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The production capacity of intercropped model of maize (Zea mays) with black locust (*Robinia pseudoacacia*)

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Abstract

A study was conducted to investigate the intercropping of legumes with cereals in different space as an approach to improve the soil nutrient content, the forage quality and the yield of cereals. Black locust was cultivated alone and intercropped with maize as follows: 2 rows maize to 2 rows Black locust (2M2R), 2 rows maize to 4 rows Black locust (2M4R), 2 rows maize to 6 rows Black locust (2M6R); 4 rows maize to 2 rows Black locust (4M2R), 4 rows maize to 4 rows Black locust (4M4R), 4 rows maize to 6 rows Black locust (4M6R) and 6 rows maize to 2 rows Black locust (6M2R), 6 rows maize to 4 rows Black locust (6M4R), 6 rows maize to 6 rows Black locust (6M6R).The experiment was laid out in randomized complete block design with three treatments and three replications. The results indicated significant increase of soil available phosphorus and soil organic matter in 2017 at harvest, while soil total nitrogen and soil available potassium decreased. However, total nitrogen and organic matter were higher in black locust leaves, black locust stems and maize stem. Low maize yield were founded in the major part of treatments while the highest biomass was founded in plants stem diameter. An increase is observed in maize and black locust height. Significant differences were founded in the character of black locust stem basal diameter. Also, significant differences in Chlorophyll concentration and WUE were observed.

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Introduction

Livestock and agriculture have recently being used to improve forage yield. This objective is achieved from several angles, including the practice of intercropping cereals with legumes. Intercropping is an advanced agricultural technique (Thayamini and Brintha, 2010) of growing two or more plants at the same time, during the same season and on the same area (Geiler *et al.*, 1991). The main purpose of intercropping is to increase productivity and the judicious use of land and inputs. The combination of legumes and maize is considered the best alternative for nitrogen economy and increased maize yield, in addition to increased productivity per unit of time and space and a higher net yield of the intercropping system on monoculture (Thayamini & Brintha, 2010). Ijoyah and Fanen (2012) reported that the success of intercropping lies in the choice of crop mix. In advanced and emerging countries, the practice of intercropping is of paramount importance for the production of subsistence foods (Adeoye *et al.*, 2005). Indeed, Bhagad *et al.* (2006) discovered that legumes can shift fixed nitrogen, an imperative resource for cereals, to cereals interspersed through their period of joint growth. Several studies on cereals-legumes intercropping are proven and reported to b effective (Hugar and Palled, 2008; Ijoyah, 2012).

The black locust (*Robinia pseudoacacia* L.), a rapidly growing woody legume (Leguminosae) was introduced in China from United States around 1887, and is noted for its strong capacity to increase and improve soil properties (Rice *et al.*, 2004; Tateno *et al.*, 2007; Xue *et al.*, 2007). The black locust also shows resistance to drought stress (Yuksek, 2012) and is one of the most widely distributed trees in the world (Garlock *et al.*, 2012). It has been extensively planted to control soil erosion in the Loess Plateau in western China for three decades (Jin *et al.*, 2011) and considerable efforts have been made to improve the growth rate and survival of black locust in arid regions. However, several studies reported the effects of black locust on soil properties with main focus on soil water conditions (He *et al.*, 2003; Wang *et al.*, 2004; 2008; Chen *et al.*, 2008b). Moreover, few studies have examined the impact of black locust on soil chemical properties and fertility, especially soil depths, and its production capacity in the intercalary model with cereals, particularly with maize. This has been a concern since changes in soil properties determine the sustainable use of land resources and also the increase in quality of fodder (Hamdollah, 2012), decreased condition for protein supplement, plant height, leaf yield, stem yield, whole proteins in plants and morpho-physiological parameters (Ali and Mohammad, 2012).

The intercropping of black locust with maize could improve the chemical properties of soils and plants and influence plant growth parameters. Therefore, to test the levels of nutrients in soils and plants, we investigated the ability of black locust intercropped with maize; and assessed the effects of the intercropping on plant growth parameters, leaf water status, leaf chlorophyll concentration and leaf photosynthesis.

Materials and methods

Experimental materials and description of study area

The investigation was conducted during the spring seasons of 2016 and 2017 at the experimental station of crop specimen farm of Northwest A & F University, Shaanxi, China (N $34^{0}20'$, E $108^{0}24'$). The area has an elevation of 466.7 m, with a temperate and semi-arid climate. Mean annual maximum and minimum air temperature at the site were 42^{0}C and -19^{0}C, respectively. Mean annual precipitation is 640 mm during the crop production. The experimental materials included robinia and maize seeds, with treatments consisted of sole robinia, and robinia and maize interaction, sown in 4 m x 25 m plot size with 0.8 m spacing between rows, 30 cm between robinia and maize plants and 20 cm between robinia plants. Black locust was cultivated alone and intercropped with maize as follows: 2 rows maize to 2 rows Black locust (2M2R), 2 rows maize to 4 rows Black locust (2M4R), 2 rows maize to 6 rows Black locust (2M6R); 4 rows maize to 2 rows Black locust (4M2R), 4 rows maize to 4 rows Black locust

(4M4R), 4 rows maize to 6 rows Black locust (4M6R) and 6 rows maize to 2 rows Black locust (6M2R), 6 rows maize to 4 rows Black locust (6M4R), 6 rows maize to 6 rows Black locust (6M6R). Fertilizers were applied to each plot before sowing at the rate of 70 kg of N ha^{-1}, 70 kg P_2O_5 ha^{-1}, and 70 kg of K_2O ha^{-1}. The soil characteristics of the study area are presented in Table 1.

Representative soil samples were collected before the experiment started, from plough layer (0-100 cm) of scattered places of the experimental area using an auger. An auger was used for soil sampling. Samples were air-dried and analyzed for total N, P and K. After harvest, soil samples were again collected for nutrients (total N, P and K) analysis. Dried samples were ground and passed through a 1-mm mesh screen and 0.25- mm-nylon screens. The soil passing through a 1- mm-screen was used for pH, while that passing through a 0.25-mm screen was used for total N and available P and K analysis. Plant samples were also collected after harvest, separated into leaves, stems and roots, air-dried and ground. A representative sample of 200g was used for laboratory chemical analysis.

Trait measurement and determination of nutrient composition

Plant height and stem diameter

Plant height (cm) and stem diameter (cm) for all of the treatments were measured using a precision straight edge (sword fish, China) and vernier caliper (ECV 150C, China), respectively (Zhang and others 2010), and then averaged.

At harvest 20 plant leaves, stems, and roots was washed separately with tap water, and then air dried determine dry biomass

Leaf water status and chlorophyll content

Leaf relative water content (RWC) was measured as described by Gao (2000). Fresh leave samples were cleaned with deionized water to remove any surface contamination and 100 mg fresh sample was homogenized in 25 mL acetone (80%) in dark at room temperature for 10 h.

A UV/V spectrophotometer was used to measure chlorophyll concentration at 646 and 663 nm, according to method described by Harborne (1984).

Photosynthetic parameters and water use efficiency (WUE)

Net photosynthetic rate, transpiration rate, stomatal conductance and intercellular CO_2 concentration were measured using a portable photosynthesis system LI-6400 (LI-COR. USA) from 9:00 am to 11:00 am on the leaves (Sheng *et al.*, 2008). Conditions in the leaf chamber were as reference CO_2 concentration = 400 μmol mol^{-1}, PPFD = 1800 μmol m^{-2} s^{-1}, relative humidity 50-70%, and block temperature = 20 °C. The ratio of net photosynthetic per transpiration was used to measure water use efficient (WUE).

Laboratory analyses

Soil and plant chemical analyses, Soil pH, were performed on soil samples using the standard soil test procedures from the Chinese Ecosystem Research Network (Editorial Committee, 1996) and the Soil Science Society of China (1999). Soil pH was determined with an electrode pH-meter by using an automatic acid-base titrator (Methrom 702) in 1:5 water suspensions. Soil and plants total nitrogen were measured using the Kjeldahl method, involving wet digestion of a soil sample to convert organic nitrogen to NH+4-N and then determining the nitrogen content. Soil and plants available phosphorus were determined calorimetrically after wet digestion with sulfuric acid (H_2SO_4) and perchloric acid ($HClO_4$). Soil and plants available potassium were measured in 1 mol-L1 NH_4OAc extracts by flame photometry. Dry leaves were fully milled and homogenized, and one aliquot of 500 mg was digested using hydrogen peroxide and sulfuric acid. The Kjeldahl method (Jones, 1991) was then used to determine the total nitrogen content.

Statistical analysis

The effects of maize with black locus intercropping on soil were studied at different soil depths in ten treatments. Data were analyzed by one-way analysis of variance (ANOVA) using SPSS statistics 16.0 (IBM SPSS Statistics, USA).

The t-test was used to test the differences in soil properties between treatments. Correlation analysis was performed to show the relationships among different properties.

Results

Soil chemical properties

Analysis of variance revealed significant differences among all the treatments and depths for total nitrogen (TN), available phosphorus (AP), available potassium (AK) and organic matter (OM) at both sowing and harvest in 2016 and 2017 (Table 2). In 2016, Compared to OM content, TN, AP and AK displayed a decreasing trend from the upper soil layer to the lower soil layer at sowing, while exhibiting an increasing trend at harvest. In 2017, AP content displayed a decreasing trend from the upper soil layer to the lower soil layer, compared to TN, AK and OM at sowing, while showing an increasing trend at harvest. In 2016, intercropped maize x black locust treatments showed higher TN, AP, AK and OM than sole black locust treatment, indicating a positive effect of the intercropping. Meanwhile, in 2017, sole black locust treatment intercropped showed higher AP, AK and OM than maize x black locust treatments, but lower TN, indicating a negative effect of the long-term intercropping.

Table 1. Soil characteristics of the study area.

Depth (cm)	Sand (%)	Clay (%)	Silt (%)	Lime (%)	Salt (%)	OM (%)	N (%)	P (ppm)	K (ppm)	pH
20-40	36.7	30.6	30.4	18.5	0.07	1.5	0.2	0.3	400	8.3

OM - organic matter; N – nitrogen; P (ppm) - phosphorus (parts per million); K (ppm) - Potassium (parts per million).

Total nitrogen

In 2016, treatment SR showed the highest rate of TN (3.73 g kg^{-1}) at 10-20 soil depth, while the lowest rates were displayed by treatments M6R2 (0.53g kg^{-1}) at 60-80 and 80-100 soils depths, and treatment M6R4 (0.55g kg^{-1}) at 80-100 soil depth at sowing. At harvest, treatment M6R4 has the highest rate of TN (3.56 g kg^{-1}) at 60-80 soil depth. Meanwhile, in 2017 differences were founded at sowing, in treatment M4R4, at depth 80-100, in depth 40-60 and depth 80-100 of treatment M4R6, and in 40-60 and depth 80-100 of treatment M6R2 (Table 2).

At sowing, treatment M2R2 showed the highest rate of TN (40.03 g kg^{-1}) at 00-10 soil depth, while the lowest rates were displayed by treatment M4R6 (1.77g kg^{-1}) at 40-60 soils depths, and (1.82g kg^{-1}) at 80-100 soil depth. At harvest, treatment M2R2 has the highest rate of TN (3.51g kg^{-1}) at 00-10 soil depth.

Available phosphorus

In 2016 at sowing, AP content was very low for all the treatments, except treatment SR (mono cropped robinia) which displayed high values of AP at all the recorded soil depths (Table 2).

Significant increase in available phosphorus was observed at harvest for treatments M2R2, M2R4, M2R6, M4R2, M4R4, M4R6, M6R2, M6R4 and M6R6, with the highest rate recorded for treatment M2R4 (21.30g kg^{-1}) at 80-100 soil depth. In 2017, at sowing significant increase in available phosphorus was observed for all the treatments. But, only treatment M2R2 at depth 20-40 shows a difference. Meanwhile, at harvest no significance difference were founded between treatments, but treatment SR has the highest rate of available phosphorus (88.5 g kg^{-1}) at 60-80 soil depth (Table 2).

Available potassium

Based on the N, P, K concentrations, in 2016 storage of soil potassium in each soil layer was estimated in the different treatments at sowing and harvest. At sowing, soil potassium was higher in M2R6, with the highest value recorded at 40-60 soil depth (19.68 g kg^{-1}) (Table 2).

Table 2. Soil chemical properties under intercropped maize with black locust 2016.

Sowing

Nutrient	Layer	M2R2	M2R4	M2R6	M4R2	M4R4	M4R6	M6R2	M6R4	M6R6	SR
Total N ($g\ kg^{-1}$)	0-10	3.49±0.35	2.71±0.18	3.33±0.38	2.21±0.20	2.40±0.72	2.45±0.28	2.71±0.71	3.35±0.08	2.83±0.33	2.86±0.09
	10-20	2.10±0.03	2.70 ±0.84	3.00±0.04	2.05±0.24	2.10±0.16	2.06±0.46	2.01±0.37	2.81±0.23	2.83±0.43	3.73±0.72
	20-40	2.00±0.23	2.31±0.29	2.21±0.58	1.83±0.04	2.05±0.03	1.88±0.04	1.45±0.11	1.48±0.03	2.83±0.18	2.84±0.48
	40-60	1.93±0.32	1.82±0.74	1.86±0.06	1.70±0.09	1.86±0.59	1.50±0.22	1.20±0.71	0.83±0.81	2.05±0.38	2.38±0.20
	60-80	1.77±0.64	1.63±0.47	1.61±0.26	1.08±0.38	1.23±0.14	1.23±0.50	0.53±0.04	0.63±0.24	1.85±0.38	3.33±0.87
	80-100	1.51 0.50	1.01±0.62	1.40±0.23	1.06±0.40	1.03±0 .55	1.08±0.19	0.53±0.04	0.55±1.09	1.24±0.13	2.61±0.34
Available P ($g\ kg^{-1}$)	0-10	0.24±0.01	0.23±0.02	0.28±0.02	0.27±0.02	0.25±0.02	0.15±0.03	0.18±0.05	0.25±0.01	0.28±0.02	8.42±2.33
	10-20	0.20±0.01	0.20±0.01	0.25±0.02	0.24±0.04	0.22±0.02	0.14±0.04	0.14±0.06	0.19±0.03	0.22±0.01	9.13±0.66
	20-40	0.20±0.01	0.19±0.01	0.21±0.01	0.21±0.02	0.20±0.03	0.11±0.02	0.13±0.01	0.18±0.01	0.20±0.00	11.24±2.83
	40-60	0.19±0.01	0.18±0.01	0.20±0.01	0.20±0.02	0.18±0.01	0.10±0.00	0.12±0.01	0.18±0.02	0.19±0.00	10.68±1.74
	60-80	0.19±0.01	0.18±0.01	0.20±0.00	0.19±0.00	0.18±0.01	0.10±0.01	0.10±0.03	0.17±0.01	0.18±0.01	7.91±2.10
	80-100	0.18±0.01	0.17±0.01	0.18±0.01	0.18 ±0.00	0.17±0.00	0.10±0.02	0.08±0.02	0.17±0.00	0.18±0.03	8.35±1.42
Available K ($g\ kg^{-1}$)	0 - 10	8.09±0.99	8.57±0.82	12.92±0.76	9.32±0.62	9.78±0.24	9.02±1.17	9.63±0.85	13.6±0.69	13.7±1.71	8.98±1.49
	10 - 20	8.04±0.63	8.07±0.51	17.52±2.29	8.66±1.43	9.78±1.12	8.88±0.68	9.00±0.39	10.23±0.16	13.14±0.87	7.82±0.10
	20-40	7.86±0.25	8.90±0.96	13.83±1.82	8.30±0.72	9.78±1.24	8.43±1.61	8.18±0.54	8.54±1.19	12.31±0.47	6.76±1.59
	40 - 60	7.84±0.32	8.10±0.45	19.68±0.82	8.19 ± 0.60	7.96±1.12	8.28±1.18	8.09±0.74	8.47±2.47	9.37±0.90	5.87±1.38
	60 - 80	7.44±0.53	9.05±1.03	16.69±1.49	7.94±1.19	7.96±0.24	8.00±0.90	7.60±0.73	7.47±0.49	8.39±1.08	9.49±0.52
	80-100	7.78±0.25	8.09±0.43	15.27±0.96	7.44±0.57	7.96±1.12	7.90±0.55	7.43±0.99	6.84±0.66	8.35±3.048	7.64±1.83
Organic matter ($g\ kg^{-1}$)	0-10	16.90±0.35	17.28±0.23	16.82±0.17	14.70±0.31	16.87±0.13	12.62±0.47	12.17±0.84	17.51±1.50	17.07±0.03	11.94±1.49
	10-20	13.81±0.43	13.21±0.11	12.3±0.48	14.05±1.46	13.59±0.65	14.07±1.10	14.02±0.92	17.01±1.44	16.89±1.49	57.94±34.24
	20-40	13.43±0.59	13.81±0.13	14.46±1.41	17.01±0.17	13.48±0.82	14.91±0.53	15.68±0.56	16.00±0.91	16.33±0.36	11.52±2.53
	40-60	16.28±0.36	16.55±0.07	16.32±0.72	16.57±1.01	14.20±1.52	14.64±01.88	16.50±0.34	15.03±1.32	15.85±0.63	12.49±0.94
	60-80	16.21±0.57	17.07±0.57	17.10±0.11	15.14±1.29	16.85±0.08	16.71±0.20	15.68±0.23	14.80±0.28	14.78±0.31	10.34±1.80
	80-100	17±0.27	17.33 ±0.13	15.46±1.52	14.61±0.81	16.86±0.09	16.08±0.09	15.52±1.48	14.57±1.61	13.36±0.73	13.89±1.44

Harvest.

Nutrient	Layer	M2R2	M2R4	M2R6	M4R2	M4R4	M4R6	M6R2	M6R4	M6R6	SR
Total N (g kg-1)	0-10	1.43±0.44	2.04±0.74	1.71±0.81	1.68±0.79	1.12±0.18	2.11±0.41	1.56±0.30	2.15±0.67	2.30±0.20	1.85±0.08
	10-20	1.11±0.13	1.86±0.63	1.36±0.57	1.21±0.13	1.86±0.61	1.68±0.43	1.30±0.21	2.05±0.81	1.61±0.45	2.73±0.62
	20-40	1.66±0.31	2.11±0.89	1.25±0.43	1.69±0.92	2.25±0.56	1.73±0.53	1.61±0.09	1.51±0.22	1.31±0.34	1.83±0.38
	40-60	2.00±0.31	2.26±0.63	1.73±0.59	1.10±0.61	2.78±0.49	2.31±0.85	2.75±0.34	2.68±0.26	2.48±0.30	1.20±0.10
	60-80	1.81±0.22	2.46±0.45	1.95±0.75	1.08±0.56	3.33±0.17	2.40±0.63	2.18±0.20	3.56±0.94	2.58±0.41	2.33±0.77
	80-100	1.76±0.38	1.53±0.59	1.98±0.56	1.21±0.34	2.13±0.68	2.51±0.46	2.16±0.60	3.16±0.18	1.83±0.30	1.51±0.24
Available P (g kg-1)	0-10	12.13±1.62	17.24±0.73	11.82±0.21	10.76±0.38	10.02±1.23	9.35±0.55	6.92±1.28	10.00±1.03	8.63±2.53	7.51±1.23
	10-20	13.74±1.25	18.03±0.92	12.85±0.22	13.44±1.61	7.76±0.38	9.52±1.49	5.16±0.89	6.62±0.44	9.01±0.46	9.50±0.56
	20-40	14.49±0.19	17.29±0.66	13.04±0.61	12.32±0.99	13.66±2.16	8.32±0.53	12.67±0.42	8.35±0.59	12.16±1.30	10.00±2.92
	40-60	12.55±0.69	16.70±0.38	7.51±1.70	10.33±1.66	8.56±0.72	7.08±0.54	7.96±0.99	10.08±2.26	13.44±1.10	6.06±0.83
	60-80	15.10±0.24	16.79±0.55	12.47±0.42	8.94±0.34	9.29±1.27	7.90±0.80	6.63±1.25	9.82±2.27	6.81±1.47	6.55±2.00
	80-100	12.56±0.33	21.30±1.77	14.23±1.14	10.63±0.64	9.11±0.49	8.33±0.66	7.80±0.82	9.07±1.82	10.68±1.59	6.24±1.32
Available K ($g\ kg^{-1}$)	0-10	7.98±0.27	7.34±1.01	7.56±1.29	8.78±0.36	6.26±0.23	6.61±0.40	11.14±0.97	7.58±0.53	7.34±0.55	7.99±0.37
	10-20	8.00±0.68	7.81±0.84	7.75±0.84	6.67±0.40	7.83±0.37	8.20±0.79	7.78±0.31	7.35±0.54	7.38±0.27	6.71±0.89
	20-40	7.00±0.23	7.16±0.79	6.60±0.36	6.55±0.76	7.10±0.76	5.77±0.54	7.58±0.82	5.72±0.19	7.63±0.85	6.65±0.47
	40-60	6.58±0.22	6.75±0.43	5.79±1.02	7.01±0.98	7.52±0.71	6.41±0.63	7.61±0.75	6.55±0.52	6.83±0.99	4.81±0.28
	60-80	6.36±0.02	8.05±0.85	6.48±0.27	6.48±0.55	7.05±0.54	6.46±0.60	7.19±1.13	8.11±1.08	6.50±0.42	6.28±0.72

	80-100	6.40±0.22	7.51±0.98	7.28±0.75	5.45±0.82	6.84±0.26	7.11±0.76	7.20±1.07	7.24±0.69	7.20±0.68	6.51±0.91
Organic matter (g kg-1)	0-10	21.80±2.33	21.34±3.05	14.70±1.17	12.73±1.37	11.82±1.85	13.09±1.37	10.80±1.83	13.13±1.77	12.71±0.64	12.88±1.39
	10-20	22.75±4.04	24.45±2.89	14.44±2.42	14.25±4.02	9.82±2.15	10.43±1.23	12.44±0.76	12.12±2.34	11.94±1.56	45.82±33.23
	20-40	24.51±1.77	18.94±3.44	14.9±0.90	13.10±1.34	11.99±1.61	10.16±1.56	10.73±1.07	12.86±1.89	13.22±1.04	12.40±1.42
	40-60	25.99±0.30	23.31±3.00	16.4±1.34	17.26±4.85	11.04±1.51	9.44±0.61	11.76±1.57	10.20±0.71	11.94±0.96	12.39±0.93
	60-80	23.94±1.67	15.61±2.60	14.64±1.13	12.55±0.58	8.846±0.44	9.87±2.04	12.87±1.05	12.58±1.96	12.17±0.41	11.23±0.78
	80-100	24.84±1.95	19.94±3.76	15.11±0.98	13.48±1.55	8.70±0.68	10.44±1.14	12.17±0.66	12.12±2.32	12.50±1.23	12.69±0.43

N, P and K refer to nitrogen, Phosphorus and potassium, respectively 2017.

Sowing

Nutrient	Layer	M2R2	M2R4	M2R6	M4R2	M4R4	M4R6	M6R2	M6R4	M6R6	SR
Total N (g kg-1)	0-10	40.03±6.23a	2.37± 0.16	3.00±2.29	2.46±0.08	2.19±0.083	2.49±0.141	2.35±0.13	2.76±0.08	2.71±0.141	2.73±0.258
	10-20	2.72±6.23	1.99± 0.16	2.62±2.29	2.13±0.08	2.04±0.083	1.92±0.141	2.26±0.13	2.32±0.08	2.19±0.141	2.42±0.258
	20-40	2.82±0.27	2.95± 0.16	8.26±2.29a	2.59±0.08	2.39±0.083	2.35±0.141	2.71±0.13	3.03±0.08	2.93±0.141	2.23±0.258
	40-60	2.47±0.27	2.25± 0.16	2.32±2.29	2.34±0.08	2.11±0.083	1.77±0.141ab	1.97±0.13b	2.24±0.08	2.12±0.141	2.78±0.258
	60-80	2.53±0.27	2.97± 0.16	2.94±2.29	2.44±0.08	2.49±0.083	2.52±0.141	2.65±0.13	2.96±0.08	2.66±0.141	2.52±0.258
	80-100	2.43±0.27	2.27±0.16	2.49±2.29	2.06±0.08	1.96±0.083b	1.82±0.141b	1.97±0.13b	2.05±0.08	2.16±0.141	2.37±0.258
Available P (g kg-1)	0-10	64.76±2.24	56.56±0.94	58.00±2.87	46.56±1.96	56.43±2.81	56.43±1.07	49.50±3.05	47.30±1.57	62.56±3.07	53.36±1.59
	10-20	65.13±2.24	53.53±0.94	57.43±2.87	49.96±1.96	60.43±2.81	60.43±1.07	65.93±3.05	57.73±1.57	57.73±3.07	54.73±1.59
	20-40	76.83±2.24ab	50.36±0.94	47.10±2.87	55.70±1.96	53.13±2.81	53.13±1.07	62.70±3.05	51.90±1.57	56.36±3.07	58.73±1.59
	40-60	62.80±2.24	55.30±0.94	41.33±2.87	59.06±1.96	44.43±2.81	44.43±1.07	54.46±3.05	47.23±1.57	58.93±3.07	51.03±1.59
	60-80	68.80±2.24	51.36±0.94	57.16±2.87	55.03±1.96	45.06±2.81	45.06±1.07	64.63±3.05	52.00±1.57	40.76±3.07	61.83±1.59
	80-100	62.00±2.24b	53.36±0.94	56.80±2.87	57.83±1.96	44.93±2.81	44.93±1.07	49.83±3.05	51.16±1.57	55.26±3.07	57.40±1.59
Available K (g kg-1)	0-10	77.24±6.11	67.82±7.78	77.54±2.61	69.97±4.33	69.37±1.21	56.57±2.44	54.85±3.38	66.88±11.25	57.28±3.37	55.04±2.88
	10-20	65.21±6.11	62.04±7.78	77.87±2.61	69.92±4.33	74.86±1.21	56.88±2.44	73.79±3.38	79.50±11.25	78.87±3.37	63.75±2.88
	20-40	67.63±6.11	55.72±7.78	85.35±2.61	79.05±4.33	73.14±1.21	57.35±2.44	72.95±3.38	8.93±11.25	68.74±3.37	60.71±2.88
	40-60	60.07±6.11	32.91±7.78	69.02±2.61	65.85±4.33	70.49±1.21	59.39±2.44	71.81±3.38	83.89±11.25	79.26±3.37	76.77±2.88
	60-80	90.59±6.11	91.91±7.78	85.03±2.61	94.67±4.33	71.65±1.21	70.53±2.44	77.56±3.38	64.03±11.25	71.89±3.37	69.37±2.88
	80-100	46.62±6.11	64.75±7.78	73.46±2.61	69.89±4.33	66.37±1.21	67.05±2.44	76.26±3.38	75.21±11.25	87.29±3.37	80.15±2.88
Organic matter (g kg-1)	0-10	12.98±0.67	7.68±0.67	9.59±0.67	4.97±0.67	8.32±.670	11.19±0.67	8.65±0.67	8.86 ±0.67	9.74±0.67	9.90±0.67
	10-20	8.19±0.53	7.45±0.53	7.84±0.53	9.20±0.53	11.19±0.53	10.63±0.53	10.29±0.53	11.23±0.53	11.09±0.53	12.52±0.53
	20-40	6.40±0.60	4.81±0.60	8.26±0.60	7.84±0.60	10.02±0.60	10.27±0.60	9.21±0.60	8.85±0.60	10.73±0.60	10.45±0.60
	40-60	8.28±0.56	7.44±0.56	7.83±0.56	10.60±0.56	10.06±0.56	10.59±0.56	9.73±0.56	10.87±0.56	12.78±0.56	12.22±0.56
	60-80	5.61±0.77	5.15±0.77	7.77±0.77	7.95±0.77	11.65±0.77	8.90±0.77	8.65±0.77	10.28±0.77	10.89±0.77	12.61±0.77
	80-100	7.08±0.67	7.10±0.67	7.88±0.67	9.07±0.67	11.21±0.67	9.80±0.67	12.32±0.67	11.36±0.67	11.31±0.67	12.97±0.67

TN, AP, AK and OM refer to total N, available P, available K and organic matter, respectively.

Harvest

Nutrient	Layer	M2R2	M2R4	M2R6	M4R2	M4R4	M4R6	M6R2	M6R4	M6R6	SR
Total N (g kg-1)	0-10	3.51±0.29	2.47 ±0.16	2.82±0.20	2.42±0.13	2.81±0.19	2.71±0.18	2.56 ±0.15	2.55±0.17	3.05±0.26	2.31±0.61
	10 - 20	2.71±0.29	1.69±0.16	1.74±0.20	1.89±0.13	2.11±0.19	1.91±0.18	1.77±0.15	2.01±0.17	1.95±0.26	1.75±0.61
	20-40	1.69±0.29	1.68±0.16	1.51±0.20	1.77±0.13	1.65±0.19	1.77±0.18	1.69±0.15	1.86±0.17	1.64 ±0.26	1.54±0.61
	40-60	1.87±0.29	1.59±0.16	1.76±0.20	1.58±0.13	1.99±0.19	1.53±0.18	1.63±0.15	1.58±0.17	1.65±0.26	1.63±0.61
	60-80	1.85±0.29	1.39±0.16	1.48±0.20	1.57±0.13	1.74±0.19	1.43±0.18	1.53±0.15	1.49±0.17	1.38±0.26	1.54±0.61
	80-100	1.75±0.29	1.42±0.16	1.53±0.20	1.51±0.13	1.46±0.19	1.64±0.18	1.64±0.15	1.37±0.17	1.28±0.26	1.61±0.61
Available P (g kg-1)	0-10	72.80±10.23	87.00±6.53	63.30±5.69	62.30±5.38	72.50±4.48	87.80±8.47	76.70±3.10	88.10±3.48	73.70±2.52	80.40±1.86
	10-20	37.60±10.23	61.60±6.53	56.90±5.69	57.10±5.38	87.50±4.48	53.60±8.47	66.20±3.10	72.90±3.48	77.20±2.52	88.50±1.86
	20-40	86.50±10.23	53.40±6.53	87.30±5.69	87.40±5.38	66.90±4.48	42.30±8.47	70.10±3.10	66.80±3.48	88.30±2.52	78.80±1.86
	40-60	34.10±10.23	87.10±6.53	66.90±5.69	64.30±5.38	64.90±4.48	87.90±8.47	88.10±3.10	82.20±3.48	77.40±2.52	80.50±1.86
	60-80	86.70±10.23	71.00±6.53	57.70±5.69	65.90±5.38	87.80±4.48	58.40±8.47	77.90±3.10	67.10±3.48	79.10±2.52	88.50±1.86

	80-100	40.20±10.23	50.90±6.53	87.20±5.69	87.20±5.38	64.20±4.48	43.40±8.47	72.80±3.10	78.30±3.48	88.40±2.52	79.30±1.86
	0-10	47.80±3.76	44.80±2.95	39.61±2.77	17.49±1.64	36.20±2.36	42.83±2.71	33.78±1.90	41.26±2.43	56.85±4.79	42.05±1.77
Available	10-20	35.28±3.76	27.17±2.95	25.91±2.77	20.94±1.64	22.05±2.36	23.70±2.71	20.94±1.90	29.45±2.43	29.37±4.79	33.23±1.77
K	20-40	26.77±3.76	27.64±2.95	23.86±2.77	21.42±1.64	21.81±2.36	29.45±2.71	22.60±1.90	27.09±2.43	27.32±4.79	31.89±1.77
(g kg-1)	40-60	23.70±3.76	26.46±2.95	26.69±2.77	22.20±1.64	21.57±2.36	27.80±2.71	22.68±1.90	26.85±2.43	29.37±4.79	31.65±1.77
	60-80	26.46±3.76	27.32±2.95	21.18±2.77	24.65±1.64	21.73±2.36	29.13±2.71	27.24±1.90	25.59±2.43	26.06±4.79	29.69±1.77
	80-100	25.28±3.76	27.01±2.95	21.73±2.77	29.45±1.64	26.06±2.36	26.77±2.71	26.30±1.90	26.14±2.43	29.37±4.79	32.68±1.77
	0-10	7.59±0.74	5.68±0.78c	6.44±0.41c	6.24±0.53c	3.48±0.88d	5.38±0.49b	6.71±0.53	10.11±0.20	9.40±0.34	9.80±0.48
Organic	10-20	9.03±0.74	8.95±0.78ab	9.21±0.41a	9.84±0.53	9.16±0.88	7.17±0.49	6.78±0.53	9.87±0.20	8.94±0.34b	9.89±0.48
matter	20-40	9.49±0.74	6.50±0.78b	7.64±0.41	9.33±0.53	6.98±0.88c	7.31±0.49	9.62±0.53	9.56±0.20	10.65±0.34	9.88±0.48
(g kg-1)	40-60	5.54±0.74c	4.96±0.78d	7.55±0.41	7.65±0.53	7.28±0.88b	8.13±0.49	8.13±0.53b	8.78±0.20b	9.05±0.34	9.80±0.48
	60-80	7.67±0.74	9.26±0.78	8.67±0.41	7.41±0.53	8.27±0.88ab	8.99±0.49	9.37±0.53	9.14±0.20	9.78±0.34	8.00±0.48ab
	80-100	10.80±0.74a	9.17±0.78	8.72±0.41	8.26±0.53ab	9.36±0.88	7.22±0.49	9.23±0.53	9.76±0.20	10.95±0.34	7.19±0.48b

TN, AP, AK and OM refer to total N, available P, available K and organic matter, respectively.

Furthermore, soil potassium was higher in soil layers of all the treatments at sowing which varied from 5.87 to 19.68 g kg^{-1}, than at harvest where the variation ranged from 4.81 to 11.14 g kg-1 (Table 2). Although, treatments M2R6, M6R4 and M6R6 displayed the highest soil potassium, there was no significant difference between the robinia and maize interaction and sole robinia.

In 2017 at sowing, soil potassium was higher in treatment M2R4, with the highest value recorded at 60-80 soil depth (91.91 g kg^{-1}), that displayed the highest soil potassium.

Although, available potassium decrease at harvest, and no significant difference were found between the robinia and maize interaction and sole robinia at sowing and harvest (Table 2).

Organic matter

In 2016, Organic matter exhibited high values at harvest compared to sowing, with highest content of 57.94 g kg^{-1} and 45.82 g kg^{-1} recorded for sole robinia (SR) at sowing and harvest, respectively (Table 2). Although, there was increase in the organic matter content at harvest, no significant differences were observed between layers for each treatment.

Table 3. Correlation coefficients between soil properties 2016.

Nutrients	TN	AP	AK	OM	Ph
Sowing			Harvest		
TN	1	0.445**	0.223	0.362**	0.292*
AP	0.18	1	0.032	0.502**	0.193
AK	0.219*	0.288*	1	0.161	0.543**
OM	0.27*	0.434**	0.292*	1	0.297*
Ph	0.525**	0.109	0.232	0.4	1

** $P < 0.01$, * $P < 0.05$.

2017.

Nutrients	TN	AP	AK	OM	Ph
Sowing			Harvest		
TN	1	0.02	0.75	0.38	0.60
AP	0.09	1	0.17	0.15	0.12
AK	0.03	0.27	1	0.12	0.47
OM	0.05	0.21	0.22	1	0.23
Ph	0.24	0.35	0.29	0.11	1

Also, in 2017, organic matter exhibited high values at harvest compared to sowing, with highest content of 12.97 g kg^{-1} and 10.80 g kg^{-1} recorded for sole robinia (SR) and M2R2 at sowing and harvest, respectively Meanwhile, significant differences were observed between layers for each treatment at harvest (Table 2).

Correlation coefficients between soil properties

Results of correlation analysis among soil chemical properties at sowing and harvest are shown in Table 3. In 2016, the soil collected at sowing showed significant and positive correlations between TN with pH ($P < 0.01$) and OM ($P < 0.05$), while AP displayed only significant and positive correlations with AK ($P < 0.05$) and OM ($P < 0.01$). AK was only significantly and positively correlated with OM ($P < 0.05$).

At harvest, TN showed positive and significant correlations with AP ($P < 0.01$), OM ($P < .0.01$) and pH ($P < 0.05$), while AP was only correlated with OM ($P < 0.01$). AK and OM exhibited positive and significant correlations with pH.

In 2017, no significant correlation were founded between nutrients content, at both sowing and harvest.

Table 4. Plant chemical properties under intercropped maize with black locust 2016.

	Nutrient	M2R2	M2R4	M2R6	M4R2	M4R4	M4R6
Robinia leaves	TN	3.51±0.66	8.66±0.57	8.69±0.52	6.34±1.30	4.49±0.43	6.45±0.55
	AP	0.18±0.05	0.31±0.18	0.08±0.03	0.08±0.04	0.10±0.04	0.09±0.04
	OM	5.56±0.50	3.54±0.58bcd	3.97±0.17	4.22±0.50	1.42±0.49d	4.34 ±0.31
	AK	63.43±0.52	101.12±41.40	60.62±2.36	57.54±2.75	60.85±1.17	64.23±3.88
Robinia stems	TN	3.86±0.21cd	8.27±0.31a	7.14±0.33	5.96±0.43	6.36±0.32	5.56±0.71
	AP	0.25±0.03	0.13 ± 0.04	0.06±0.03	0.06±0.02b	0.09±0.04	0.13±0.04
	OM	3.05±0.20	4.50±0.75abc	3.51±0.31	3.26±0.60	3.38±0.24	3.56±0.57
	AK	46.91±1.61	43.98±3.42	51.76±2.12	50.40±2.39	43.70±0.61	52.30±2.70
Maize leaves	TN	2.80±0.37cd	8.12±0.63	8.93±0.40	8.24±0.55	8.61±0.76	6.84±0.27ab
	AP	0.15±0.04	0.33±0.14	0.52±0.22	0.17±0.09	0.29±0.15	0.06±0.02
	OM	4.17±0.46	5.80±0.57a	3.73±0.50	4.68±0.25	3.36±0.59b	4.07±0.44
	AK	60.67±0.92	58.68±1.08	58.40±3.64	59.50±1.59	61.37±4.01	71.82±1.86a
Maize stems	TN	3.19±0.99	3.03±0.38	5.45±0.68	5.34±0.25	3.04±0.44	2.10±0.77
	AP	0.05±0.92	0.05±0.02	0.08±0.02	0.44±0.13ab	0.11±0.04	0.08±0.03
	OM	3.88±0.26ab	3.91±0.45	3.80±0.23	4.37±0.34	4.44±0.69	2.94±0.33 c
	AK	78.44±0.57	72.61±2.69	63.51±3.34b	73.41±3.34	79.39±1.08	70.97±1.09

Continued

	Nutrient	M6R2	M6R4	M6R6	SR
Robinia leaves	TN	4.20±0.63	5.25±0.44	4.21±0.52	6.01±1.05
	AP	0.13±0.03	0.09±0.04	0.09±0.04	0.12±0.06
	OM	4.25±0.50	4.07±0.39	3.73±0.49	3.300±0.57cd
	AK	60.03±0.33	61.00±0.76	59.81±0.27	61.79±3.33
Robinia stems	TN	4.35±0.99	4.65±0.33	5.51±0.71	5.29±1.09
	AP	0.17±0.06	0.10±0.04	0.07±0.03	0.14±0.04
	OM	3.15±0.41	2.66±0.33c	3.39±0.75	5.19±0.37ab
	AK	41.83±1.80	50.58±2.39	42.63±3.66	47.66±3.88
Maize leaves	TN	6.66±0.75	7.37±0.62	4.47±0.72bc	
	AP	0.12±0.03	0.07±0.02	0.05±0.01	
	OM	3.95±0.20	4.34±0.31	4.02±0.48	
	AK	51±0.69c	59.66±1.67	63.34±3.04	
Maize stems	TN	1.52±0.53	2.99±0.61	2.68±0.50	
	AP	0.06±0.02	0.15±0.04	0.08±0.05	
	OM	3.87±0.33bc	4.06±0.81	5.21±0.32	
	AK	72.62±4.69	72.36±1.75	72.40±2.46	

TN, AP, AK and OM refer to total nitrogen, available phosphorus, available potassium and organic matter, respectively.

2017

	Nutrient	M2R2	M2R4	M2R6	M4R2	M4R4	M4R6
Robinia leaves	TN	12.89±0.43	12.74±0.43	15.50±0.43	13.16±0.43	12.06±0.43	15.11±0.43
	AP	0.89±0.08	0.65±0.08	0.48±0.08	0.81±0.08	0.29±0.08	0.21±0.08
	OM	21.84±1.31	22.63±1.31	20.67±1.31	13.98±1.31	11.92±1.31	14.23±1.31
	AK	27.74±0.40	27.34±0.26	27.03±0.12	27.42±0.28	27.11±0.22	27.95±0.25
Robinia stems	TN	5.24±0.22	5.76±0.22	5.62±0.22	5.20±0.22	5.04±0.22	5.88±0.22
	AP	0.21±0.08	0.25±0.08	0.16±0.08	0.19±0.08	0.29±0.08	0.68±0.08
	OM	12.65±0.26	12.92±0.26	11.14±0.26	11.85±0.26	13.10±0.26	13.61±0.26
	AK	27.26±0.40	27.87±0.26	27.63±0.12	27.63±0.28	27.63±0.22	27.95±0.25
Maize leaves	TN	7.03±0.32	8.28±0.32	7.99±0.32	8.96±0.32	7.41±0.32	8.19±0.32
	AP	0.45±0.08	0.24±0.08	0.58±0.08	0.61±0.08	0.27±0.08	0.33±0.08
	OM	12.94±1.27	11.97±1.27	11.59±1.27	12.58±1.27	12.51±1.27	12.32±1.27
	AK	27.24±0.40	276.87±	27.48±0.12	27.93±0.28	27.24±0.22	27.48±0.25
Maize stems	TN	2.66±0.28	2.95±0.28	2.53±0.28	1.75±0.28	1.07±0.28	2.83±0.28
	AP	0.61±0.07	0.46±0.07	0.17±0.07	0.54±0.07	0.36±0.07	0.57±0.07
	OM	12.25±0.22	11.61±0.22	11.44±0.22	10.48±0.22	12.62±0.22	11.68±0.22
	AK	27.77±0.40	27.48±0.26	27.32±0.12	27.16±0.28	27.24±0.22	27.69±0.25

Continued

	Nutrient	M6R2	M6R4	M6R6	SR
Robinia leaves	TN	16.31±0.43	13.79±0.43	13.71±0.43	14.91±0.43
	AP	0.17±0.08	0.19±0.08	0.24±0.08	0.22±0.08
	OM	12.62±1.31	12.79±1.31	14.57±1.31	13.02±1.31
	AK	27.19±0.22	27.79±0.21	27.87±0.23	27.48±0.16
Robinia stems	TN	6.02±0.22	4.71±0.22	4.17±0.22	6.73±0.22
	AP	0.87±0.08	0.72±0.08	0.28±0.08	0.26±0.08
	OM	12.83±0.26	13.17±0.26	14.14±0.26	12.83±0.26
	AK	27.08±0.22	27.71±0.21	27.56±0.23	27.16±0.16
Maize leaves	TN	9.56±0.32	10.04±0.32	8.11±0.32	
	AP	0.41±0.08	0.96±0.08	0.86±0.08	
	OM	23.81±1.27	12.42±1.27	12.84±1.27	
	AK	27.00±0.22	27.32±0.21	27.40±0.23	
Maize stems	TN	2.99±0.28	2.83±0.28	4.13± 0.28	
	AP	0.81±0.07	0.81±0.07	0.75±0.07	
	OM	10.93±0.22	10.90±0.22	11.21±0.22	
	AK	276.16±0.22	27.85±0.21	27.85±0.23	

TN, AP, AK and OM refer to total nitrogen, available phosphorus, available potassium and organic matter, respectively.

Plant chemical properties

Black locust is a deciduous legume species which increase nitrogen concentrations and storage in leaves and soil. Concentrations of N, P, K and OM in all the treatments under intercropped maize with black locust are shown in Table 4. In 2016, the concentrations of total nitrogen and available phosphorus were higher in maize leaves than in maize stem, black locust leaves and black locust stems, with treatment M2R6 displaying the highest concentrations of total nitrogen (8.93 g kg^{-1}) and available phosphorus (0.52 g kg^{-1}). Available potassium concentrations were significantly higher in black locust leaves, black locust stems, maize leaves and maize stems than the other nutrients; with treatment M2R4 exhibiting the highest available potassium concentration in black locust leaves (101.12 g kg^{-1}).

Table 5. Correlation coefficients between leaves nutrients 2016.

Nutrients	Total N	Available P	Available K	Organic matter
black locust leaves				
Total N	1			
Available P	0.442**	1		
Available K	0.235	0.032	1	
Organic matter	0.365**	0.504**	0.161	1
black locust stems				
Total N	1			
Available P	0.223	1		
Available K	0.108	0.129	1	
Organic matter	0.42**	0.05	0.252	1
Maize leaves				
Total N	1			
Available P	0.064	1		
Available K	0.552**	0.437	1	
Organic matter	0	0.432**	0.267	1
Maize stems				
Total N	1			
Available P	0.185	1		
Available K	0.124	0.006	1	
Organic matter	0.046	0.246	0.13	1

** $P < 0.01$, * $P < 0.05$.

2017

Nutrients	Total N	Available P	Available K	Organic matter
black locust leaves				
Total N	1			
Available P	0.81	1		
Available K	0.99	0.84	1	
Organic matter	0.97	0.88	0.98	1
black locust stems				
Total N	1			
Available P	0.86	1		
Available K	0.98	0.86	1	
Organic matter	0.98	0.87	0.99	1
Maize leaves				

Total N	1			
Available P	0.92	1		
Available K	0.99	0.91	1	
Organic matter	0.96	0.84	0.96	1
Maize stems				
Total N	1			
Available P	0.96	1		
Available K	0.95	0.95	1	
Organic matter	0.94	0.94	0.99	1

Available phosphorus was higher in the leaves of black locust than the stem, while maize stem displayed more phosphorus levels than maize leaves. Organic matter content showed significant differences among treatments in the leaves and stems of robinia and maize. In 2017, the concentrations of total nitrogen and organic matter were higher in maize leaves than in maize stem, black locust leaves and black locust stems, with treatment M6R2 displaying the highest concentrations of total nitrogen (16.31g kg^{-1}) and organic matter (23.81g kg^{-1}). Organic matter content showed significant differences among treatments in the leaves and stems of robinia and maize.

Table 6. Plant growth parameters under intercropped maize with black locust 2016.

Treatment	Plant height (cm)		Stem diameter (cm)		Dry weight (g $plant^{-1}$)					Ratio	
					Leaf		Stem		Root	Leaf/Stem	
	Robinia	Maize	Robinia	Maize	Robinia	Maize	Robinia	Maize	Maize	Robinia	Maize
M2R2	98.30±0.44ef	19.43±0.84d	3.25±0.59c	2.22±0.22d	99.83±0.88a	10.57±0.87c	99.84±1.49c	11.67±0.84e	14.88±1.04d	0.99±0.01c	0.89±0.03b
M2R4	114.45±0.54d	17.07±0.90d	3.39±0.50c	2.67±0.45c	67.79±0.82bc	10.65±0.85c	67.97±0.83e	15.34±1.07b	19.23±0.76a	0.99±0.08c	0.69±0.14d
M2R6	124.08±1.14c	78.89±0.82a	2.94±0.46be	2.50±0.20cd	66.37±0.85bc	12.33±0.96b	20.41±0.97f	15.15±0.92b	20.07±0.90a	3.26±0.05a	0.81±0.06cd
M4R2	129.08±0.48bc	28.81±0.89bc	2.72±0.15ef	3.00±0.11bc	49.25±0.90e	10.06±0.87c	98.98±0.80c	10.13±0.80c	14.31±0.57d	0.49±0.00f	0.99±0.20a
M4R4	110.10±1.40de	21.36±0.87c	6.50±0.52a	2.50±0.30cd	71.50±0.84b	9.95±0.83d	69.55±0.85e	11.83±0.65e	14.14±0.28d	1.02±0.00b	0.84±0.02c
M4R6	101.19±0.47e	39.43±0.83b	2.94±0.24e	2.10±0.17e	88.76±0.82ab	9.31±0.88d	186.56±0.76a	14.20±0.80c	15.59±0.40c	0.47±0.00f	0.65±0.05e
M6R2	127.55±2.27b	38.41±0.84b	3.44±0.31b	3.61±0.34a	54.52±0.86d	13.75±0.83a	85.16±0.86d	17.08±1.03a	17.04±0.38b	0.71±0.10d	0.81±0.03cd
M6R4	97.36±0.47f	13.17±0.93e	3.94±0.46b	2.78±0.15c	57.42±0.83d	8.52±0.79e	108.24+0.60b	13.01±0.67d	15.40±1.26c	0.53±0.99e	0.60±0.11f
M6R6	121.34±0.42cd	25.30±0.83c	3.00±0.47d	3.06±0.60b	61.95±0.84c	9.17±0.83d	105.55±0.83b	15.65±1.44b	13.78±1.21e	0.59±0.01e	0.63±0.07e
SR	134.91±0.36a		1.33±0.83f		74.57±0.87b		50.59±0.80ef			1.50±0.04b	

Each value is the mean (±SE) of the replicates (Duncan's test, P < 0.05). The same letter within each column indicates no significant difference among treatments (P < 0.05).

2017

Treatment	Plant height (cm)		Stem diameter (cm)		Dry weight (g $plant^{-1}$)					Ratio	
					Leaf		Stem		Root	Leaf/Stem	
	Black locust	Maize	Robinia	Maize	Robinia	Maize	Robinia	Maize	Maize	Robinia	Maize
M2R2	287.33±36.17b	177±21.12	4.33±0.88	2.22±0.16d	241.13±20.61	168.35±21.80	276.86±18.24	149.09±20.05	99.82±12.97	0.87±1.12	1.12±1.08
M2R4	240±6.80c	66.33±5.78d	3.16±1.69d	2.66±0.25	307.31±20.61b	233.72±21.80	201.81±18.24	175.59±20.05	94.91±12.97	1.52±1.12	1.33±1.08
M2R6	284±8.02	109.33±16.85	5±0.57	2.50±0.16	282.22±20.61	105.08±21.80	323.52±18.24	75.83±20.05	34.89±12.97	0.87±1.12	1.38±1.08
M4R2	297.66±24.12	113.33±12.73	3.66±0.33	3±0.11	284.92±20.61	121.84±21.80	285.84±18.24	143.44±20.05	98.72±12.97	0.99±1.12	0.84±1.08
M4R4	296±18.58	170.33±8.64	3.66±0.33	2.50±0.18	196.16±20.61	114.37±21.80	258.83±18.24	99.97±20.05	64.01±12.97	0.75±1.12	1.14±1.08
M4R6	285±3.78	121.33±8.17c	3.33±0.33	3±0.11	249.46±20.61c	111.78±21.80	228.99±18.24	100.40±20.05	49.71±12.97	1.08±1.12	1.11±1.08
M6R2	316.33±28.90	230±9.71	6±1.00a	3.61±0.28a	240.01±20.61	207.28±21.80	212.75±18.24	217.60±20.05	136.77±12.97	1.12±1.12	0.95±1.08
M6R4	258.66±25.20	111.33±10.47	5.16±2.42	2.77±0.12	215.89±20.61	189.10±21.80	260.42±18.24	186.59±20.05	86.80±12.97	0.82±1.12	1.01±1.08
M6R6	304.66±10.92	230.66±4.48	4.66±1.20	3.05±.30ab	179.72±20.61d	204.26±21.80	253.39±18.24	165.26±20.05	117.52±12.97	0.69±1.12	1.23±1.08
SR	299±17.24ab		3.83±0.16bc		406.79±20.61a		399.16±18.24			1.01±1.12	

Each value is the mean (±SE) of the replicates (Duncan's test, P < 0.05). The same letter within each column indicates no significant difference among treatments (P < 0.05).

The results of correlation analysis among leaves chemical properties are shown in Table 5. In 2016 black locust leaves total nitrogen showed highly significant and positive correlations with available phosphorus (0.442) and organic matter (0.365), while available phosphorus was only positive and significantly correlated with organic matter (0.504).

Table 7. Leaf water status and chlorophyll concentration of black locust intercropped with maize, subjected to ten different treatments. 2016.

Treatment	Leaf water status		Leaf chlorophyll status
	RWC (%)	WUE (μmol CO_2 $mmol^{-1}$ H2O)	($mg\ g^{-1}$)
M2R2	191.93±0.05a	38.01±30.80d	35.78±2.07c
M2R4	191.89±0.19b	48.72±50.64b	40.34±2.00a
M2R6	191.89±0.19b	15.00±10.31ef	37.12±2.56b
M4R2	191.89±0.19b	10.31±57.97f	33.16±1.24d
M4R4	191.89±0.19b	35.05±37.74e	35.05±2.51cd
M4R6	191.89±0.19b	48.57±75.93b	37.85±2.73b
M6R2	191.89±0.19b	47.63±59.11c	37.01±1.54bc
M6R4	191.89±0.19b	45.58±36.78cd	32.51±2.11e
M6R6	191.89±0.19b	57.07±75.88a	37.72±3.61b
SR	191.89±0.19b	35.36±13.31e	11.82±0.93f

Each value is the Mean±SE of the replicates (Duncan's test, P < 0.05). The same letter within each column indicates no significant difference among treatments (P < 0.05).

2017

Treatment	Leaf water status		Leaf chlorophyll status
	RWC (%)	WUE (μmol CO_2 $mmol^{-1}$ H2O)	($mg\ g^{-1}$)
M2R2	170.58±5.32b	2883.18±72.28e	36.56±1.75cd
M2R4	170.60± 5.32ab	4674.29±1528.79c	40.42±0.99a
M2R6	170.65±5.32a	3622.78±409.15d	39.20±1.33ab
M4R2	170.61±5.34ab	4116.23±721.77c	36.25±1.24cd
M4R4	169.08±5.83c	4326.95±581.49c	36.82±1.46c
M4R6	161.90±3.94d	2561.67±827.22f	39.82±1.49ab
M6R2	158.37±1.23f	2847.20±407.64e	38.63±1.40b
M6R4	158.40±1.24ef	2823.07±958.05e	37.30±2.07bc
M6R6	159.40±0.87e	16055.31±11919.49b	37.83±1.65bc
SR	159.54±0.91de	17371.52±4974.72a	12.88±6.21d

For robinia stems, only total nitrogen displayed significant and positive correlation with organic matter (0.42). For maize leave, total nitrogen and available phosphorus exhibited highly and significant correlations with available potassium (0.552) and organic matter (0.432), respectively, whereas no significant correlations were recorded among nutrients for maize stems. Thus, positive impact of increasing nitrogen availability on leaf and soil nutrients may in turn influence the correlation relations between soil and plant nutrients. In 2017, leaves chemical properties didn't showed significant correlations (Table 5).

Plant Biomass and Yield

Biomass of plants in the experiment was estimated based on the algometric relationship and the diameter of each plant in sample treatments (Fig.1). In 2016, treatments M2R6, M6R2 and M2R2 showed the highest biomass of maize for leaves, stems and roots, respectively. For black locust, treatments M2R2 and M6R4 displayed the highest biomass for leaves and stems, respectively. Leaves and stems biomass of black locust in treatments SR were closely similar.

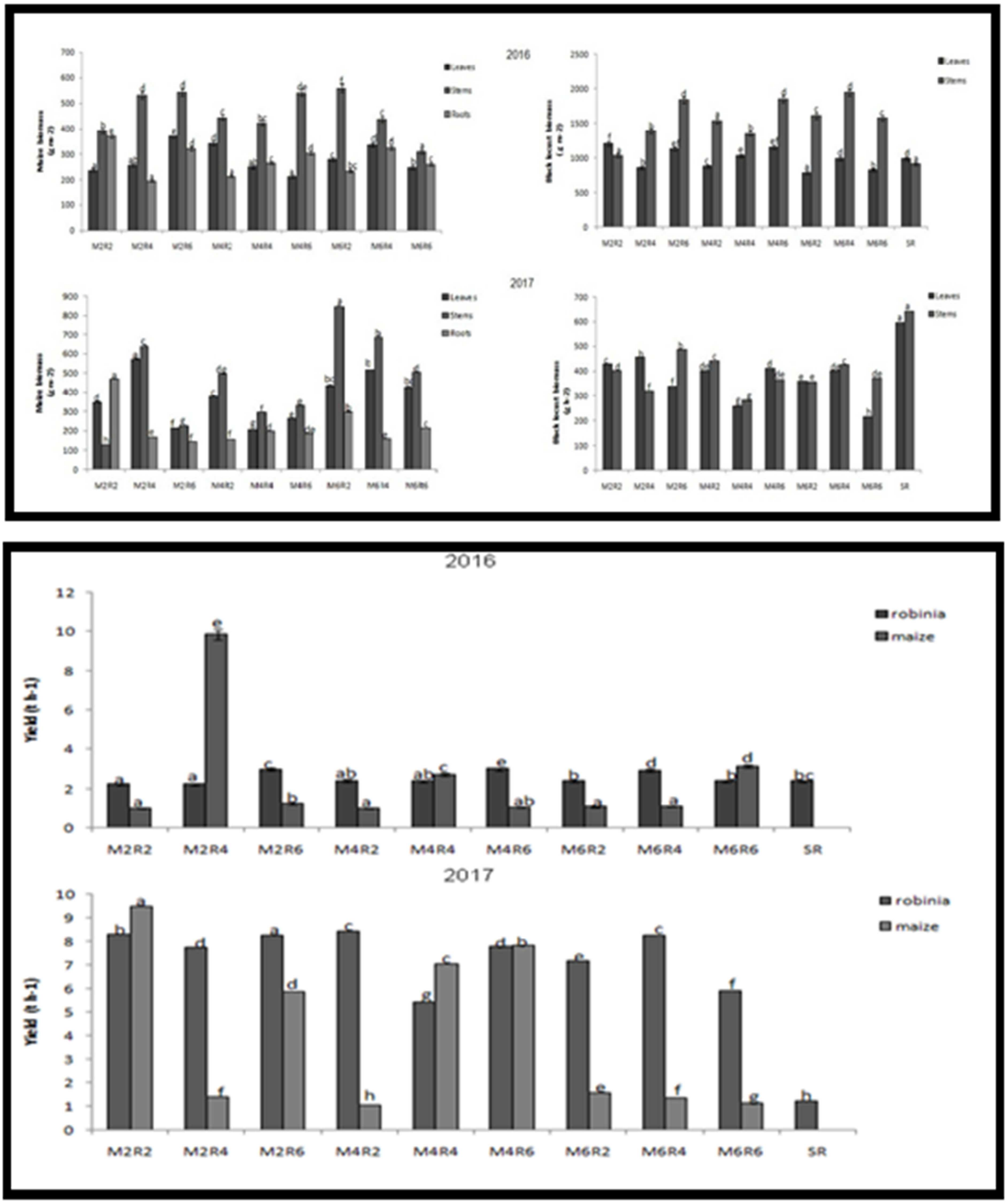

Fig. 1. Plant biomass and yield under intercropped maize with black locust. A: Maize biomass, B: black locust biomass, C: maize and black locust yield.

In 2017, treatments M2R4, M6R2 and M6R2 showed the highest biomass of maize for leaves, stems and roots, respectively. For black locust, treatments SR displayed the highest biomass for leaves and stems, respectively. Leaves and stems biomass of black locust in treatments M4R2 were closely similar. In 2016, maize yield differed significantly between treatment M2R4 and others treatments. The highest average maize yield was obtained from treatment M2R4 (9.8526 t ha^{-1}), whereas treatments M4R2, M4R6, M6R2 displayed the lowest maize yield. Although, treatment M4R6 exhibited the highest biomass for black locust, no significant difference was observed among all treatments.

In 2017, maize yield differed significantly between treatment M2R2 and treatments M2R4, M4R2, M6R2, M6R4 and M6R6. The highest average maize yield was obtained from treatment M2R2 (9.4602 t ha^{-1}), whereas treatments M4R2, M4R6, M6R2 displayed the lowest maize yield. Meanwhile, treatment M4R2 exhibited the highest biomass for black locust (Fig. 1).

Plant growth parameters

In 2016, the analysis of variance revealed significant differences among all treatments for plant height, stem diameter and dry weight of black locust and maize (Table 6).

Sole black locust displayed higher plant height than black locust intercropped with maize, while showing smaller stem diameter. Treatments SR (134.91) and M2R6 (78.89) exhibited the highest plant height for black locust and maize, respectively, while the lowest plant height was recorded for M6R4 for both black locust (97.36) and maize (13.17).

The largest stem diameter was recorded for M4R4 (6.50) and M6R2 (3.61) for black locust and maize, respectively. For black locust, treatments M2R2 (99.83) and M4R6 (186.56) showed the largest leaf and stem diameter, respectively, while for maize, treatments M6R2 (13.75 and 17.08) exhibited the largest leaf and stem diameter. Also in 2017, the analysis of variance revealed significant differences among all treatments for plant height, stem diameter and dry weight of black locust and maize. Sole black locust displayed higher plant height and stem diameter than black locust intercropped with maize. Treatments M6R2 (316.33) and M4R4 (170.33) exhibited the highest plant height for black locust and maize, respectively, while the lowest plant height was recorded for M2R4 for both black locust (240) and maize (66.33). The largest stem diameter was recorded for M6R2 (6) and (3.61) for black locust and maize, respectively (Table 6).

Leaf water status, chlorophyll concentration and photosynthetic parameters

In 2016, results of the analysis of variance showed significant differences among all treatments for WUE and leaf chlorophyll, while no there was significant difference among all treatments for leaf relative water content (RWC) (Table 7).

Treatment M6R6 displayed the highest WUE (57.07), whereas the lowest WUE was recorded for treatment M4R2 (10.31). The highest leaf chlorophyll status was displayed by treatment M2R2 (40.34), whereas treatment SR showed the lowest leaf chlorophyll. In 2017, results of the analysis of variance showed significant differences among all treatments for leaf relative water content (RWC), WUE and leaf chlorophyll (Table 7). Treatment M2R6 displayed the highest RWC (170.65), whereas the lowest RWC was recorded for treatment M6R2 (158.37). Treatment SR displayed the highest WUE (17371.52), whereas the lowest WUE was recorded for treatment M6R4 (2823.07).The highest leaf chlorophyll status was displayed by treatment M2R4 (40.42), whereas treatment SR showed the lowest leaf chlorophyll.

In 2016, leaf photosynthesis (Pn), stomatal conductance (gs), leaf intercellular CO_2 concentration (Ci) and transpiration rate (Tr) displayed significant differences among all treatments. Treatment M4R4 showed the highest leaf photosynthesis, followed by treatment M2R4 (Fig. 2a), while treatment M4R4 and M6R2 exhibited the highest stomatal conductance (Fig. 2b). Treatment M6R6 significantly displayed the highest leaf intercellular CO_2 concentration (Fig. 2c), whereas the highest transpiration rate was recorded for treatment M2R2 (Fig. 2d). In 2017, leaf photosynthesis, stomatal conductance, leaf intercellular CO_2 concentration and transpiration rate also displayed significant differences among all treatments. Treatment SR significantly exhibited the highest leaf photosynthesis, followed by treatment M4R4 (Fig. 2e), Also, treatment SR showed the highest stomatal conductance (Fig. 2f). Treatment M6R6 significantly displayed the highest leaf intercellular CO_2 concentration (Fig. 2g), whereas the highest transpiration rate was recorded for treatment M6R4 (Fig. 2h).

Discussion

Black locust has the ability to modify the soil environment, but the changes in physical and chemical properties of areas where it occurs have never been discussed comprehensively. In the present study, we investigated the ability of black locust intercropped with maize; and assessed the effects of the intercropping on plant growth parameters and yield.

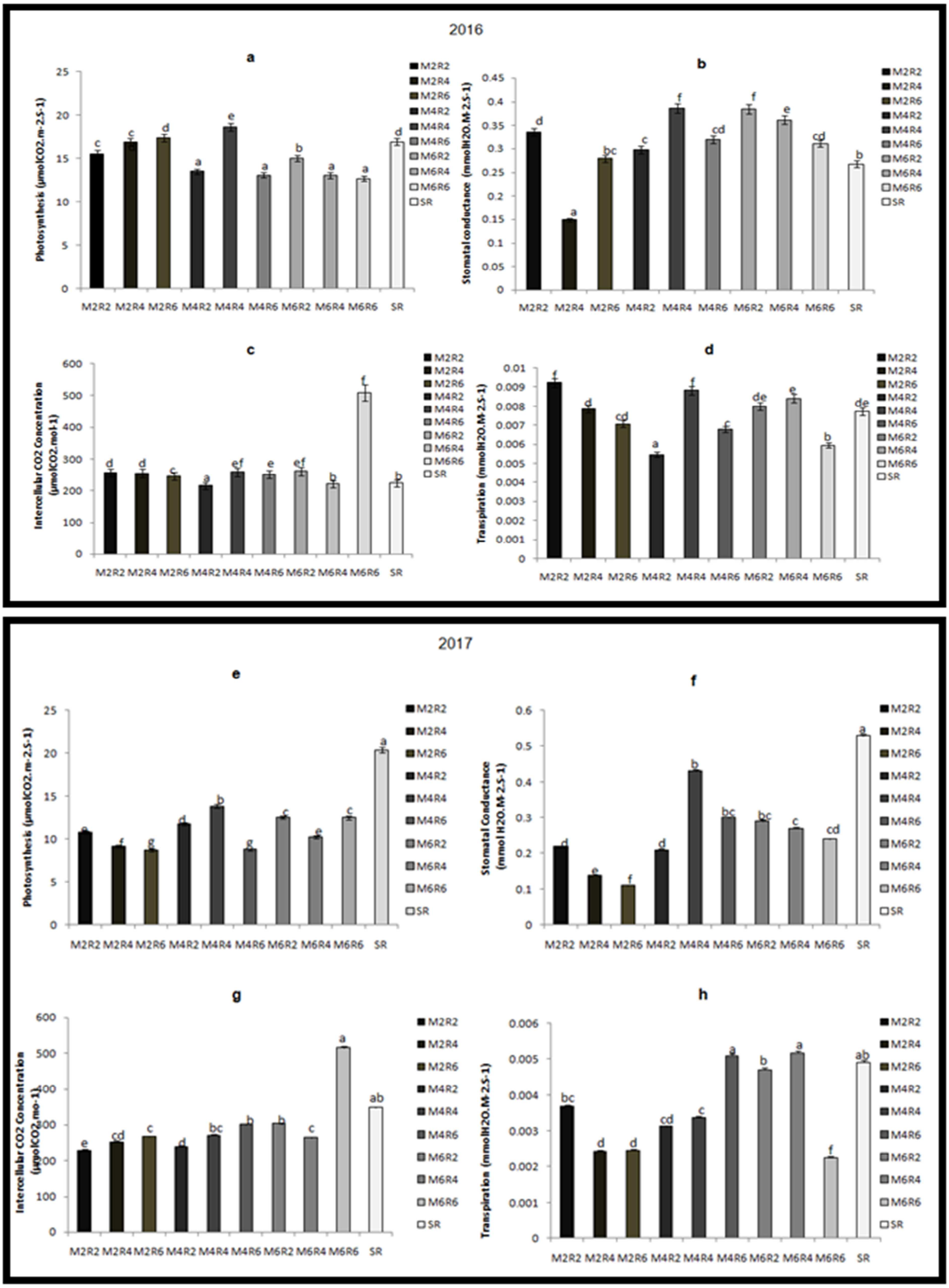

Fig. 2. Photosynthetic parameters under intercropped maize with black locust. Leaf photosynthesis, Stomatal conductance, Intercellular CO_2 concentration and Transpiration.

In 2016 and 2017, a decrease of total nitrogen at harvest with soil depths in majority of treatments is similar to those obtained for black locust stands in eastern Germany, by Goldacker (2002). This result may be due to low N fixation and/or high mineralization rates of organic N due to coarse texture and favorable climatic conditions.

In our experiment, significant increase of phosphorus is observe at harvest, in treatments M2R2, M2R4, M2R6, M4R2, M4R4, M4R6, M6R2, M6R4 and M6R6, and the highest rate is recorded by treatment M2R4 (21.30) at depth 80-100, in 2016. This increase was probably due to the use of phosphorus during the growth of black locust, and resulting to his decrease in soil. Zhao *et al.* (2007) founded a decrease in soil phosphorus in Mongolian pine plantations and Chen et al. (2000) make the same observation in mixed plantations (pinus ponderosa) and (pinus nigra) compare with native grassland. At opposite, legume plant can improve phosphorus availability in soils, as shown by Nuruzzaman (2005). In 2017, similarly to the previous year, significant increase of phosphorus is observed at harvest. Indeed, Langenbruch *et al.* (2012) found that leaf litterfall rich in $Ca2+$ and $Mg2+$ (ash, lime or maple) can reduce acidifying effect and increase the nutrient availability in top soils, and that ability increase the value of the tree layer species composition. Although, according to Rice *et al.* (2004) black locust leaves have similarly high cation content.

The results show a decrease of potassium at harvest for overall treatments, in 2016 and 2017 (Table 2). In 2016, difference between the highest quantity of potassium at sowing, observed in treatment M2R6 (15.27), from 60-80 soil depth, and the highest quantity of potassium at harvest, recorded by treatment M6R2 (11.14), from 00-10 soil depth is considerable. That difference between the highest quantity of potassium at sowing, observed in treatment M2R2 (76.83), from 20-40 soil depth, and the highest quantity of potassium at harvest, recorded by treatment M6R6 (56.85), from 00-10 soil depth increased considerably in 2017.

The present investigations show that plant potassium decreased under the intercropping of black locust with maize. These differences suggest that changes in potassium concentrations in soil lead to decrease, due to the increase of organic matter with the decomposition of litter (Forrester *et al.* 2013).

In 2016, a significant increase of organic matter at harvest is observe in overall treatments of plant nutrient; especially for treatment M2R2, that has the highest quantities at 0-10, 10-20, 20-40, 40-60, 60-80 cm depths; when the highest quantity at sowing (17.51), is observed in Treatment M6R4, at 0-10 depth layer. Meanwhile, in 2017, a significant decrease is observed at harvest in overall treatments. This observation suggest that increased of black locust favor the increase of organic matter As is known, the decomposition of the soil mantle in forest land, favor the increase of organic matter content in subsurface soils. Hong Li *et al.*, (2013) founded that microbial transformation is the key factor of rapid decomposition of organic amendments added to soils.

In 2016, overall concentrations of total nitrogen were higher in maize leaves, in maize roots and black locust leaves. Similar results were also obtained with different pine species, black locust and other legumes (Abarchi *et al.* 2009). Available potassium and phosphorus concentrations were also significantly higher than other nutrients in black locust stems, maize leaves and maize stems and maize roots. In 2017, an increase of total nitrogen and organic matter were higher in black locust leaves, black locust stems and maize stem is observed. Indeed, Horst and Waschkies (1987) founded that intensive black locust root development in turn are able to provide an enhanced P uptake by plants through a reduction of the diffusion paths in soil, as well as through rhizosphere acidification mechanism (Fohse *et al.* 1991).

Higher proportion of C-enriched structural compounds like lignin and cellulose favor the higher C contents in stem of black locust compared to roots and leaves. Luo *et al.* (2006) make the same observation in other tree species.

More, Reef *et al.* (2010) founded that proteins (N-rich compounds) and nuclear acids are essential for plant growth. These observations suggest that the higher C contents in stem of black locust have impacted the black locust and maize stems biomass; and explained the highest biomass found in plants stem of the results, in 2016 and 2017.

Maize is known as common component in many intercropping system in the tropics (Ijoyah, 2012).In 2016, Maize yield of treatment M2R4 was improved, as well than overall treatments in 2017, as is showed in results. Indeed, Olufemi and Odebiyi (2001), Mpairwe *et al.* (2002) and Dapaah *et al.* (2003) observed that maize grain yield is affected by different legume species and intercropping produced higher maize grain yield than slope cropping. In the same way, Nzabi *et al.* (2000) reached at the conclusion that there is a benefit for maize under intercropping with legume because maize yield is improved. Oppositely, Silwana and Lucas founded in 2002 that maize yield reduced under intercropping and weed infestation. Maize yield reduction under intercropping could be due to the competition effect by the crops for nutrients, moisture and space as showed by Adeniyan *et al.* (2007). This competition for nutrients, moisture and space between black locust and maize could be at the origin of the low maize yield observed in 2016 in treatments M2R2, M2R6, M4R2, M4R6, M6R2, M6R4, that all are less than 2 t ha-1. Lauk and Lauk (2009), finally concluded that sole crops produce high yields when growing under conditions where cereal intercropping with legumes has no advantages over cereal sole crops,. However, when evaluated over a number of years the intercrops are expected to show more stable yields than the specific sole crops. On this finding, we could say that the intercropping system is more appropriate in terms of sustainability than sole cropping of cereals since the legume component will enrich the soil through nitrogen fixation. Low maize yield in the major part of treatments could be also finding in the weather conditions of the region, that is semi arid. Also, water stress significantly affected maize growth processes, by decreasing biomass and reducing grain yield as showed by Cakir (2004).

In fact, maize yield due to water stress depends on some factors, including severity and duration of water limitations, vulnerability to soil drought (Farooq *et al.* 2009) and long water stress period (Cakir, 2004).

In 2016 and 2017, results showed that intercropping maize with black locust has positively affect maize and black locust height. An increase is observed in maize and black locust. Black locust and maize height increment is due to the N-fixing ability of that plant. These results are at the opposite of those of Silwana and Lucas (2002) who showed that maize monocrop was taller than intercropping with beans both in the absence and presence of weeds. And Thwala and Ossom (2004) did not find any significant differences between maize monocrop and intercropping with sugar beans and groundnuts. showed significant differences in the character of black locust stem basal diameter between the different treatments. Also, maize stem basal diameter showed a significant difference between treatment M2R4 and the remained treatments. Differences observed between treatments are due to the fact that maize used nitrogen fixed by black locust for his own growth. Similar results were reported by Bakhet *et al.*, (2006) and Cheema *et al.*, (2010). In 2017, results showed an increase of black locust and maize stem basal diameter of black locust and maize was lower in 2016 than in 2017 where a significant increase is observed. This low dry weight observed in 2016 is attributed to water stress. Suralta *et al.* (2010) observed that under elevated moisture stress, plants show a progressive decrease in leaf area, height growth rate and shoot dry matter. Often, Black locust had the largest diameter within the fixed area plots, which may be attributed to their routinely fast growth (Boring and Swank, 1984).This fast growth ability of black locust favored the increase of his basal diameter and maize in 2017.

In 2016 and 2017, significant differences in Chlorophyll concentration and WUE were found between all treatments. In 2016, RWC don't show any difference, but in 2017, significant differences are founded between all treatments. In 2017, significant increase is observed between all treatments of WUE.

Also, an increase is founded between all treatments of Chlorophyll. This is probably due to the ability of plants in this treatment to easily adapt to land under drought stress. This result is in agreement with the studies of Evelin and others (2009) who found that under drought stress, mycorrhizal plants can absorb more water and nutrient than non-mycorrhizal plants. Photosynthesis is able to provide the organic blocks for plant growth and development. Benefit of higher relative water content (RWC) and water use efficient (WUE) for moving water through the plants to the evaporating surfaces and maintaining stomata opening in leaves have been shown by Nelsen and Safir (1982). Zhu and others founded in 2012 that plant photosynthetic efficiency and environmental stress can be asses by chlorophyll concentration.

In 2016, treatment M4R4 had higher photosynthesis and stomatal conductance, but lower intercellular CO2 concentration (Fig. 2). Meanwhile, in 2017, a significant decrease is observed between the majorities of the sub-cited parameters, which indicates that a high gas exchange capacity is maintains by decreasing stomatal resistance and by increasing CO2 assimilation and transpiration fluxes. According to the findings of Zhu and others (2011), Arbuscular Mycorrhizal Fungi can maintains high gas exchange capacity of black locust, and decrease stomatal resistance by increasing CO2 assimilation and transpiration fluxes.

Conclusion

Intercropping of maize with black locust is a high technical potential of crop-to-crop interaction and demonstrate an improvement of environmental sustainability (such as improved fertility of soils, reduced prevalence of crop diseases in the field). In this study, soil chemical properties under black locust varied with soil depths. Results show that in 2016, total nitrogen and available potassium decrease at harvest, while available phosphorus and organic matter increased.

In 2017, total nitrogen, available potassium and organic matter decrease at harvest while available phosphorus increased. Change in soil nutrient contents has an influence on plants nutrient contents.

In 2016, total nitrogen was higher in black locust leaves, maize leaves and maize roots. Available phosphorus and Available potassium was higher in black locust stems, maize leaves, maize stems and maize roots. Meanwhile in 2017, total nitrogen and organic matter were higher in black locust leaves, maize leaves, maize stems and maize roots.

The higher C contents in stem of black locust have impacted black locust and maize stems biomass; and explained the highest biomass found in plants stem. Competitive ability of black locust for nutrients is at the origin of the low maize yield in 2016. Intercropping black locust with maize has also improved some morpho-physiological parameters, such as plant growth, leaf water status, photosynthesis and stomatal conductance. Critical areas of black locust (*Robinia pseudoacacia*) intercropped with maize were highlighted, and the advantages were discussed. It is therefore imperative to adventure further into more studies in intercropping of different crops for the betterment of human life.

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