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Original article

Investigating the response of soil and vegetable crops to poultry and cow manure using ground and satellite data

Khalid A. Al-Gaadi [a,b], Rangaswamy Madugundu [a,*], ElKamil Tola [a]

[a] Precision Agriculture Research Chair, King Saud University, Riyadh, Saudi Arabia
[b] Department of Agricultural Engineering, College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia

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ABSTRACT

Based on the massive production of cow and poultry manures, farmers in Saudi Arabia are moving towards the application of organic fertilizers in their farms. Therefore, the present work was conducted to study the response of soil and selected vegetable crops to poultry and cow manures, using ground data and Landsat-8 and Hyperion images. The studied vegetable crops are cabbage, cauliflower, broccoli, and lettuce. A total of 100 t ha^{-1} organic manures were applied as a pre-planting treatment. A 12.5 ha field in Tawdeehiya Farms, 200 km southeast of Riyadh, was earmarked for this study. The field was divided into sectors cultivated with the above-mentioned vegetable crops. Soil characteristics, including the soil pH, the electric conductivity (EC), the nitrogen (N), the phosphorus (P) and the potassium (K), were examined before the application of manures and 25 days after the transplanting process. Observations on crops chlorophyll content, number of leaves, the diameter of merchantable products and yield were also investigated. Furthermore, the relationship between the crop performance and yield was investigated through the satellite images generated vegetation indices (VIs). This study revealed the better performance of poultry manure compared to cow manure in terms of development and production parameters of the experimental crops. Dynamics of the chlorophyll content across the crop growth period revealed that all the tested crops responded significantly ($R^2 = 0.69$; $P = 0.001$) to the poultry manure treatments. Among the tested crops, the chlorophyll content, curd or head sizes and crop yields were quite better in poultry manure applied plots. The investigation of crop yield was significant with poultry manure ($R^2 = 0.64$; $P = 0.001$) than cow manure ($R^2 = 0.57$; $P = 0.001$) using the OSAVI and mNDVI, respectively.

1. Introduction

Agricultural land is the most valuable resource for food and fiber production required to meet the human and animal needs. Vegetable crops, however, are of utmost importance in terms of health because they are a rich and relatively cheaper source of vitamins and a range of foods necessary for a balanced diet (Robinson, 1990). In Saudi Arabia, an area of about 106,176 ha was under vegetable crops in 2013–2014, with a recorded total yield of 2,731,370 tons (GAS-KSA, 2015). In order to meet the productivity of a crop, the usage of agro-chemicals is common practice. However, optimum usage of maintenance of crop and agricultural land is essential. Most farmers use large quantities of inorganic fertilizers (such as superphosphate, urea sulphate, and ammonium nitrate sulphate) to enhance crop production, resulting in high soil acidity, high amounts of nutrient losses through leaching and soil erosion, in addition to high radiation levels due to the increased chemical contents in the soil (Ndukwe et al., 2012; Alharbi, 2013).

Soil degradation due to biochemical materials are considered less hazardous compared to that caused by inorganic fertilizers and pesticides, as they are directly linked to environmental degradation and health risks (Peyvast et al., 2008). Inorganic fertilizers, which are less complex and have high nutrients concentrations, are formulated to provide specific plant nutrients. However, for organic fertilizers which are naturally derived from living substances including bat and bird excrement, animal manure or vegetable matter (e.g. compost and crop residues), nutrients are released more slowly, and therefore takes more time to supply nutrients to plants than inorganic fertilizers.

* Corresponding author at: King Saud University, Riyadh 11451, Saudi Arabia.
E-mail address: rmadugundu@ksu.edu.sa (R. Madugundu).

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The major advantage of organic fertilizers is the enhancement of the soil organic matter (SOM), which is associated with the increased availability of plant nutrients, in addition to the improvement of the soil capacity by reducing nutrients leaching, increasing soil water holding capacity, and hence, improving the soil water availability (Subaedah et al., 2016). Thus, applying animal manure on agricultural lands is considered as a good practice for recycling nutrients and organic matter, which in turn improve the soil quality and field performance (Yang et al., 2001). Moreover, organic manure, especially cow and poultry manures, is considered as effective organic fertilizers. In this regard, many successful applications of cow and poultry manures, to improve soil fertility, nutrients and crop yield have reported by many researchers (Adekiya and Agbede, 2009; Ewulo et al., 2008; Usman, 2015; Milas and Vincent, 2017). However, improper use of organic manures on agricultural soils can significantly reduce the performance of manures and adversely affect productivity.

The feasibility of using satellite images, in the qualitative and quantitative assessment of the vegetation cover, has been demonstrated in a wide range of researches (Bannari et al., 1995; Basso et al., 2004). In this regard, the multi-spectral sensors, such as Landsat and Hyperion has a long history of work on studies investigating spectro-biophysical relationships (Thenkabail, 2003). Vegetation indices (VIs) are appropriate criteria for monitoring and assessing the health status of plants and agronomic parameters such as crop type, crop cover, leaf area, biomass, and nutrients status (Zarco-Tejada et al., 2013; Simic et al., 2011; Rao et al., 2015).

The NDVI, OSAVI, simple ratio, chlorophyll index (CI_{green}), green red index (GRI) and the modified NDVI (mNDVI) are found to be most suitable indices for the investigation of crop sensitivity to the applied agricultural inputs and other structural elements (Blackburn, 1998; Rondeaux, et al., 1996; Yu et al., 2014).

Based on the massive production of cow and poultry manures, farmers in Saudi Arabia are moving towards the application of organic fertilizers in their farms. However, there is still a significant shortage of information about crop performance and production when using organic fertilizers. In addition, some issues related to manure applications have not yet been intensively investigated, including temporal changes of organic fertilizers, crop needs and availability of nutrients, as well as the manure management practices. Therefore, this study was conducted to investigate the response of soil and vegetable crops to poultry and cow manures, using ground data and Landsat-8 and Hyperion images.

2. Materials and methods

2.1. Study area

An agricultural field (12.5 ha) of Tawdeehiya Arable Farm (TAF) was earmarked for this study (Fig. 1). The TAF is a commercial farm in the central region of Saudi Arabia, about 200 km Southeast of Riyadh. The study area experiences hot summers (up to 45 °C) and cold to moderate winters (6 – 21 °C), with a low mean annual rainfall of about 90 mm. Corn, alfalfa, Rhodes grass, and vegetables (cabbage, lettuce, broccoli, carrot, etc.) were the major crops in the experimental farm. As the rainfall is very low, the crops are cultivated with supplementary irrigation water through center pivot irrigation systems.

2.2. Field experiments

The experimental field was bifurcated into two portions (Fig. 1). The western part was earmarked for cow manure application and the eastern part was applied with poultry manure. The field was

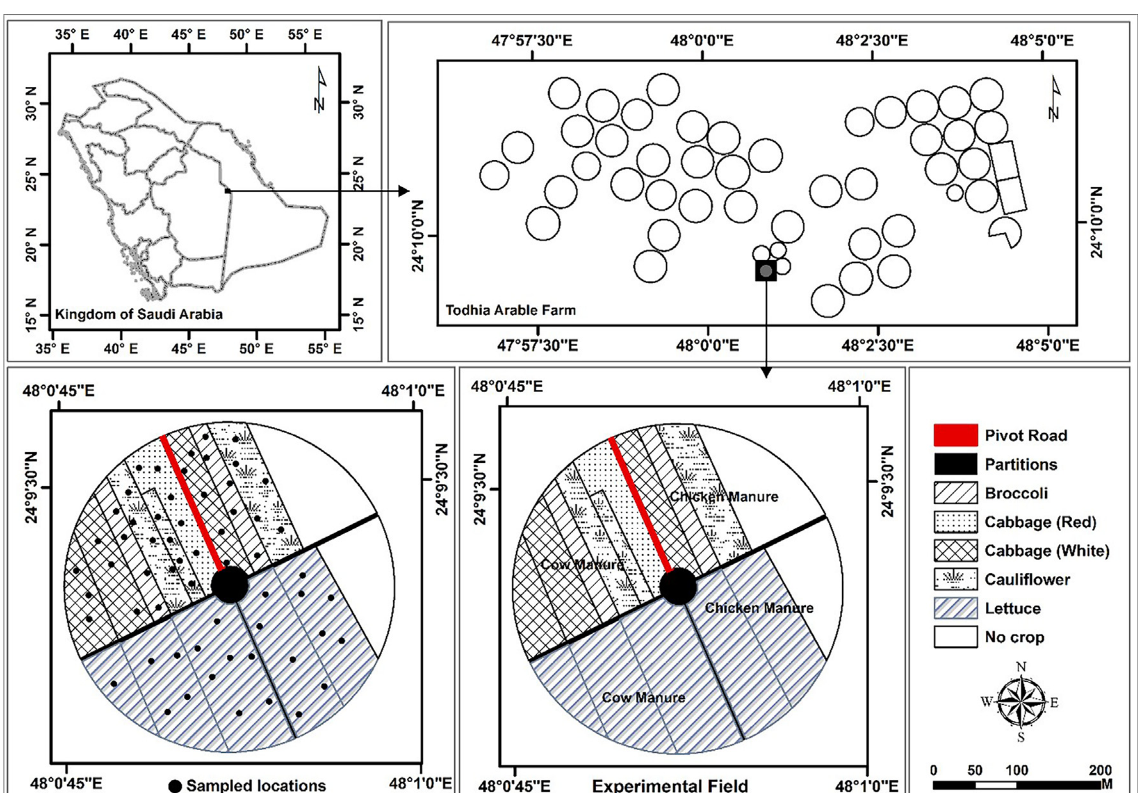

Fig. 1. Location map of the experimental field (Field ID: 20B) - Tawdeehiya Farms, Saudi Arabia.

further divided into sub-divisions, where the tested vegetable crops were cultivated. The studied vegetable crops were three cauli group vegetables (cabbage – "*Brassica oleracea* var. *capitata* L."; cauliflower – "*Brassica oleracea* var. *botrytis* L."; broccoli – "*Brassica oleracea* var. *italica* L.") and one aster family vegetable (lettuce – "*Lactuca sativa* L."). Both poultry and cow manures were added to the experimental plots at an application rate of 100 t ha^{-1}, as a pre-planting treatment, during the last week of October 2016. After land preparation and manure application, the field was leveled and a broad bed furrow system was established across the experimental field, with a bed top width of 1.5 m and a bed length of 175 m. Seedlings of the selected vegetables were transplanted at space of 30 cm between two plants. Information on crop type, plant population and the quantity of the applied irrigation water is presented in Table 1.

2.3. Collection of field observations

2.3.1. Collection and analysis of soil samples

Random soil samples, from the upper 0–20 cm soil layer, were collected from 90 sampling locations (Fig. 1). The collected soil samples were cleaned from unwanted roots and debris and then subjected to air drying process until a constant weight was achieved. The air-dried soil samples were screened through 2.0 mm and 0.4 mm sieves. The designated sampling points were fixed and their coordinates were identified using a differential GPS. Soil samples were collected at different stages covering the whole crop cultivation processes as given in Table 2. The collected soil samples were analyzed for the basic chemical characteristics including soil Nitrogen (N), Phosphorous (P), Potash (K), the potential of Hydrogen (pH) and Electrical Conductivity (EC).

2.3.2. Crop growth parameters

A total of 90 fixed geo-referenced sampling locations, each of 1.5 m^2, were identified randomly and used for bi-weekly ground-based monitoring of plant development, synchronous with Landsat-8 image acquisition dates. The four corners of each sampling location were fixed, and their positions were recorded with a differential GPS (Trimble, Geo XH). During each field visit, data representing the growth and health of crops, such the crop developmental stage and the crop canopy characteristics (e.g. ground cover "GC" fraction, chlorophyll content and spectral reflectance) were documented. The GC fraction of the soil background was estimated from the images captured by the multispectral camera (ADC, Tetracam Inc, USA), using the Tetracam PixelWrench2 software program (version 1.2.3.1). Where the SPAD meter was used for the measurement of chlorophyll content. Thermal images were collected, using an IR Thermal Camera (FLIR Ts-650), to study the dynamics of the surface temperature for the tested crops across the growth period.

Table 1
Details of crops and farming practices.

Crop	Variety	Plant population	Irrigation (mm)
Cabbage (white)	Bonnet	11.1 Plants m^{-2}	880
Cabbage (red)	Red Rovite		720
Cauliflower	Solid Snow		660
Lettuce (Iceberg)	Orly & Bombola		740
Broccoli	Pomet		800

Table 2
Details of soil samples collection.

Time of sample collection	Code	Date of sample collection
Pre-application of organic manure	PA	October 12th, 2016
After manure application	AA	November 1st, 2016
20 days after application	AA-20	November 20th, 2016
At the time of transplantation	AT	January 8th, 2017
Three weeks after transplantation	AT-3	February 6th, 2017
At the time of harvest	AH	March 14th, 2017

2.3.3. Crop yield parameters

Crop response to the type of manure was also investigated through the assessment of yield parameters including plant diameter, plant weight, head diameter, head weight and yield (dry matter). The same sample locations, used for the collection of the crop biophysical parameters, were considered for the assessment of yield parameters. An area of 1.5 m × 1.75 m (i.e. full width of the bed), having about 25 plants, was harvested and used for the collection of crop yield parameters. The number of leaves, head/curd diameter was determined from five randomly selected plants at each sampling location. The marketable portion (yield) of the crop was collected and oven dried for dry matter yield.

2.4. Remotely sensed data and image analysis

Remotely sensed satellite images (15 Landsat-8 (OLI) and 10 Hyperion sensors) were downloaded (free-of-cost) from the USGS website (https://earthexplorer.usgs.gov/) for the study period from January 1st to April 6th, 2017, and used for this study. The downloaded satellite images were first pre-processed and converted to spectral radiance (Mishra et al., 2014) and subsequently processed for TOA reflectance images. The temporal profiles of the selected VIs (Eq. (1) to Eq. (8)) were developed from the TOA corrected images. (Jordan, 1969; Rouse et al., 1974; Rondeaux et al., 1996*; Rondeaux et al., 1996#; Gitelson et al., 2003*; Gitelson et al., 2003#; Inoue et al., 2008; Sims and Gamon, 2002). The ENVI (ver. 5.2) software program was used for image analysis and VIs development.

$$SR = NIR - Red \tag{1}$$

$$NDVI = (NIR - Red)/(NIR + Red) \tag{2}$$

$$OSAVI = (1 + 0.16) \cdot \frac{\rho 800 - \rho 670}{\rho 800 + \rho 670 + 0.16} \tag{3}$$

$$OSAVI = (1 + 0.16) \cdot \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red} + 0.16} \tag{4}$$

$$CI_{green} = \frac{\rho 750 - \rho 550}{\rho 550} \tag{5}$$

$$CI_{green} = \frac{\mathrm{NIR} - \mathrm{Green}}{\mathrm{Green}} \tag{6}$$

$$\mathrm{GRI} = \frac{\mathrm{Green}}{\mathrm{Red}} \tag{7}$$

$$mNDVI = (\mathrm{NIR} - \mathrm{Red})/((\mathrm{NIR} + \mathrm{Red} - 2) \cdot \mathrm{Blue}) \tag{8}$$

Where, SR is the simple ratio; NDVI is the normalized difference vegetation index; OSAVI is the optimized soil-adjusted vegetation index; CI_{green} is the chlorophyll index green; GRI is the green–red index and mNDVI is the modified NDVI; * and # representing Hyperion and Landsat, respectively. The Hyperion hyperspectral data is quite useful in determining the CI_{green} and OSAVI at particular wavelengths than the Landsat-8 products.

3. Results and discussion

3.1. Soil and manure parameters

Prior to the execution of the field treatments, the soil of the experimental field and the proposed organic manures (cow and poultry manures) were subjected to laboratory analysis for the basic characteristics. The laboratory results, presented in Table 3, represent the basic soil nutrients (nitrogen, phosphorus, and potassium) in addition to the soil pH and soil EC. Results indicated that the soil in the experimental field was alkaline non-saline (pH = 7.58 & EC = 1.27 dS m^{-1}) with low concentrations of the major nutrients. Applied organic manures indicated that both cow and poultry manure are characterized by higher pH and EC values compared to the soil of the experimental field. The results indicated that the poultry manure showed a moderate salinity compared to the slightly saline cow manure. The results also showed higher levels of N and K nutrients in both cow and poultry manures than in the soil prior to manure application. However, the concentration of the P nutrient was more in soil than that of the applied organic manures.

The dynamics of soil nitrogen (N) content in the experimental field after the application of the investigated cow and poultry manures is given in Fig. 2. Immediately after application (AA), the soil N concentration in the poultry manure plots ranged between 1.26% and 1.61%. While the N concentration in the cow manure plots ranged between 0.90% and 1.06%· The mean value of the N concentration, in the cow manure plots, increased from 0.96% at the time of manure application to 1.47% at harvesting. While in the poultry manure plots, the N concentration increased from 1.47% at the time of manure application to 1.97% at harvesting. These results indicated a better response of soil nitrogen content to poultry manure than to cow manure.

3.2. Canopy temperature regimes

Observations on the surface temperature of the experimental plots were collected using an IR-Thermal Camera (Model: FLIR Ts-650) across the study period. In general, the manure performance related to surface temperature was similar for both poultry (20.9 °C) and cow (20.7 °C) manure plots. However, there were noticeable differences in the surface temperatures among the tested vegetable crops (Fig. 3). The lowest temperature was observed for Cauliflower in both cow (19.7 °C) and poultry (19.8 °C) manure plots. While, the highest surface temperature was observed for plots cultivated with Green Cabbage for areas treated with both cow (21.7 °C) and poultry (21.9 °C) manures. Overall, the performance of poultry manure was slightly high when compared with cow manure treated plots (RMSE and MBE of 1.97% and 0.8%, respectively).

3.3. Chlorophyll content

As illustrated in Fig. 4, the measured chlorophyll content (SPAD values) in the Poultry manure plots ranged between 30.7 for the Cauliflower at the initial growth stage of the crop (TC) and 98.2 for the Broccoli during the full canopy/high growth period (EH). However, the SPAD values observed in the cow manure plots ranged between 32.4 for the Red Cabbage at the initial growth stage (TC) and 90.7 for the Green Cabbage at the full canopy stage (EH). Overall results revealed that the SPAD values of vegetable crops cultivated in the Poultry manure plots were relatively high

Table 3
Physiochemical properties of the soil and applied organic manure.

Manure/soil	pH	EC (dS m^{-1})	Nitrogen (g kg^{-1})	Phosphorus (g kg^{-1})	Potassium (g kg^{-1})
Soil (0–20 cm)	7.58	1.27	0.19	0.07	0.13
Cow	7.81	2.81	0.33	0.01	0.69
poultry	8.22	4.27	1.09	0.04	0.21

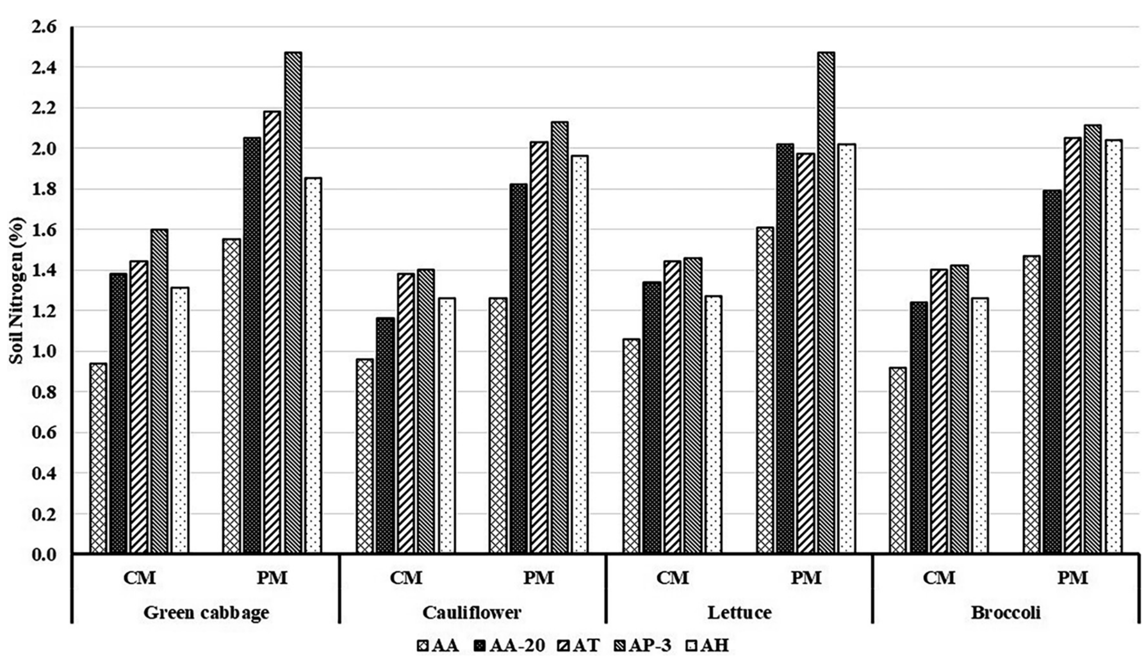

Fig. 2. Dynamics of nitrogen content in the experimental field. AA: after-manure application, AA-20: 20 days after-manure application, TT: transplantation time, TT-3: three weeks after transplantation time, HT: harvest time, PM: poultry manure and CM: cow manure.

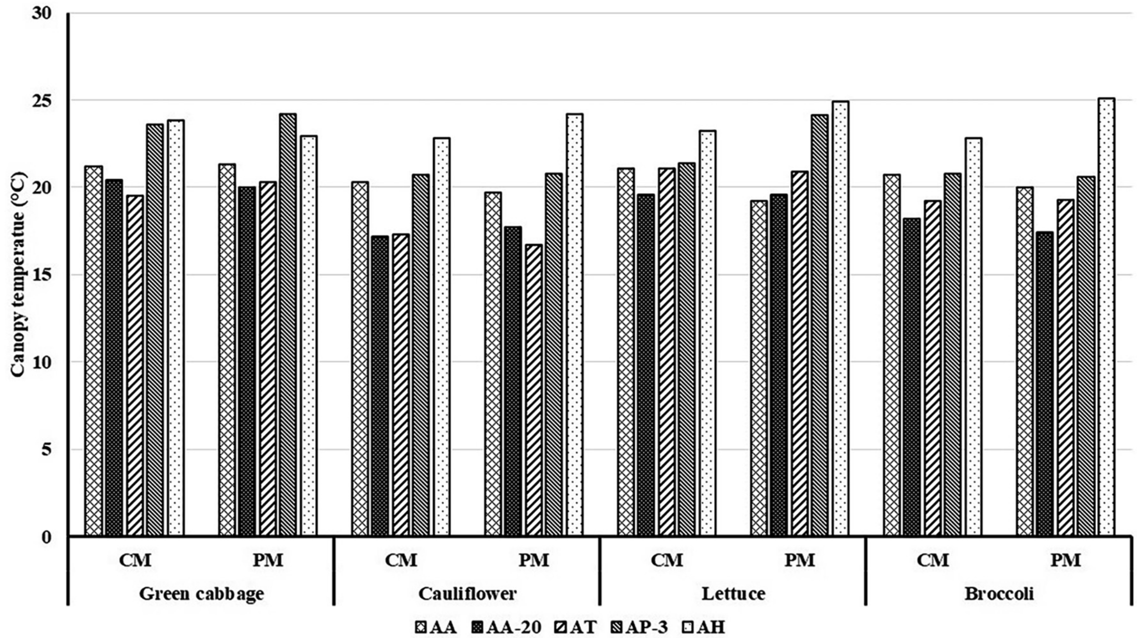

Fig. 3. Canopy temperature (°C) of the experimental plots at different crop stages. AA: after-manure application, AA-20: 20 days after-manure application, TT: transplantation time, TT-3: three weeks after transplantation time, HT: harvest time, PM: poultry manure and CM: cow manure.

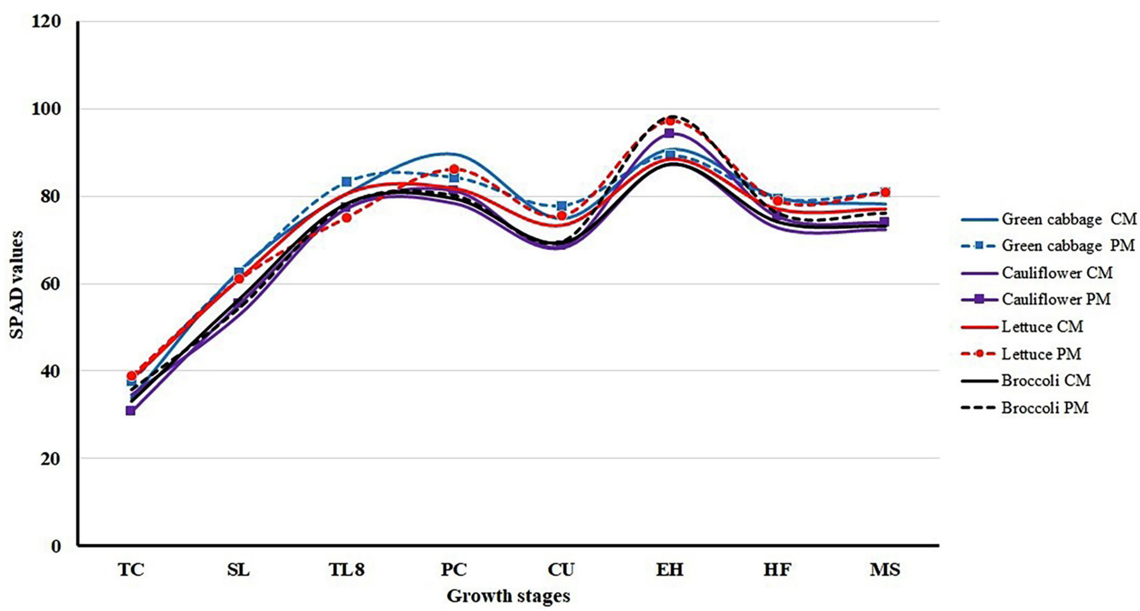

Fig. 4. Dynamics of Chlorophyll content (SPAD value) of the examined vegetable crops across their growth periods. TT: transplantation time, SL: seedling stage, TL8: plant with 6–8 leaves, PC: pre-cupping (i.e. plants with 13–19 leaves), CU: cupping (i.e. plants with 20–26 leaves), EH: early head formation stage, HF: head-fill stage, MS: maturity stage, PM: poultry manure and CM: cow manure.

(72.3) compared to that recorded in the cow manure plots (70.7). This may be resultant of nitrogen at smaller amounts the poultry manure (Patidar and Mali, 2002). These results proved the significance of poultry manure in enhancing the chlorophyll content compared to the cow manure.

3.4. Crop yield parameters

Results of crop biophysical parameters measured at the harvesting time of the investigated vegetables are presented in Table 4. The highest mean number of leaves per plant was recorded for broccoli (26.19) in both Poultry (23.2) and cow (20.7) manure plots. The lowest mean number of leaves, however, was recorded for lettuce in both Poultry (12.6) and cow (11.9) manure plots. It was found that the greatest cup diameter (28.2 cm) and the greatest curd diameter (26.4 cm) were recorded in poultry manure plots for Green Cabbage and Cauliflower, respectively. These results are similar to that of Ouda and Mahadeen (2008) who also reported maximum Cabbage head diameter (31.9 cm) under high fertilizer level. The increase in a cup (Cabbage and Lettuce) and curd (Cauliflower and Broccoli) diameters may be due to the fast release of nitrogen from poultry manure, which improved the available soil nutrient resulting in healthy plant vigor, and hence, in more number of leaves (Pitta et al., 2012). The results also revealed a similar

Table 4
Crop biophysical parameters at harvesting time.

Treatment/plot	crop	Yield parameters				
		Plant height (cm)	No. of leaves per plant	Length of the largest leaf (cm)	Width of the largest leaf (cm)	Head/curd diameter (cm)
Cow manure	Green cabbage	24.7	14.7	26.1	23.8	18.7
	Red cabbage	20.8	19.1	12.6	13.8	13.9
	Cauliflower	61.8	14.0	59.4	28.2	16.2
	Lettuce	24.2	11.9	14.2	12.8	10.8
	Broccoli	61.0	20.7	21.6	22.4	14.2
	Mean	**38.5**	**16.1**	**26.8**	**20.2**	**14.8**
Poultry manure	Green cabbage	28.0	19.2	25.2	10.5	20.1
	Cauliflower	76.2	18.2	64.2	28.8	18.0
	Lettuce	27.1	12.6	20.1	21.4	11.6
	Broccoli	54.5	23.2	23.2	20.8	16.8
	Mean	**46.4**	**18.3**	**33.2**	**20.4**	**16.6**

Table 5
Crop yield (fresh and dry weight) of the investigated vegetable crops.

Treatments/plots	crop	Fresh yield		Dry yield	
		Cup/curd weight (kg)	Yield (t ha^{-1})	Cup/curd weight (kg)	Yield (t ha^{-1})
Cow manure	Green cabbage (GC)	2.22	123.20	0.65	46.2
	Red cabbage (RC)	0.79	78.40	0.41	37.3
	Cauliflower (CF)	0.79	42.32	0.22	12.9
	Lettuce (LE)	0.78	48.72	0.16	11.8
	Broccoli (BR)	0.73	57.60	0.30	21.6
	Mean	**0.83**	**66.45**	**0.35**	**25.9**
Poultry manure	Green cabbage (GC)	2.45	142.40	0.75	53.4
	Cauliflower (CF)	0.86	57.28	0.30	21.5
	Lettuce (LE)	0.92	63.60	0.18	12.6
	Broccoli (BR)	0.81	64.96	0.34	24.4
	Mean	**0.93**	**74.56**	**0.39**	**28.1**

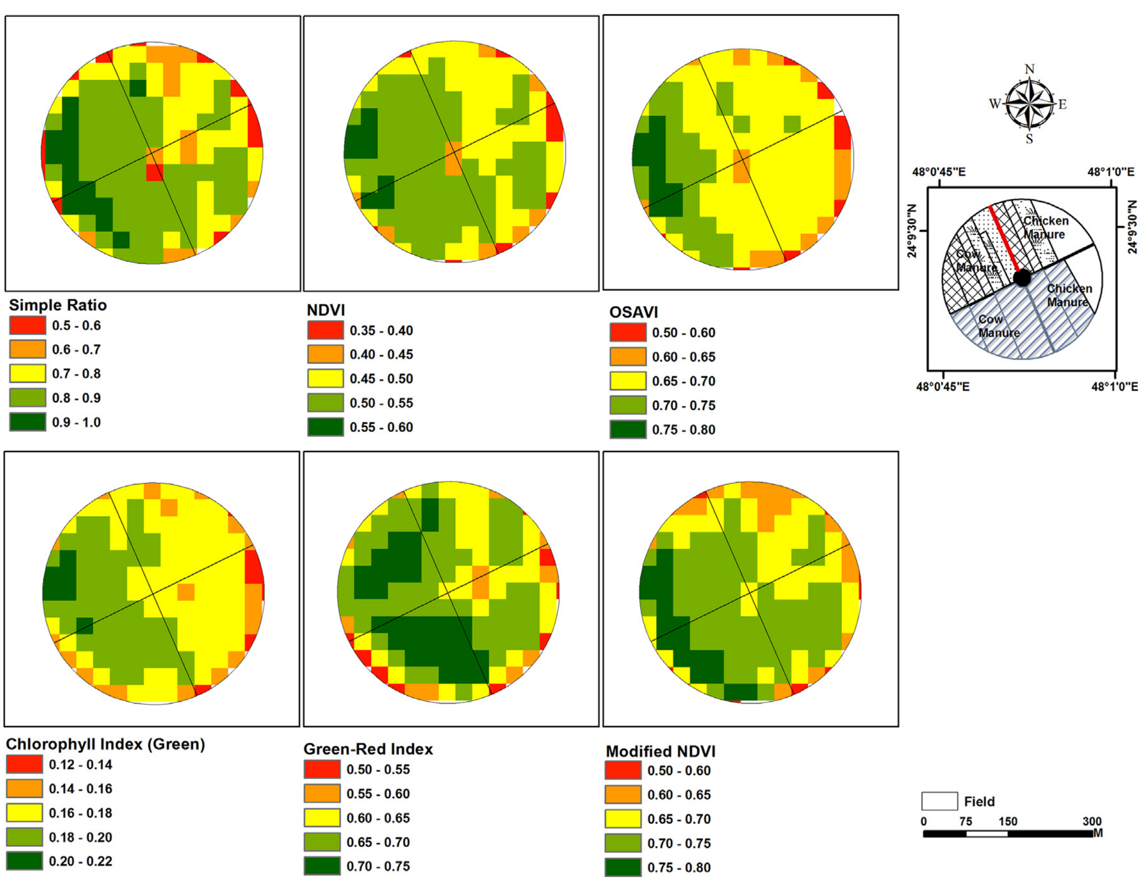

Fig. 5. Vegetation indices derived from Landsat-8 data.

response to the curd weight to the application of cow and Poultry manures.

3.5. Crop yield

The results of crop yields are presented in Table 5. The mean fresh yield of vegetable crops cultivated with poultry manure was found to be high (74.56 t ha^{-1}) compared to cow manure (66.45 t ha^{-1}) treated plots. Among the cultivated crops, the highest yield (dry weight) was recorded from the green cabbage (46.2 t ha^{-1} and 53.4 t ha^{-1} for cow and poultry manure, respectively). Whereas, the least yield was observed for lettuce (12.6 t ha^{-1} and 11.8 t ha^{-1} for cow and poultry manure, respectively). These results indicated that poultry manure plots produced higher yields compared to cow manure plots. These results are consistent with Islam et al. (2010), who observed more plant curd weight associated with plants received poultry manure. This can be attributed to the assistance of poultry manure in the enhancement of plant vital processes, and subsequently increases crop yields (Khalid et al., 2014).

3.6. Vegetation indices (VIs)

Selected VIs (SR, NDVI, OSAVI, Cl_{Green}, GRI, and mNDVI) were utilized to assess the plant vigor and health conditions of the investigated vegetables throughout the growth period for both Poultry and cow manure treated areas (Figs. 5 and 6). The mean cumulative values of the VIs the extracted from both Landsat-8 and

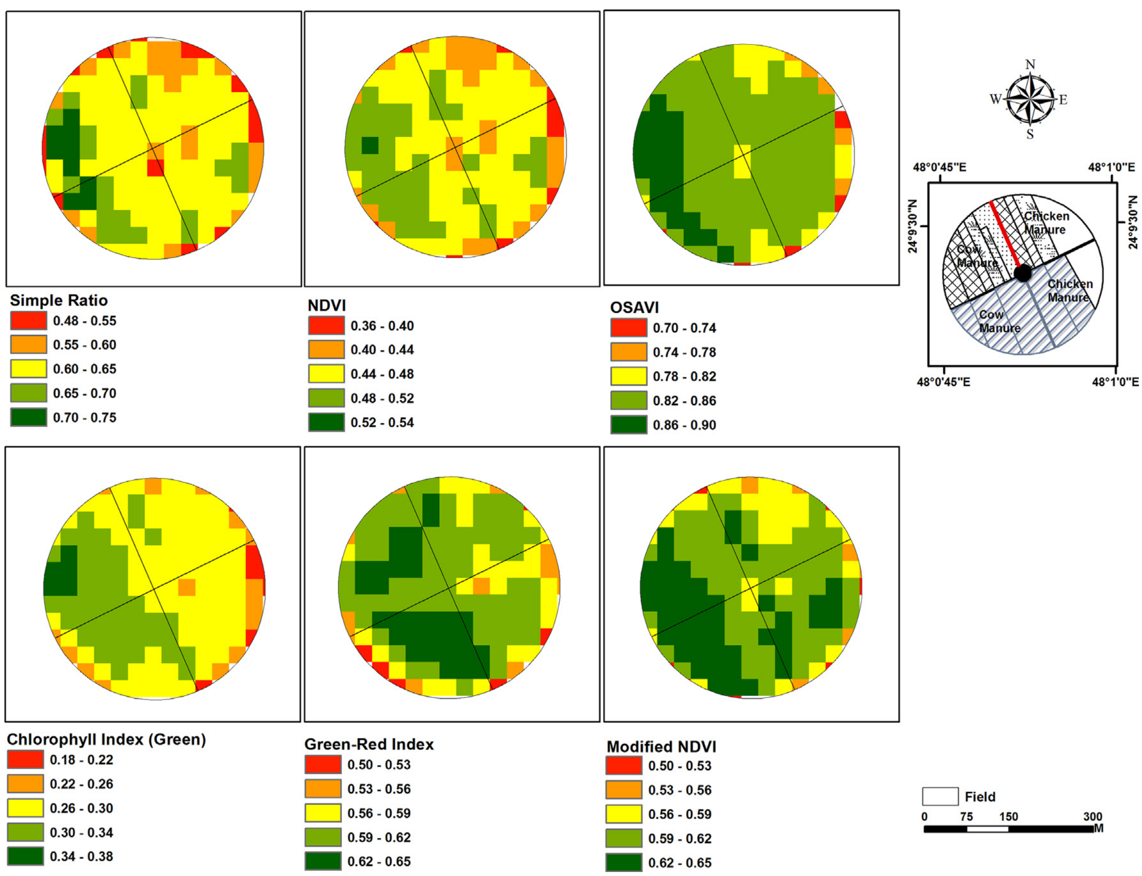

Fig. 6. Vegetation indices derived from Hyperion data.

Table 6
Linear regression (R^2) values between crop yield and the studied VIs of the tested crops (GC = green cabbage; RC = red cabbage; CF = cauliflower; LE = lettuce; BR = broccoli; * is highly significant at P>=0.01; * is significant at P>=0.05; NS is non significant).

Sensor	VIs	Cow manure					Poultry manure					
		GC	RC	CF	LE	All	BR	GC	CF	LE	BR	All
Landsat-8	SR	0.83**	0.54^{NS}	0.78**	0.78*	**0.67***	0.82*	0.78*	0.84*	0.79**	0.84*	**0.70***
	NDVI	0.59*	0.53*	0.50*	0.61**	**0.56***	0.50*	0.55*	0.49*	0.41*	0.51*	**0.49***
	OSAVI	0.73**	0.76*	0.63**	0.72**	**0.68***	0.74*	0.68**	0.76*	0.72**	0.67*	**0.71***
	Cl_{Green}	0.18^{NS}	0.22^{NS}	0.25*	0.17^{NS}	**0.21**^{NS}	0.25^{NS}	0.22*	0.26^{NS}	0.32*	0.24^{NS}	**0.26**^{NS}
	GRI	0.65*	0.72*	0.69*	0.62*	**0.67***	0.62*	0.69*	0.61*	0.65*	0.63*	**0.64***
	mNDVI	0.63*	0.68*	0.68*	0.69*	**0.67***	0.70*	0.69*	0.70*	0.64*	0.61*	**0.67***
Hyperion	SR	0.73**	0.48*	0.68**	0.69**	**0.65****	0.73**	0.69*	0.74**	0.70**	0.74*	**0.72****
	NDVI	0.52*	0.47*	0.44*	0.54*	**0.49***	0.44*	0.48*	0.43*	0.36*	0.45*	**0.43***
	OSAVI	0.69**	0.72**	0.73**	0.81*	**0.62****	0.76**	0.77*	0.75**	0.82**	0.76*	**0.77****
	Cl_{Green}	0.21^{NS}	0.25*	0.28*	0.19^{NS}	**0.23***	0.28*	0.24^{NS}	0.30*	0.37*	0.28*	**0.29***
	GRI	0.57*	0.63*	0.61*	0.55*	**0.59***	0.54*	0.61*	0.54*	0.57*	0.56*	**0.56***
	mNDVI	0.55*	0.60*	0.59*	0.61*	**0.59***	0.62*	0.61*	0.62*	0.56*	0.53*	**0.59***

Hyperion data was correlated (R^2) against the yield (Table 6). The R^2 of VIs of the tested crops extracted from Hyperion images was relatively higher than values extracted from Landsat-8 images. There is a significant relationship between crop yield and obtained VIs. In the case of OSAVI and SR of both the Landsat-8 and Hyperion found to be highly significant correlation when compared to other studied VIs. The results of the extracted VIs indicated that the performance of poultry manure was better on most of the investigated vegetables compared to cow manure. For the cauliflower performed better with poultry manure, as indicated with the SR derived from Landsat-8 (R^2 of 0.84), compared to (R^2 of 0.84) with cow manure. Moreover, all the tested crops cultivated in poultry manure plots performed better compared to that in cow manure plots. Overall, the investigation of crop yield was significant with poultry manure than cow manure using the OSAVI of Landsat-8 ($R^2 = 0.68$; $P = 0.001$) and Hyperion data ($R^2 = 0.77$; $P = 0.001$).

4. Conclusion

A study was conducted to investigate the impact of poultry and cow manures on soil and selected vegetable crops. This study also focused on the assessment of crop performance using Landsat-8 and Hyperion images. The studied crops included cabbage, cauliflower and broccoli, and lettuce. The investigations conclude as follows:

- The performance of poultry manure was better compared to cow manure as indicated the improvement in the soil physiochemical properties (EC, pH, N, P, and K). The performance of poultry manure was better compared to cow manure as indicated by the improvement in the soil physiochemical characteristics (EC, N, P, and K).
- The dynamics of the chlorophyll content across the crop growth period revealed that all the tested crops responded significantly with the poultry manure treatments. Among the tested crops, the chlorophyll content, curd or head sizes and crop yields were quite better in poultry manure applied plots.
- The investigation of crop performance through OSAVI and mNDVI was significant for both the poultry and cow manure applied crops. Overall, the investigation of crop yield was significant with poultry manure than cow manure using the OSAVI of Landsat-8 ($R^2 = 0.68$; $P = 0.001$) and Hyperion data ($R^2 = 0.77$; $P = 0.001$).

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