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EFFECT OF MULCHING ON NUTRIENT UPTAKE AND EFFICIENCY OF FERTILIZERS IN MID-EARLY CABBAGE PRODUCTION

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ABSTRACT

A three-year field trial was conducted to determine the effects of mulching with black polyethylene film and fertilizing with organic and mineral fertilizers in mid-early cabbage production. The two-factor trial was set up as a split-plot design. The main plots included unmulched and mulched treatments. The sub-plots consisted of unfertilized control and five fertilized treatments. In the first and third trial years, total cabbage yield, total head yield, and average head weight were significantly higher on black polyethylene film plots than on unmulched plots. However, in the second year, the mean air temperature during cabbage growing exceeded the long-term average, and values of the examined parameters did not differ significantly between the mulched and unmulched treatments. In all three years, amounts of removed nutrients were significantly higher in treatment with composted pig manure + mineral fertilizer. Mulching significantly increased fertilizer use efficiency in the first and third years, while the second year saw better results on unmulched plots.

Key words: cabbage, organic fertilizers, mineral fertilizers, black polyethylene film, head yield, head weight

INTRODUCTION

Head cabbage is one of the most important and most widely cultivated vegetables in the Republic of Serbia at an area of around 9,314 ha, with average yields of 24.8 t/ha and total production of about 223,916 t in the last five years [http://www.fao.org/faostat/en/#data].

Soil mulching is essential for vegetable production. There are two types of mulches – organic and inorganic [Uwituze et al. 2017], and several benefits of using them: soil temperature increases under artificial mulch, soil moisture is conserved, early growth is promoted, and higher earlier yield of better quality can be expected, as well as a cleaner harvested product [Lamont 2001, Farjana et al. 2019]. Fertilizer use is optimal under mulch since it neither leaches nor is wasted [Lamont 2001]. Mechanical weeding becomes obsolete, and herbicide use is reduced when using plastic mulch [Adamczewska-Sowinska and Turczuk 2018].

Furthermore, plastic mulch keeps the soil oxygenated, crumbly, and loose [Lamont 2001, Parmar et al. 2013]. Plant growth and development are stimulated on account of ample oxygen available to the root and augmented microbial activity [Kumar and Dey 2011, Parmar et al. 2013]. The efficiency of applied fertilizer and irrigation increases with mulching [Roy et al. 1990], as well as nitrogen (N) efficiency by 53% [Sweeney et al. 1987].

Appropriate cabbage nutrition is vital for high-yielding cabbage heads of good quality. Organic fertilizers directly affect plant growth as a source of all necessary macro- and micronutrients in forms accessible to plants during mineralization and improve physical and chemical soil properties [Abou El-Magd et al. 2006]. Organic fertilizers take longer to transform nutrients into accessible forms. The mineralization rate of organic fertilizers depends on the type of fertiliz-

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er, degree of organic matter decomposition, temperature, and microbiological activity, and their value as a source of nutrients for plants varies greatly [Pang and Letely 2000].

Mineral fertilizers have a faster nutritive effect and benefit plant growth and yield [Abou El-Magd et al. 2006]. Even though farmers apply disproportionately high rates of mineral fertilizers to attain high yields, the use of mineral fertilizers must be more rational, or else it could cause adverse effects on human health or lead to groundwater and environmental pollution [Arisha and Bradisi 1999, Guo et al. 2011]. Similarly, uncontrolled excessive use of organic fertilizers could lead to N leaching into groundwater or soil becoming contaminated with heavy metals and harmful microorganisms [Cabilovski et al. 2014]. Da Costa et al. [2012] stated that a large portion of the applied nutrients is not removed by plants, namely around 50% of N. Guo et al. [2011] reported that around 45% of globally applied phosphorus (P) is removed by plants, and the remainder could pollute groundwater [Liu et al. 2003].

Farmers have almost wholly relied on applying mineral fertilizers to provide crop supply with nutrients and attain high yields. Hence, food prices and fertilizer costs are strongly correlated [Khabarov and Obersteiner 2017]. Since the cost of mineral fertilizers is exceptionally high, and the quantity of manure that can be used for vegetable farming decreases every year, the question of the rational use and efficiency of the applied fertilizers remains.

Therefore, this study aimed to determine the effects of mulching with black polyethylene film on total yield, total head yield, average head weight, uptake of N, P_2O_5 and K_2O, and effectiveness of applied organic and mineral fertilizers in mid-early cabbage production.

MATERIALS AND METHODS

Experimental site. The field trial was conducted in 2010, 2012, and 2013 at the experimental field (45°75'3"N and 19°13'52"E) of the Agricultural Extension Service, Sombor, in Vojvodina province, Serbia. The soil on the experimental site is haplic phaeozem (PHh), formed on loess terrace, the primary soil type in Vojvodina province (northern part of Serbia), covering 60% of agricultural land. The primary soil properties are shown in Table 1.

Drip irrigation was used in the trial without additional fertilization during the growing seasons. Total monthly precipitation and average air temperature during the trial are given in Figure 1.

Experimental design and treatments. The trial was carried out using a two-factorial split-plot completely randomized design, with ground cover management (mulch) as a whole-plot factor and fertilization treatments in a split-plot. The trial was conducted in four replicates in 2010 and three in 2012 and 2013. The main plots (factor A) included unmulched treatment (control) and treatment mulched with black polyethylene film. The sub-plots (factor B) fertilization treatments were as follows: 1. control – unfertilized (Ø); 2. mature cattle manure (CM), 3. composted pig manure (PM), 4. CM + mineral NPK fertilizer, 5. PM + mineral NPK fertilizer and NPK fertilizer only. Organic fertilizers were applied at 20 t ha^{-1} (CM and PM). The chemical composition of the applied organic fertilizers is given in Table 2. Mineral complex NPK fertilizer (formulation 11 : 11 : 21) was applied at the rate of 500 kg ha^{-1}, which contained 55 kg N, 55 kg P_2O_5 and 105 kg K_2O. The whole amount of organic and mineral fertilizers was applied before transplanting the cabbage.

Table 1. Soil properties (soil depth 0–30 cm)

Year	pH H_2O	pH KCL	Humus (%)	Total N (%)	AL-P_2O_5 (mg100g^{-1})	AL-K_2O (mg100g^{-1})	$CaCO_3$ (%)	Mineral N	
								NH_4-N (kg ha^{-1})	NO_3-N (kg ha^{-1})
2010	7.6	7	3.12	0.2	21.9	22.1	4.59	28	36.05
2012	8.01	6.85	2.48	0.12	17.8	21.3	3.82	27.3	46.4
2013	8.55	7.62	1.94	0.1	19.6	19.7	7.40	23.1	30

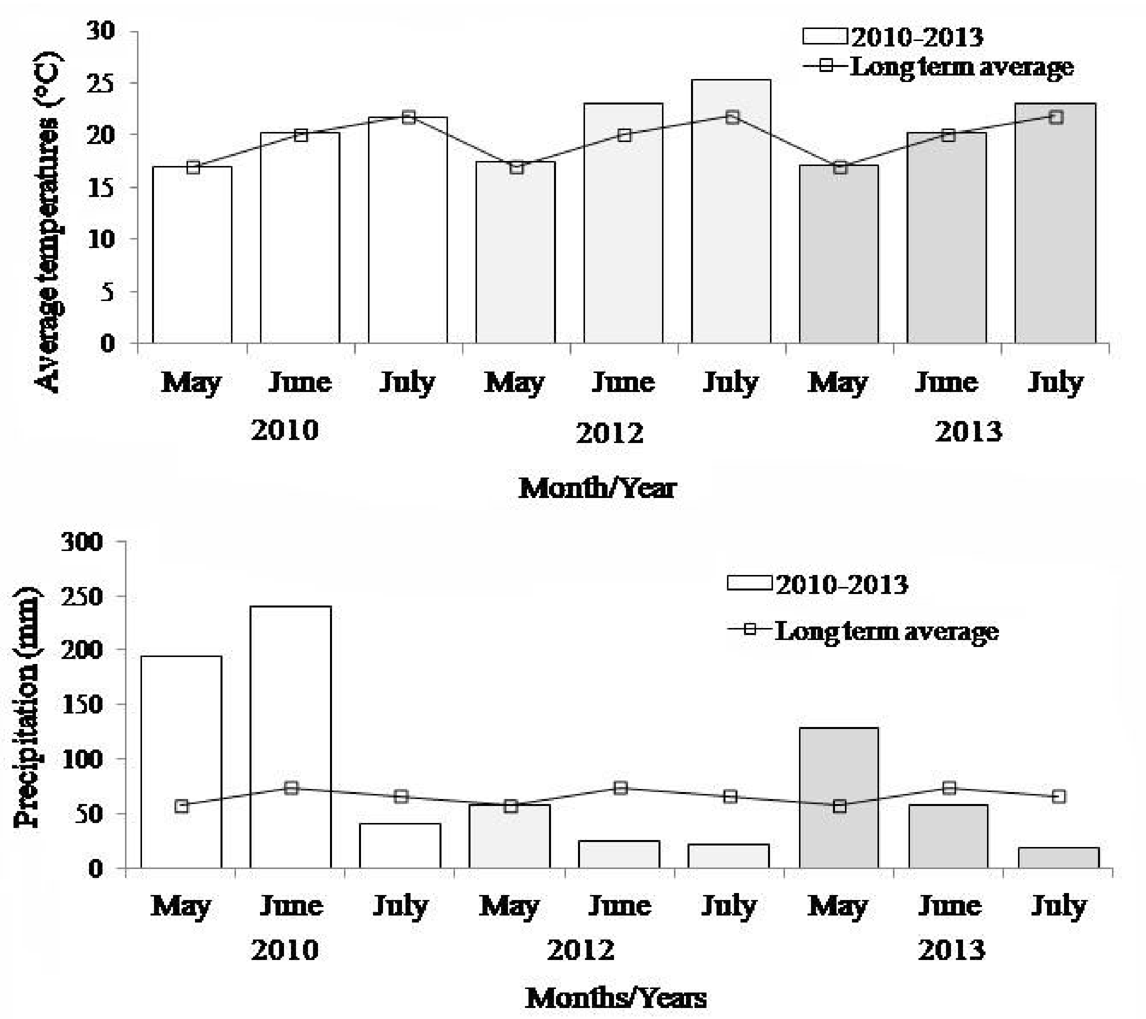


Fig. 1. Mean air temperature (°C) and precipitation (mm) in the cabbage growing period

Table 2. Chemical analysis of manure

Year	Type of manure	pH H_2O	pH KCL	N (%)	P_2O_5 (%)	K_2O (%)	Ash (%)	Organic matter (%)
2010	CM	6.9	6.6	1.2	1.82	0.33	24.84	75.16
	PM	7.9	7.7	1.3	3.58	1.68	16.48	83.52
2012	CM	6.8	6.6	1.4	2.28	0.58	24.32	75.68
	PM	7.9	7.8	2.6	3.95	1.62	16.95	83.05
2013	CM	6.9	6.7	2.2	3.17	0.91	25.36	74.64
	PM	7.8	7.6	3.1	4.90	1.32	16.01	83.99

CM – mature cattle manure, PM – composted pig manure

The applied amounts of used organic fertilizers are shown in Table 3, calculated on the manure analysis results.

The early hybrid Adema RZ F1 was used in the trial. Seedlings were produced in a greenhouse in compressed square blocks (3 × 3 × 3 cm) using peat moss as the growing medium. The cabbage seedlings were transplanted to the open field in the stage of 5 to 6 true leaves, with a 40 cm distance within rows and 60 cm between rows, thus reaching a density of 4.2 plants m^2. The plot size was 6 m^2, and there were 25 plants on a single plot per replicate. The soil was mulched with non-degradable black polyethylene film (density 920 kg m^3, thickness 20 µm, width 80 cm), with two rows of cabbage being planted on one mulch strip. The drip irrigation method was applied with one dripper liner installed along every row of planted cabbage, with a 4 l/h/m capacity. The dates of sowing, transplanting, and harvesting in all three trial years are given in Table 4.

Measurements and analytical determination. All plants were used to determine the analyzed parameters. Cabbage was harvested when the crop was technologically mature. Biological yield and head yield were measured at the end of the growing period. The quantity of N, P_2O_5, and K_2O removed by plants was calculated based on the total yield, dry matter content, and contents of N, P, and K in dry matter. Nutrient use efficiency was expressed by partial nutrient balance.

The partial nutrient balance (PNB) is obtained by comparing the amount of nutrient removal by total yield and the rate of applied nutrients through fertilizers.

$$PNB = U_H/F$$

where U_H is the nutrient content of a harvested portion of the crop, and F is the rate of nutrient applied [Fixen et al. 2015].

When PNB is 1, soil fertility is assumed to be stable. Values below 1 designate that nutrient input through fertilizers exceeds nutrient output through yield. Alternatively, values above 1 suggest that nutrient output is higher than input, which might be desirable when nutrient content in the soil is higher than

Table 3. Applied amounts of nutrients in three trial years (kg ha^{-1})

Treatments	Year								
	2010			2012			2013		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Ø	0	0	0	0	0	0	0	0	0
CM	118	178	32	137	223	57	216	311	89
PM	127	351	165	254	387	159	301	480	129
CM + $N_{55}P_{55}K_{105}$	173	233	137	192	278	162	271	366	194
PM + $N_{55}P_{55}K_{105}$	182	406	270	309	442	264	356	535	234
$N_{55}P_{55}K_{105}$	55	55	105	55	55	105	55	55	105

CM – mature cattle manure, PM – composted pig manure

Table 4. The dates of sowing, transplanting, and harvesting in all three trial years

	2010	2012	2013
Sowing	20 March 2010	3 April 2012	23 March 2013
Transplanting	8 May 2010	10 May 2012	4 May 2013
Harvesting	8 July 2010	17 July 2012	23 July 2013

recommended. When nutrient content in the soil is at the level of recommended content or below, then PNB > 1 is not sustainable [Fixen et al. 2015].

The pH value of the soil was determined in a suspension of soil and H_2O (1 : 2.5) using a Metrel MA 3657 pH meter [ISO 10390]. Calcium carbonate ($CaCO_3$) content in the soil was determined volumetrically using a Scheibler calcimeter. A CHNS analyzer (Elementar Vario EL, GmbH, Hanau, Germany) determined the soil's total N and C content. Plant-available P and K in the soil were extracted with an AL solution (0.1 M ammonium lactate and 0.4 M acetic acid, pH 3.75) at a soil-to-solution ratio of 1 : 20 (w/v) [Enger et al. 1960]. The content of dry matter in organic fertilizer was determined gravimetrically (70°C for 24 h). Total N content was determined using a CHNS analyzer ("Elementar Vario EL"). K concentration in organic fertilizer was determined after wet-digestion with a mixture of HNO_3:$HClO_4$ (4:1, v/v), using an atomic absorption spectrometer ("Shimadzu 6300") with flame technique, while P concentration in the solutions was measured colorimetrically by spectrophotometer "Jenway 6105" (USA).

Statistical analysis. Statistical analysis of experimental data was accomplished by two-factor analysis of variance (ANOVA) using TIBCO Statistica 14.0.0.15 software package (TIBCO Software Inc., 2020). The first factor was ground cover (with or without mulch), and the second was fertilization. In post-hoc analysis, mean values were compared using Fisher's least significant difference test (LSD test) at the level of significance $\alpha = 0.05$. Uppercase mark significance in the difference among mulching treatments. Lowercase letters mark significance in the difference among fertilizing treatments. Treatments significantly different don't have common letters.

RESULTS AND DISCUSSION

The total yield of cabbage, total head yield, and average head weight are shown in Table 5. In 2010 the treatment PM+NPK had the highest total cabbage yield, total head yield, and average head weight. All other treatments had significantly lower values.

The application of fertilizers considerably affected total cabbage yield, total head yield, and average head weight in 2012. The highest total yield on fertilized plots was found in PM + NPK, which was 64% higher than the control values. The highest total head yield and average head weight values were achieved on PM treatment. The values of the analyzed parameters did not differ significantly between PM, CM + NPK, PM + NPK, and NPK treatments. The lowest values were measured in the control.

The highest total yield in 2013 was found in CM + NPK, and the lowest in CM. These results agree with Kandil and Gad [2009], who reported that the highest yields due to synergy between organic and mineral fertilizers were obtained. High values were also found in PM+NPK and PM. There was no significant difference between the control and NPK. The highest value of total head yield on fertilized plots was achieved on PM + NPK treatment, but there was no significant difference between PM, CM+ NPK, and PM + NPK. The lowest values of total head yield were measured in control and CM. The highest values of average head weight occurred on CM + NPK and PM + NPK, while the values recorded on control and CM were lower by 20% and 16%, respectively. All fertilized treatments showed significantly higher average head weight than control, except CM.

In 2010 and 2013, total cabbage yield, total head yield, and average head weight were significantly higher on black polyethylene mulched plots. In 2012 values of the examined parameters did not differ significantly between the mulched and unmulched treatments. In May 2012, the mean monthly air temperature was 17.5°C, which exceeded the long-term average by 0.4°C. June and July 2012 were also hotter than the long-term average by 2.4°C and 3.2°C, respectively. When the soil was covered with black polyethylene film, high air temperatures caused an increase in soil temperature [Lamont 2001, Kumar and Day 2011]. Due to high air and soil temperatures in the mid-early cabbage growing period, mulching had no beneficial effects on total cabbage yield, total head yield, and average head weight in 2012. Diaz-Perez [2009] reported that dark-colored plastic film mulch could be beneficial for spring production in areas where early spring is cool since different seasons saw varying effects of mulch on plant growth and yield.

Furthermore, Trdan et al. [2008] strongly suggested using black polyethylene film in cold and wet springs, while Siwek et al. [2007] discussed the effectiveness

Table 5. Total cabbage yield, total head yield, and average head weight depending on fertilization and mulching

Fertilization, mulch	Total yield ($t\ ha^{-1}$)	Total head yield ($t\ ha^{-1}$)	Average head weight (kg)
2010			
Ø	43.18 c	31.48 c	1.04 c
CM	43.11 c	33.36 c	1.03 c
PM	68.03 b	54.74 b	1.63 b
CM + NPK	66.02 b	50.10 b	1.58 b
PM + NPK	83.94 a	63.64 a	2.01 a
NPK	70.23 b	53.57 b	1.63 b
Unmulched	57.11 B	43.11 B	1.35 B
Mulched	67.72 A	52.51 A	1.62 A
2012			
Ø	53.56 c	36.82 c	0.92 c
CM	65.98 b	47.17 b	1.18 b
PM	82.58 a	60.64 a	1.52 a
CM + NPK	79.61 a	58.67 a	1.47 a
PM + NPK	83.42 a	59.86 a	1.50 a
NPK	80.06 a	59.01 a	1.48 a
Unmulched	73.69 A	53.61 A	1.34 A
Mulched	74.71 A	53.78 A	1.34 A
2013			
Ø	51.93 b	23.92 c	0.60 c
CM	47.96 c	25.01 c	0.63 bc
PM	55.40 a	28.18 ab	0.72 a
CM + NPK	56.15 a	29.26 a	0.75 a
PM + NPK	55.97 a	29.57 a	0.75 a
NPK	49.79 b	27.04 b	0.66 b
Unmulched	45.69 B	23.99 B	0.61 B
Mulched	60.04 A	30.34 A	0.76 A

Ø – control, unfertilized; CM – mature cattle manure, PM – composted pig manure. Values followed by different uppercase (mulching) and lowercase (fertilization) letters are statistically significantly different at $p < 0.05$ within the same year

of mulching, finding that it largely depends on the climate and weather conditions of a particular year, and reported somewhat higher yields in cooler spring.

Black polyethylene mulch significantly enhanced root growth [Diaz-Perez 2009, Kumar and Day 2011] due to the favorable hydro-thermal regime of soil [Parmar et al. 2013] and aided in protecting the plants from low temperatures during May nights [Trdan et al. 2008], which is essential when cabbage is grown in spring. In all three trial years, mean daily temperatures were below the long-term average in early and late May, except for late May of the first trial year. Black polyethylene mulch retains soil moisture [Trdan et al. 2008], particularly near the crop root zone, and diminishes evaporation loss [Parmar et al. 2013]. Soil moisture is vital for microbial and biochemical soil properties. When the soil moisture content is low, the metabolic activity of microorganisms is reduced, whereby respiration and mineralization of nutrients are decreased [Schimel et al. 2007].

Mulched cabbage showed higher values in 2010 and 2013 than the unmulched treatment: higher total cabbage yield by 18.58% and 31.40%, higher total head yield by 21.80% and 26.46%, and higher average head weight by 20.0% and 26.46%, respectively. Many authors reported on increased cabbage yields due to black polyethylene film, most confidently of all Trdan et al. [2008], who claimed the highest crop yield when grown in such a way. Tiwari et al. [2003] reported that cabbage yield on black film mulched soil was higher than unmulched cabbage yield by 5% to 9.6%, lower than ours in the first and third years. Verma et al. [2017] attained a cabbage yield increase owing to black film mulch by 22.4%, which correlates to our results, stating that it was due to improved soil conditions and more intensive utilization of nutrients, primarily N. Significantly higher yield due to black polyethylene film was reported on Chinese cabbage by Easmin et al. [2009] and on lettuce by Siwek et al. [2007]. Statistically significant increase in cabbage head weight due to black polyethylene mulch is in agreement with Sarker et al. [2003] and Trdan et al. [2008] and could be the advantageous outcome of the mulch preserving moisture and water, reducing nutrient uptake by weed and suppressing weed, increasing nutrient use efficiency and yield potential [Uwituze et al. 2017, Saudy et al. 2021].

Quantities of N, P_2O_5, and K_2O removed by the aboveground mass of cabbage are shown in Table 6. During the first and third trial years, mulched crops removed significantly higher amounts of N, P_2O_5, and K_2O than the unmulched ones. The mulched crops removed 26.7% more N, 16.1% more P_2O_5, and 10.6% more K_2O in the first year, 48.6% more N, 33.4% more P_2O_5, and 24.7% more K_2O in the third year. Black polyethylene film increases soil temperature in the plant root zone [Baghour et al. 2003], which improves nutrient uptake [Tindall et al. 1990]. Mulches improve nutrient use efficiency and uptake so plants can grow and develop properly [Kumar and Day 2011, Parmar et al. 2013, Uwituze et al. 2017]. In the second trial year, the mulched treatment showed significantly higher amounts of removed N, by 11.65% more than the unmulched treatment. There was no significant difference in removed P_2O_5, while the unmulched treatment showed a significantly higher amount of K_2O removed (5.9%). Cabbage removes most K_2O later in the growing period when the cabbage head grows. In the second trial year in the period of head growth, exceptionally high air temperatures increased soil temperature, which in extremely hot years caused extreme soil temperature increase below black mulch film in the plant root zone [Djigma and Diemkouma 1986]. Soil temperature below black mulch film can reach as high as 70°C [Hanada 1991], which most certainly has adverse effects on K_2O uptake since the optimal soil temperature in the root zone for the uptake of most macroelements in tomatoes falls around 25°C [Tindall et al. 1990], whereas broccoli, being most alike cabbage since both belong to the same species *Brassica oleracea*, yields highest under soil temperature of 21-25°C in the root zone [Diaz-Perez 2009].

In all three trial years, the highest amounts of N, P_2O_5, and K_2O were removed in the treatment PM+NPK, while the lowest uptake of all three elements was in control, except for P, which had the lowest uptake in CM treatment in the first year.

The second trial year was the highest amount of all three elements removed. Removed quantities of N, P_2O_5 and K_2O are in agreement with Reza et al. [2016] who reported on cabbage uptake of 122.2 kg ha^{-1} N, 20 kg ha^{-1} P_2O_5 and 90 kg ha^{-1} K_2O, and Chaterjee et al. [2016] who communicated 151–172 kg ha^{-1} N, 18.8–20 kg ha^{-1} P_2O_5 and 103.4–114.3 kg ha^{-1} K_2O. Salo et al. [2002] stated higher quantities of removed nutrients but also higher yields, with an output of 213–243 kg ha^{-1} N, 36–40 kg ha^{-1} P_2O_5, and 302–345 kg ha^{-1} K_2O through cabbage yield of 90 t ha^{-1}.

PNB-N was significantly higher in black polyethylene mulched treatments in the first and third trial years. It agrees with Sweeney et al. [1987], who reported on 30% N fertilizer use efficiency, which reached 53% in mulched crops. In 2012 there was no significant difference between mulched and unmulched treatments. In all three trial years, PNB-N in NPK treatment was above 1 (Fig. 2A), suggesting less N was applied than removed, and crops also used up N, which was mineralized during the growing period to form yield [Goreta et al. 2005]. All other fertilized treatments showed PNB-N below 1, signifying more nutrients were applied than removed. Such values are in agreement with Guo et al. [2011], who stated that only 30-35% of applied N is removed by plants on average worldwide, or 50% in temperate climate zones, while the rest contaminates surface and groundwater by leaching into deeper layers [Conversa et al. 2013]. Similarly, Zhang et al. [2004] reported that N fertilizer use is often double than recommended in intensive vegetable farming. Unrestricted N application is wasteful and can extend the growing period and post-

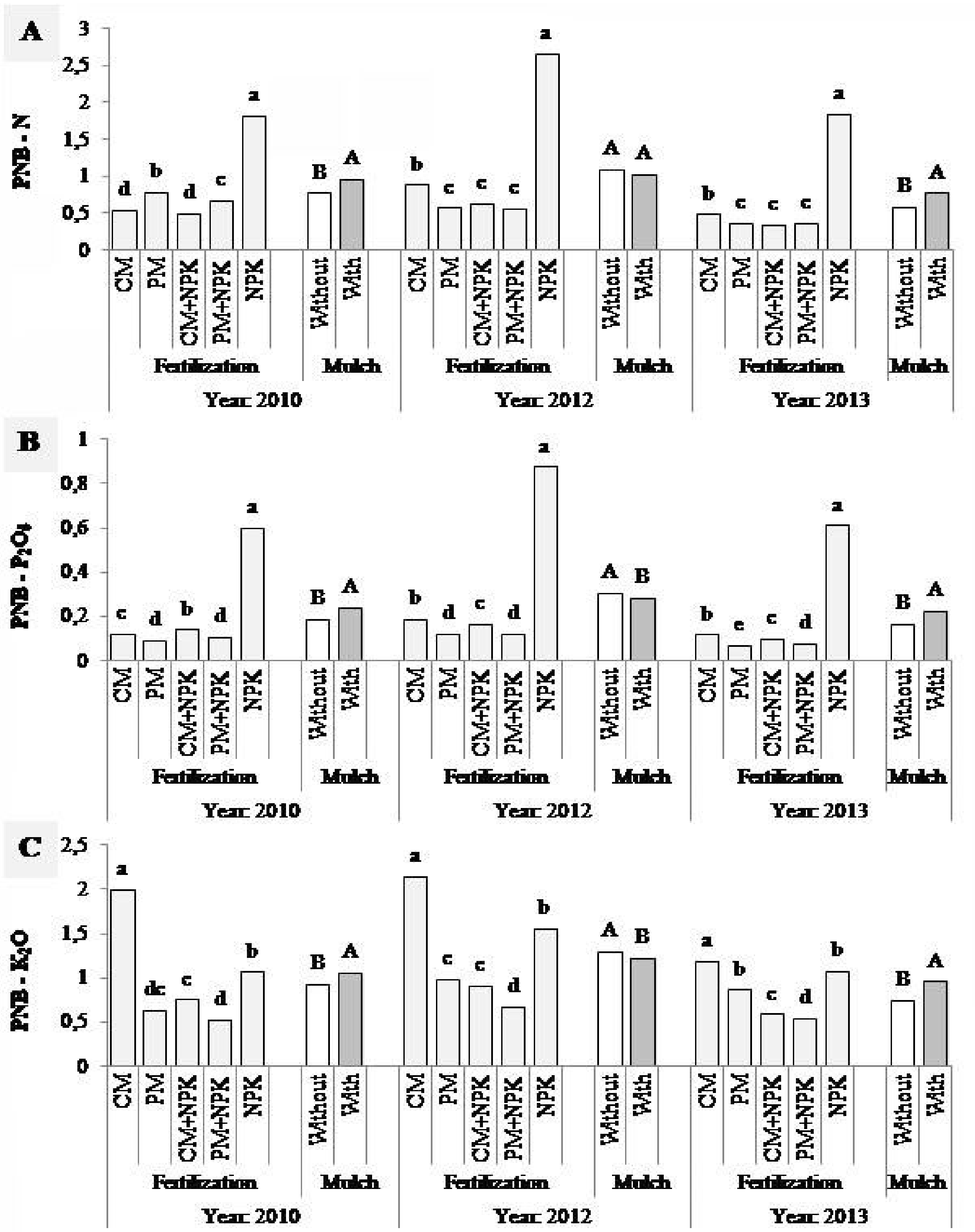
Table 6. Amounts of N, P_2O_5, and K_2O removed by cabbage

Fertilization, mulch	Removed N (kg ha^{-1})	Removed P_2O_5 (kg ha^{-1})	Removed K_2O (kg ha^{-1})
2010			
Ø	61,1 d	18,2 c	67,8 c
CM	62,7 d	21,6 c	63,5 c
PM	98,4 bc	30,6 b	104,1 b
CM + NPK	83,6 c	32,1 b	102,6 b
PM + NPK	121,7 a	41,6 a	141,3 a
NPK	100,1 b	32,7 b	111,3 b
Unmulched	77,6 B	27,3 B	93,5 B
Mulched	98,3 A	31,7 A	103,4A
2012			
Ø	89,3 d	26,8 d	99,6 d
CM	120,2 c	41,6 c	121,8 c
PM	144,6 b	45,7 bc	156,5 b
CM + NPK	120,0 c	46,2 bc	147,5 b
PM + NPK	169,6 a	54,0 a	176,2 a
NPK	146,0 b	48,0 b	163,1 b
Unmulched	124,4 B	43,4 A	148,2 A
Mulched	138,9 A	44,0 A	140,0 B
2013			
Ø	90,4 d	28,0 d	103,5 d
CM	103,4 bc	36,0 b	105,1 dc
PM	106,9 b	33,0 c	110,9 bc
CM + NPK	92,5 d	35,5 b	113,4 b
PM + NPK	126,1 a	39,4 a	126,5 a
NPK	100,9 c	33,4 c	112,6 b
Unmulched	83,2 B	29,3 B	99,7 B
Mulched	123,6 A	39,1 A	124,3 A

Ø – control, unfertilized; CM – mature cattle manure, PM – composted pig manure. Values followed by different uppercase (mulching) and lowercase (fertilization) letters are statistically significantly different at $p < 0.05$ within the same year

pone crop maturity [Easmin et al. 2009], increasing economic costs and negatively affecting human health [Elgala et al. 2022]. Therefore, the reasonable use of nitrogen fertilizers should be of primary importance for protecting the environment from pollution and farm profitability [Saudy et al. 2020].

PNB-P_2O_5 was significantly higher in the mulched crop in 2010 and 2013 and in the unmulched crop in 2012. In this three-year trial, in all fertilized treatments, more P_2O_5 was applied than removed, meaning that PNB-P_2O_5 was below 1 (Figure 2B). Treatment with NPK showed the highest values, while all other treatments showed values from 0.1 to 0.2, which agrees with Guo et al. [2011] in a spring cabbage trial. Simpson et al. [2011] reported on P_2O_5 removal of 40-90% of the applied quantity. In addition to positive



Values followed by different uppercase (mulching) and lowercase (fertilization) letters are statistically significantly different at $p < 0.05$ within the same year

Fig. 2. Partial nutrient balance (PNB) for N (A), P_2O_5 (B), and K_2O (C)

effects on soil's physical, chemical and biological properties, organic fertilizers used in this study also contained amounts of P_2O_5 which significantly exceeded cabbage requirements. The remainder of the applied but unremoved P_2O_5 can reach waterbodies through surface runoff and leaching [Sharpley et al. 2001].

PNB-K_2O was significantly higher in mulched treatments in 2010 and 2013 and significantly higher in unmulched treatments in 2012 (Fig. 2C). Treatments with CM and NPK showed the value of PNB-K_2O above 1 in all three trial years, meaning less K_2O was applied than removed. Other treatments showed values below 1, suggesting that more K_2O was applied through fertilizers than the crops removed. Our results disagree with Guo et al. [2011], who reported 0.25 to 0.27 in treatments with mineral fertilizers.

PNB values below 1 in all treatments, except for NPK and CM in the third year, indicate a risk of potential environmental contamination. Since the early and mid-early cabbage growing period is short, 60 days on average, vegetable and field crops could be grown as succeeding crops after the cabbage harvest. The soil's excess nutrients could be removed after the cabbage harvest.

CONCLUSION

Black polyethylene film significantly increased total cabbage yield, total head yield, average head weight, P_2O_5 and K_2O removal and fertilizer use efficiency in the first and third trial years. Additionally, mulching significantly affected N uptake in all three years. The applied organic fertilizers contained significantly higher amounts of P_2O_5 than the crops removed. Since the mean air temperature during the cabbage growing period in the second trial year exceeded the long-term average, there was no positive mulching effect for the most analyzed parameters. Based on the obtained results, it can be concluded that mulching efficiency depends on the climate and weather conditions during growing period, and black polyethylene mulch should be used in cool conditions of early spring. The experimental results suggested that nutrient combinations from different sources significantly affect the total yield, total head yield, and average head weight of cabbage. Combined mulching and PM or PM+NPK fertilizer application could be recommended in mid-early cabbage production.

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