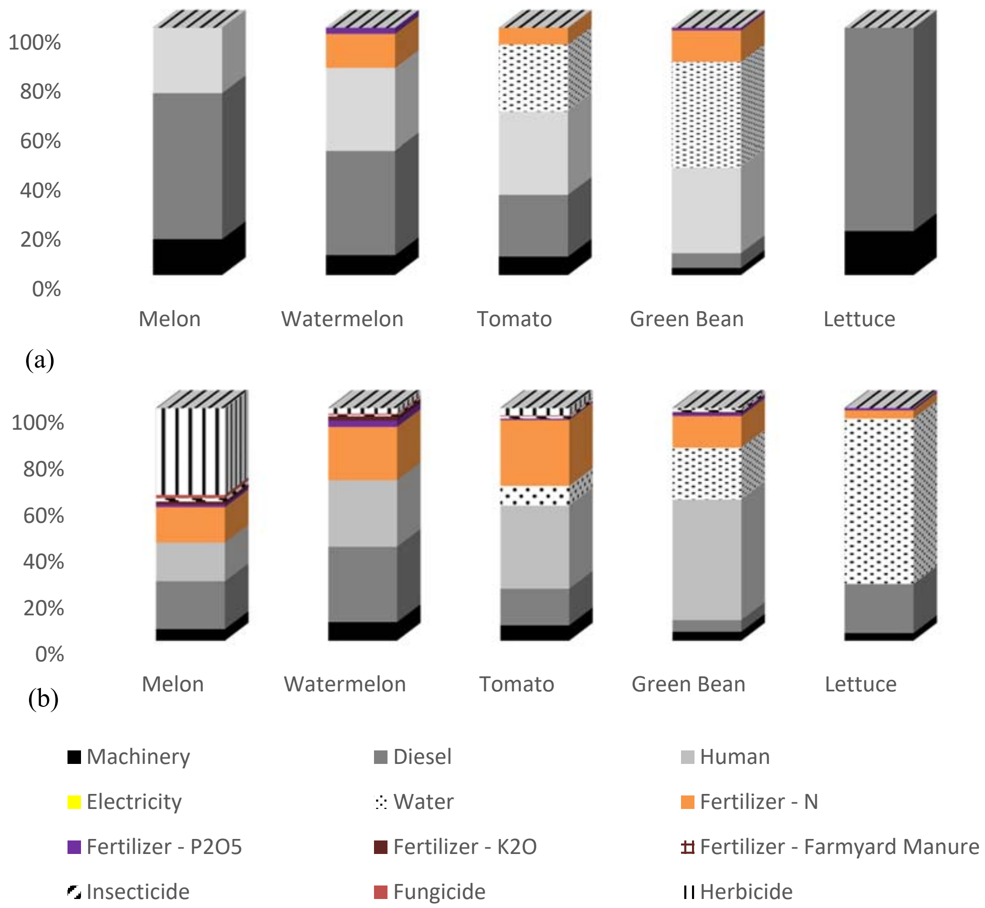

Fig. 1. Fractional (%) shares of 12 agricultural inputs in generating (a) minimum and (b) maximum CO_2-equivalent ($CO_{2\text{-eq}}$) GHG emissions for growing vegetables in Turkey in 2015.

Given the above national estimates in the present study, the $CO_{2\text{-eq}}$ GHG emission ranged annually from 5088.2 and 6544.8 kg ha^{-1} for tomato in Iran whose major share comes from water (46.3%), farmyard manure (22.7%), N fertilizer (9.5%), diesel fuel (9.9%), and human labor (7.5%) (Houshyar et al., 2015a). Mirasi et al. (2015) reported 4752 kg $CO_{2\text{-eq}}$ GHG emission ha^{-1} yr^{-1} from tomato production in Iran which was accounted for by consumptions of diesel (58.1%) and chemical fertilizer plus biocides (37.5%). The largest contributor of agricultural production in Turkey belonged to grains, with $CO_{2\text{-eq}}$ GHG emissions (ha^{-1} in 2015) of 126.2 to 1886.8 kg for barley, 619.3 to 5765.1 kg for maize and 744.0 to 1352.2 kg for silage maize. As far as the best-case scenario was concerned, the most significant sources of $CO_{2\text{-eq}}$ GHG emissions were diesel for wheat (48.1%) and barley (39.9%), N fertilizer (26.4%) and machinery (24.6%) for wheat, and machinery (37.6%) and N fertilizer (19.1%) for barley. Irrigation had the highest share elucidating 72.6 and 67.3% of $CO_{2\text{-eq}}$ GHG emissions from the production of maize and silage maize, respectively. As for the worst-case scenario, irrigation ranked the first in accounting for $CO_{2\text{-eq}}$ GHG emissions for wheat, barley, and both maize crops. The total $CO_{2\text{-eq}}$ GHG emissions based on the best-case scenario ranged from 434.0 Gg for maize to 994.4 Gg for wheat (Fig. 2a). According to the worst-case scenario, the $CO_{2\text{-eq}}$ GHG releases were estimated at 19943.4 Gg from the wheat production and 555.13 Gg from the silage maize production (Fig. 2b).

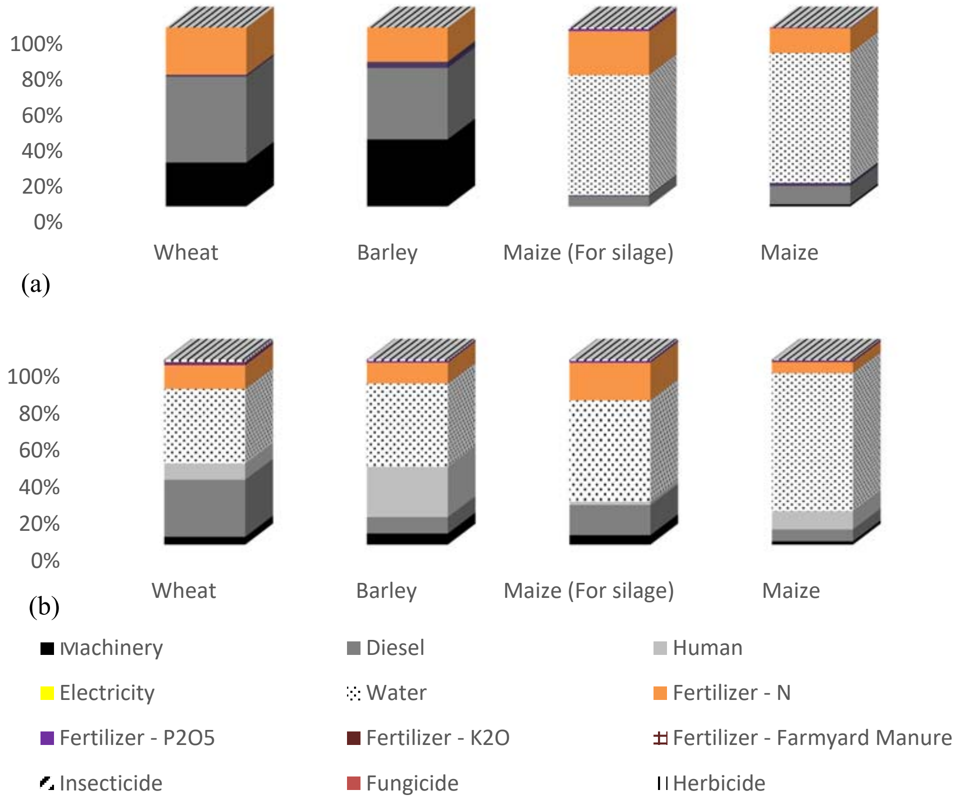

Fig. 2. Fractional (%) shares of 12 agricultural inputs in generating (a) minimum and (b) maximum CO_2-equivalent ($CO_{2\text{-eq}}$) GHG emissions for growing grains in Turkey in 2015.

Compared to the national estimates of the present study, the annual $CO_{2\text{-eq}}$ GHG emission varied between 410 and 1130 kg ha^{-1} from the wheat production in western Canada under the different climate and applications of fertilizer rates and seeding techniques (Khakbaza et al., 2009). Maize production in Iran caused 12864.8 kg $CO_{2\text{-eq}}$ GHG emission ha^{-1} yr^{-1} of which electricity (76.6%), fertilizer (17.1%) and diesel (6.3%) consumptions were responsible for (Yousefi et al., 2014). Khoshnevisan et al. (2013) estimated the annual $CO_{2\text{-eq}}$ GHG emission at 2724.6 kg.ha^{-1} for wheat in Iran which was reduced to 2684.3 kg.ha^{-1} by energy optimization strategies whose largest share came from electricity (73.6%), chemical fertilizer (13.6%) and diesel (7.6%) consumptions. The adoption of the best crop management practices was reported to result in 20% less $CO_{2\text{-eq}}$ GHG emission ha^{-1} and 40% less $CO_{2\text{-eq}}$ GHG emission per ton of wheat in Iran (Soltani et el. 2013). The best crop management practices used in Iran led to 1922 kg $CO_{2\text{-eq}}$ GHG emission ha^{-1} from the wheat production which was partitioned into the components of chemical fertilizer + biocides (51.5%), diesel (28.8%), and machinery (19.7%) (Mirasi et al., 2015).

The $CO_{2\text{-eq}}$ GHG emissions based on the best-case scenario in 2015 were estimated to vary between 70.7 and 1809.5, 233.7 and 2991.4 and 421.3 and 2555.4 kg ha^{-1} for chickpea, soybean, and haricot beans, respectively. The largest sources of $CO_{2\text{-eq}}$ GHG emissions were diesel (67.5%) and machinery (30.9%) for chickpea, diesel (57.1%), N fertilizer (18.1%), and machinery (17.5%) for soybean, and labor (42.4%), diesel (41.2%) and N fertilizer (9.3%) for haricot bean. For the worst-case scenario, irrigation became the largest source for the production of leguminosae. The total minimum and maximum $CO_{2\text{-eq}}$ GHG releases varied between 8.58 Gg for soybean and 39.43 Gg for haricot bean (Fig. 3a) and between 109.88 Gg for soybean and 650.14 Gg for chickpea (Fig. 3b), respectively.

Minimum and maximum $CO_{2\text{-eq}}$ GHG emissions per ha were estimated at 1777.1 to 9319.9 kg for sugarbeet, 353.1 to 2590.1 kg for sunflower, 1154.9 to 4366.6 kg for cotton, 557.8 to 3671.4 kg for rose, 1639 to 4684.5 kg for potato, 1295.2 kg for sorghum, 614.3 kg for sesame, 320.7 to 409.4 kg for colza, 640.5 to 2728.4 kg for onion, and 1515.5 to 2578.7 kg for garlic. The highest share of minimum and maximum $CO_{2\text{-eq}}$ GHG emissions belonged to labor for rose, sesame, onion and garlic, to diesel for colza, to irrigation for sunflower, cotton and sorghum, to electricity and irrigation for sugarbeet, and to electricity and labor for potato, respectively.

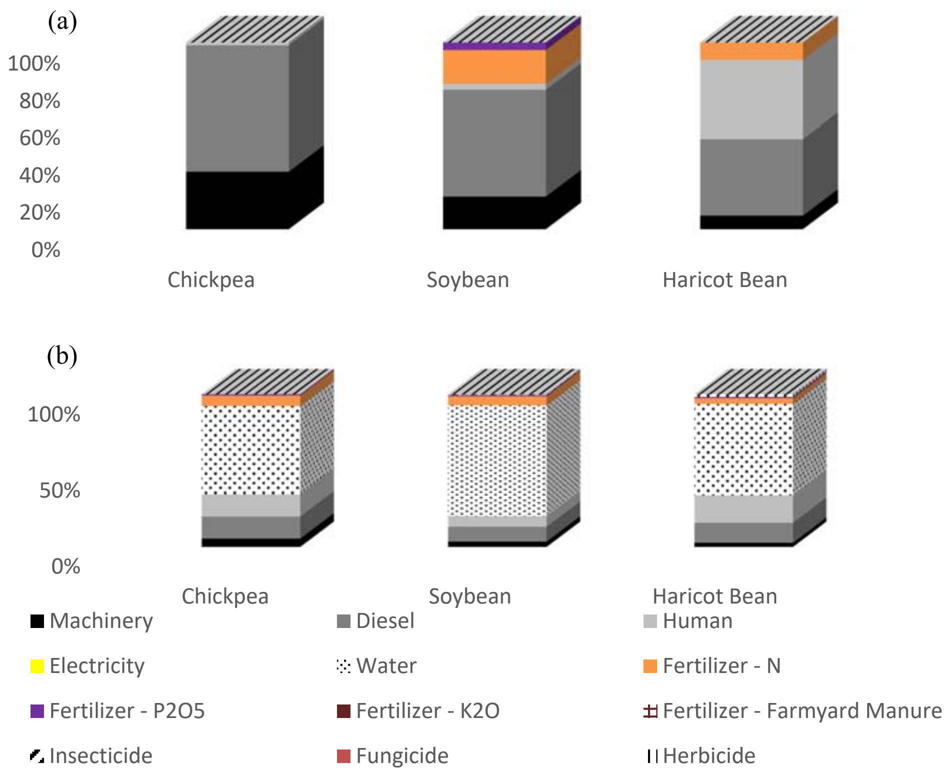

Fig. 3. Fractional (%) shares of 12 agricultural inputs in generating (a) minimum and (b) maximum CO_2-equivalent ($CO_{2\text{-eq}}$) GHG emissions for growing leguminosae crops in Turkey in 2015.

The minimum and maximum $CO_{2\text{-eq}}$ GHG releases were 489.1 to 2565.5 Gg from sugarbeet, 242.0 to 1775.0 Gg from sunflower, 501.24 to 1895.1 Gg from cotton, 1.68 to 11.0 Gg from rose, 252.5 to 721.7 Gg from potato, 2.1 Gg from sorghum, 17.2 Gg from sesame, 11.2 to 14.3 Gg from colza, 36.96 to 157.4 Gg from onion, 3.1 to 5.3 Gg from garlic (Fig. 4a and b), respectively.

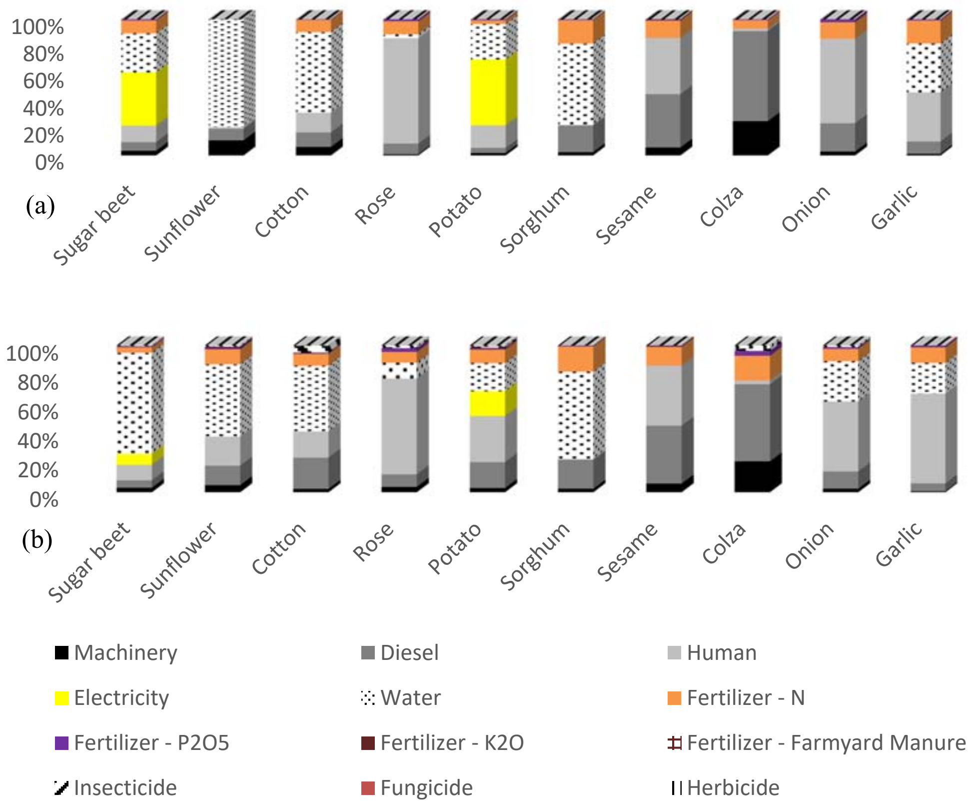

Fig. 4. Fractional (%) shares of 12 agricultural inputs in generating (a) minimum and (b) maximum CO_2-equivalent ($CO_{2\text{-eq}}$) GHG emissions for growing industrial, tuberous and feed crops in Turkey in 2015.

Sorensen et al. (2014) reported 915, 817 and 855 g $CO_{2\text{-eq}}$ GHG emissions per kg product for the conventional, reduced and no tillage systems, respectively, using the rotations of spring barley, winter barley, winter wheat, and rape seed. The fertilizer production, and machinery were stated to contribute to 28 to 33% and 6 to 8% of the total $CO_{2\text{-eq}}$ GHG emission per kg product (Sorensen et al. 2014). The total $CO_{2\text{-eq}}$ GHG emissions were reported to range from 5970.1 to 8249.1 kg ha^{-1} for different cropping systems of sugarcane in Iran, with the maximum share belonging to electricity (42.3 to 54.9%), irrigation, machinery, and diesel fuel (Sefeedpari et al., 2014). $CO_{2\text{-eq}}$ GHG emission from the potato production in Iran was estimated at 992.9 kg ha^{-1}, with its 37.3% from chemical fertilizers, 32.8% from diesel, and 20.5% from irrigation (Pishgar-Komleh et al., 2012). This value changed to 2283 kg ha^{-1} and 116.4 kg per ton potato for another farm in Iran, with the highest contributors being electricity (65%), chemical fertilizer (20%) and diesel (10%) (Khoshnevisan et al., 2014). $CO_{2\text{-eq}}$ GHG emission from the sugarbeet production in UK varied between 910 and 1540 kg ha^{-1} and between 15 and 34 kg per ton product according to different production scenarios (Tzilivakis et al., 2005). This value from sugarbeet in Iran was 9847.8 kg ha^{-1}, with and the biggest share from electricity (73%), fertilizer (20%), and diesel (7%) (Yousefi et al., 2014).

The minimum and maximum $CO_{2\text{-eq}}$ GHG emissions (kg ha^{-1}) from the fruit production varied between 540.8 and 29462.4 for apple, 350.7 and 2546.5 for apricot, 3084.7 and 5553.3 for cherry, 1234.8 and 6411.4 for peach, 1572 and 1211.0 for mandarin, 2285.6 and 3364.6 for orange, 2016.4 and 4613.0 for lemon, 790 and 4057.1 for pomegranate, and 198.5 and

1228.4 for pistachio. The maximum contributors of the fruit production to the best-case CO_{2-eq} GHG emissions were diesel for apricot (38.5%), peach (37.7%), mandarin (44.7%), orange (30%), lemon (32.1%) and pistachio (58.1%); machinery for apple (52.5%); electricity for cherry (59.4%); and labor for pomegranate (49.4%) in CO_2 production. Those to the worst-case CO_{2-eq} GHG emissions were labor for apricot (37.0%), mandarin (39.9%), orange (32.0%), lemon (27.9%), pomegranate (38.1%), and pistachio (39.1%); electricity for cherry (33.0%) and peach (28.1%); and diesel for apple (10.0%). The minimum and maximum CO_{2-eq} GHG emissions varied between 99.7 and 9180.2 Gg for apple, 42.8 and 311.0 Gg for apricot, 251.1 and 452.0 Gg for cherry, 54.9 and 285.3 Gg for peach, 68.4 and 183.2 Gg for mandarin, 124.1 and 182.6 Gg for orange, 57.6 and 131.7 Gg for lemon, 24.3 and 124.7 Gg for pomegranate, 57.8 and 357.9 Gg for pistachio, respectively (Fig. 5 a and b).

CO_{2-eq} GHG emission was 1195.8 kg ha^{-1} from the Iranian apple production, with biocides (69%), diesel (17%) and chemical fertilizers (10%) as the biggest contributors (Taghavifor and Mardani, 2015) and varied between 755.1 and 939.6 kg ha^{-1} from the Iranian orange production, with fertilizer (34.9 to 40.4%), diesel (31.7 to 33.4%) and machinery (18.3-22%) as the biggest contributors (Nabavi-Pelesaraei et al. 2014; Nabavi-Pelesaraei et al. 2016).

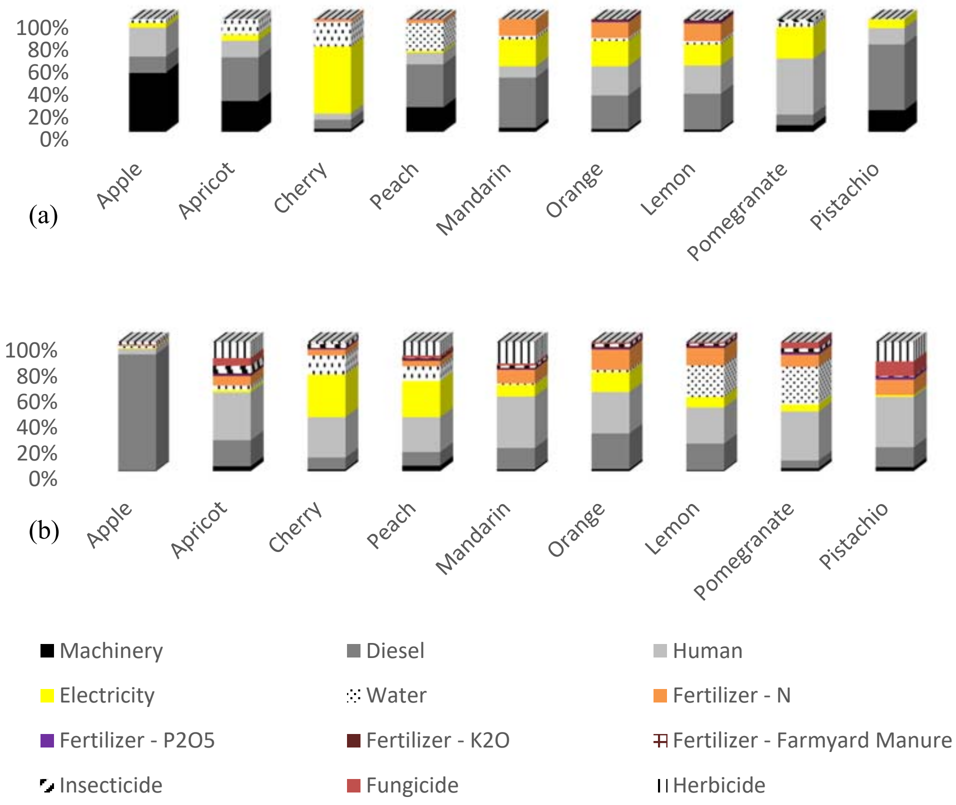

Fig. 5. Fractional (%) shares of 12 agricultural inputs in generating (a) minimum and (b) maximum CO_2-equivalent (CO_{2-eq}) GHG emissions for growing fruits in Turkey in 2015.

The minimum CO_{2-eq} GHG emissions based on the best-case scenario occurred in Şanlıurfa, Konya and Adana, respectively (Fig. 6). The maximum CO_{2-eq} GHG emissions based on the worst-case scenario occurred in Konya, Sanliurfa and Ankara, respectively (Fig. 6).

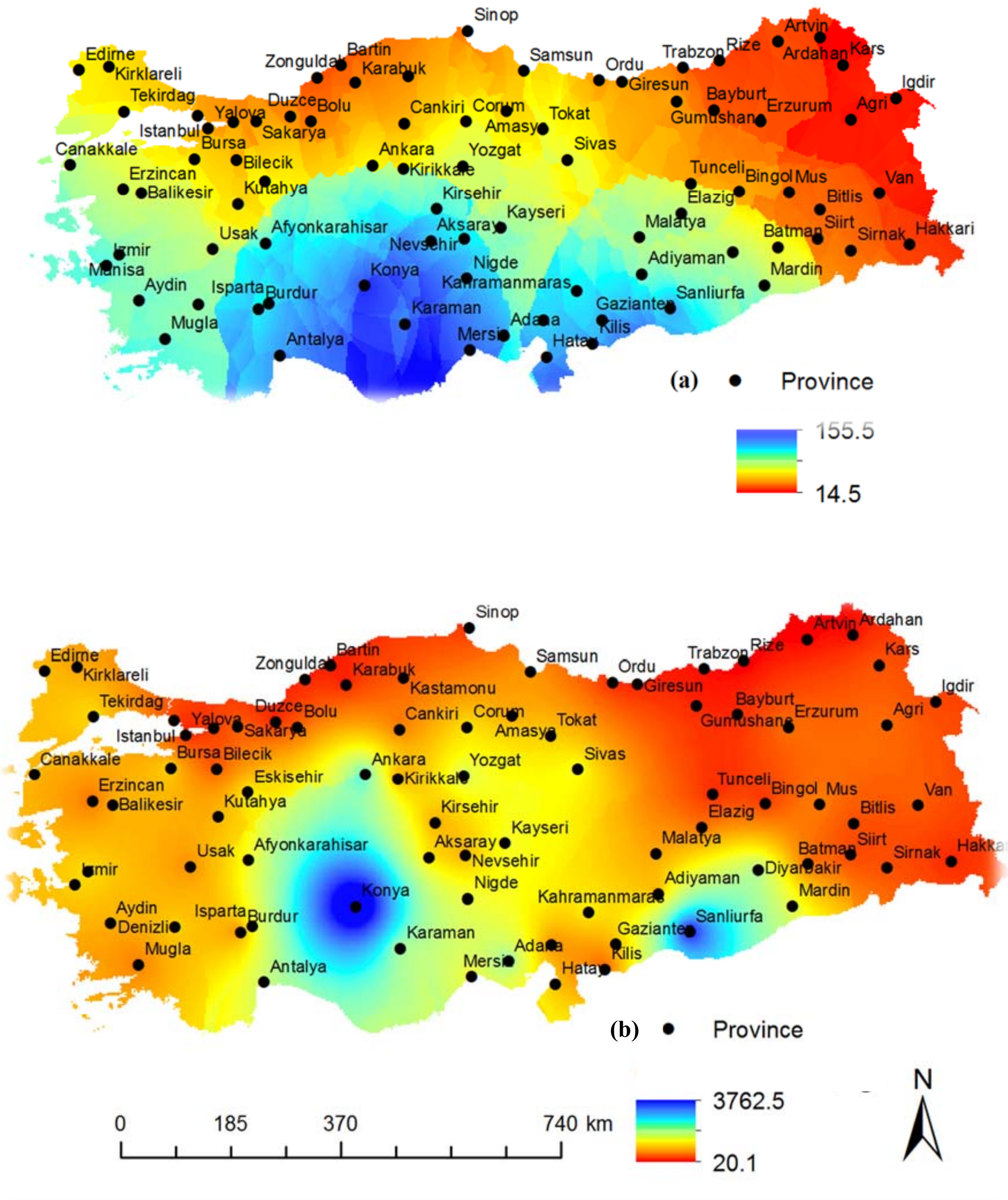

Fig 6. National map of (a) minimum and (b) maximum total CO_2-equivalent ($CO_{2\text{-eq}}$) GHG emissions (Gg = 10^6 kg) from 12 agricultural inputs used in agricultural production of 31 crops in 2015, based on empirical Bayesian kriging (n = 100).

CONCLUSIONS

The adoption of different agricultural management practices including crop rotation, nutrient, tillage, irrigation and biocide systems generates energy use efficiency with different implications for $CO_{2\text{-eq}}$ GHG emissions. The best- and worst-case scenario estimates showed that the total $CO_{2\text{-eq}}$ GHG emissions associated with 12 agricultural inputs ranged from 155.5 to 3762.5 Gg for the production of 31 crops in 2015. Increased efficiencies of energy, water, fertilizer and biocide uses, increase uses of alternative renewable energy resources and technologies, reduced dependence on fossil fuels, and defragmentation of large agricultural lands all show an environmental benefit in the form of reduced CO_{2-eq} GHG emission. Optimized agricultural systems or the best management practices strive for achieving the balance among agricultural productivity, energy and economic efficiency, and environmental impacts such as GHG emissions. Innovative practices and technologies such as precision agriculture are also needed to tighten and reduce the fossil fuel-based energy budgets of the agricultural production processes in accordance with social acceptance and ecological requirements across the world.

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