Tropentag 2014, Prague, Czech Republic
September 17-19, 2014

Conference on International Research on Food Security, Natural Resource Management and Rural Development
organised by the Czech University of Life Sciences Prague

Nutrient capture efficiency, use efficiency and productivity in sole cropping and intercropping of rapeseed, bean and corn

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proposed outline

Introduction

Nutrients are the second most important limiting factor after water in crop production. Nitrogen, phosphorus and potassium are the most required nutrients in crop production (Mengel and Kirkby, 2001). Therefore, enhancing efficiency and productivity of these nutrients can be regarded as an important management factor in crop production (Brussaard *et al*., 2007). Increasing nutrient efficiency, not only reduces environmental pollution but also improves economic incomes for farmers (Rathke *et al*., 2006). Capture efficiency is the ratio of nutrient uptake to the available nutrient (Cassman *et al*., 2002; Brussaard *et al*., 2007; Tittonell *et al*., 2007). Capture efficiency of nitrogen for cereals have been reported to be 33% worldwide, which is 42% for developed countries and 29% for developing countries (Raun and Johnson, 1999). Nutrient use efficiency is the ratio of seed yield to the amount of nutrient in the above ground parts of plant (Rathke *et al*., 2006). Tittonell *et al*. (2007) described nutrient use efficiency as dry matter produced (Kg) by each Kg of nutrient uptake. The minimum and maximum amount of nutrient use efficiency for corn has been reported to be 30-70 Kg per Kg nitrogen, 200-600 Kg per Kg phosphorus and 30-130 Kg per Kg potassium (Janssen, 1998). Nutrient productivity is the amount of biomass produced per unit of available nutrient (An *et al*., 2005). Rathke *et al*. (2006) calculated nitrogen productivity as seed yield per amount of nitrogen applied. Nutrient productivity is the product of capture efficiency and use efficiency (Cassman *et al*., 2002). Morris and Garrity (1993) reported in intercropping, average of phosphorous and potassium uptake increased 43 and 35 percent compared to sole cropping, in turn. Root system is extensive in intercropping and it is possible to uptake immobile nutrients like phosphorous and potassium from larger area. In Gunes *et al.* (2007) study, legume species increased phosphorus availability for wheat and it was shown by increasing in wheat yield and enhancing in phosphorus concentration in above ground part of wheat plant, too. Legumes in intercropping with grass, provide large amount of nitrogen needed for grass. In Ghosh *et al*. (2006) study, activity of Nitrate-reductase enzyme which is necessity for optimum use of soil nitrogen and also chlorophyll amount in sorghum in intercropping was more than that in sole cropping. With consideration to ecological and agronomic importance of intercropping systems, this experiment was conducted for examining of intercropping and sole cropping of three crops including rapeseed, bean and corn with a view to investigation of nutrient efficiency in terms of capture, use and also productivity for the main plant nutrients of nitrogen, phosphorus and potassium.

Material and Methods

This experiment was conducted in two growing seasons of 2007-2008 and 2008-2009 in research farm of Faculty of Agriculture, Ferdowsi University of Mashhad, Iran in a geographical location of latitude 36° and 16′ North and longitude 59° and 38′ East with an altitude of 985m above the sea level in a loamy soil. The treatments were arranged in a randomized complete block design with three replications. These treatments included monoculture of rapeseed (sown 23 September), bean and corn (sown in 30 April) as sole cropping and simultaneous intercropping of bean and corn (sown in 30 April), two-stage relay intercropping (rapeseed sown in 23 September and bean and corn in 30 April) and finally three-stage relay intercropping (rapeseed sown in 23 September, bean sown in 9 April and corn sown in 30 April). Modena cultivar of rapeseed, Derakhshan cultivar of bean and late maturating 704 cultivar of corn were used. Crops were sown in plots of 3m×4m with 1m distance between each plot. Plants were cultivated in rows of 50cm apart with plant density of 20, 14 and 7 plant/m^2 for rapeseed, bean and corn, respectively. There were six rows in each plot. In intercropping plots, species were sown in alternating single rows with replacement design. Triple Super phosphate and Potassium sulfate fertilizers were applied pre planting stage in 21 September 2007 & 21 September 2008 with a rate of 100 and 150 $Kg.ha^{-1}$, respectively. In addition, urea fertilizer was applied at a rate of 150 $Kg.ha^{-1}$ in two splits for rapeseed and corn sole cropping. In order to determine nutrients content of plants, three plants from each species were picked up at harvesting stage. Nitrogen, phosphorus and potassium content were measured by the standard methods of Kejeldal (Ogg, 1960; PECO Distillation Unit PDU-500), spectrophotometer (unico2100/visible) and flame photometer instruments (Telf AZMOON pars 310C). The amount of each nutrient captured in dry matter per ground square meter was calculated as nutrient yield. Total nutrient capture for each species was calculated as the product of nutrient content and total dry matter. Capture efficiency, use efficiency and productivity (based on total dry matter and seed yield) for each species and land equivalent ratio based on capture efficiency, use efficiency and productivity for nutrients were calculated by the following equations:

Equation (1): Nutrient Capture Efficiency (NCE) (for each species)= plant nutrient content (for each species)/available nutrient (Ehdaie *et al*., 2001).

Equation (2): Nutrient Use Efficiency based on Total Dry Matter (NUE_{DM}) (for each species)= total dry matter (for each species)/plant nutrient content (Tittonell *et al*., 2007).

Equation (3): Nutrient Use Efficiency based on Seed Yield (NUE_{SY}) (for each species)= seed yield (for each species)/plant nutrient content (Rathke *et al*., 2006).

Equation (4): Nutrient Productivity based on Total Dry Matter (NP_{DM}) (for each species)= NUE_{DM} (for each species)×NCE (for each species) (An *et al*., 2005).

Equation (5): Nutrient Productivity based on Seed Yield (NP_{SY}) (for each species)= NUE_{SY} (for each species)×NCE (for each species) (Ehdaie *et al*., 2001).

Equation (6): Land Equivalent Ration (LER); $LER = \sum_{i=1}^{m} Yi/Yii$

In this equation Yi is seed yield or total dry matter of a species in intercropping, and Yii is seed yield or total dry matter of the same species in sole cropping. Statistical analysis was done by Excel and MSTAT-C softwares. Duncan's multiple range tests was used for means comparison.

Results and Discussion

Based on results, nitrogen productivity based on total dry matter in corn was highest at sole cropping (53.5 $Kg.kg^{-1}$) and simultaneous intercropping (67.8 $Kg.kg^{-1}$) compared to that in relay intercropping systems (21.4 & 24.2 $Kg.kg^{-1}$), significantly ($P \leq 0.01$) (Table 1). For bean, nitrogen productivity based on seed yield was highest at sole cropping (4.5 $Kg.kg^{-1}$) and simultaneous (4.3 $Kg.kg^{-1}$) intercropping, significantly ($P \leq 0.01$) (Table 1) compared to that in relay intercropping systems (2 & 1.5 $Kg.kg^{-1}$). For corn, nitrogen productivity based on seed yield was highest at simultaneous intercropping (20.4 $Kg.kg^{-1}$) , significantly ($P \leq 0.01$) (Table 1).

Based on results, phosphorus productivity based on seed yield in rapeseed was highest at sole cropping (31.6 $Kg.kg^{-1}$) compared to that in relay intercropping systems (21.2 & 20.2 $Kg.kg^{-1}$), significantly ($P \leq 0.01$) (Table 1). For bean, phosphorus productivity based on seed yield was highest at sole cropping (22.5 $Kg.kg^{-1}$) and simultaneous intercropping (21.3 $Kg.kg^{-1}$) compared to that in three-stage relay intercropping systems (9.3 $Kg.kg^{-1}$) , significantly ($P \leq 0.01$) (Table 1). For corn, phosphorus productivity was highest at sole (270.5 & 77.1 $Kg.kg^{-1}$ based on dry matter and seed yield, in turn) and simultaneous intercropping (240.7 & 71.9 $Kg.kg^{-1}$ based on dry matter and seed yield, in turn) compared to that in relay intercropping systems (around 114.6 & 31.45 $Kg.kg^{-1}$ based on dry matter and seed yield, in turn), significantly ($P \leq 0.01$) (Table 1). Based on results, in rapeseed, potassium productivity based on seed yield was highest at sole cropping (5.6 $Kg.kg^{-1}$) compared to that in relay intercropping systems (3.7 $Kg.kg^{-1}$), significantly ($P \leq 0.01$) (Table 1). In bean, the lowest potassium productivity was obtained at three-stage relay intercropping system (1.5 $Kg.kg^{-1}$), significantly ($P \leq 0.01$) (Table 1). In corn, potassium productivity was highest at sole cropping (48.9 & 13.9 $Kg.kg^{-1}$ based on dry matter and seed yield, in turn) and simultaneous intercropping (52.5 & 15.9 $Kg.kg^{-1}$ based on dry matter and seed yield, in turn) compared to that in relay intercropping systems (around 20.25 & 5.55 $Kg.kg^{-1}$ based on dry matter and seed yield, in turn), significantly ($P \leq 0.01$) (Table 1). Values of LER were higher than 1 for relay intercropping combinations and LER values in relay intercropping combinations were significantly ($P \leq 0.01$) higher than that in simultaneous intercropping. Other researchers confirmed the superiority of intercropping in using of resource, effectively (Gunes *et al.* 2007).

Table 1: Nitrogen (N), Phosphorus (P) and Potassium (K) economy and yield characteristics for sole and intercropping of rapeseed (*Brassica napus*), bean (*Phaseolus vulgaris*) and corn (*Zea mays*); (Mean of two years of 2007-2008 & 2008-2009)

Trait	Units	Sole cropping			Simultaneous intercropping		Two-stage relay intercropping			Three-stage relay intercropping		
		Rapeseed	Bean	Corn	Bean	Corn	Rapeseed	Bean	Corn	Rapeseed	Bean	Corn
N concentration in total dry matter	$g.kg^{-1}$	12.7	21.0	9.9	18.5	7.2	6.5	18.0	7.5	6.5	18.0	7.5
Nitrogen capture (DM)	$Kg.ha^{-1}$	115.9	70.4	177.2	60.7	120.2	55.1	37.6	52.5	57.9	30.3	57.0
Nitrogen capture efficiency	%	31 a*	26 a	53 a	21 ab	47 a	15 b	11 bc	16 b	15 b	9 c	18 b
Nitrogen use efficiency (DM)	$Kg.kg^{-1}$	81.0 b	47.7 b	100.9 c	54.4 a	144.2 a	154.8 a	56.25 a	133.9 b	155.2 a	56.3 a	134.5 b
Nitrogen use efficiency (SY)	$Kg.kg^{-1}$	18.3 b	17.2 a	28.8 c	20.2 a	43.4 a	25.8 a	18.4 a	37.6 b	24.2 a	16.9 a	36.4 b
Nitrogen productivity (DM)	$Kg.kg^{-1}$	25.1 a	12.4 a	53.5 a	11.4 a	67.8 a	23.2 a	6.2 a	21.4 b	23.3 a	5.1 a	24.2 b
Nitrogen productivity (SY)	$Kg.kg^{-1}$	5.7 a	4.5 a	15.2 b	4.3 ab	20.4 a	3.9 a	2.0 bc	6.0 c	3.6 a	1.5 c	6.6 c
P concentration in total dry matter	$g.kg^{-1}$	1.6	3.0	1.0	2.9	1.0	0.9	1.5	1.2	0.8	1.5	1
Total Phosphorus capture (DM)	$Kg.ha^{-1}$	13.1	10.4	17.8	9.4	16.3	7.3	3.3	8.6	7.6	2.6	7.5
Phosphorus capture efficiency	%	20.0 a	16.0 a	27.0 a	14.0 a	24.0 a	11.0 b	5.0 b	13.0 b	11.0 b	4.0 b	11.0 b
Phosphorus use efficiency (DM)	$Kg.kg^{-1}$	732.0 b	375.0 b	1002.0 a	402.8 b	1003.0 a	1163.0 a	751.7 a	916.7 a	1181.0 a	750.0 a	1000.0 a
Phosphorus use efficiency (SY)	$Kg.kg^{-1}$	158.1 a	140.5 b	285.5 a	152.1 b	299.4 a	192.7 a	255.8 a	255.8 a	184.1 a	232.3 a	270.0 a
Phosphorus productivity (DM)	$Kg.kg^{-1}$	146.4 a	60.0 a	270.5 a	56.4a	240.7 a	127.9 a	37.6 a	119.2 b	129.9 a	30.0 a	110.0 b
Phosphorus productivity (SY)	$Kg.kg^{-1}$	31.6 a	22.5 a	77.1 a	21.3 a	71.9 a	21.2 b	12.8 ab	33.2 b	20.2 b	9.3 b	29.7 b
K concentration in total dry matter	$g.kg^{-1}$	13.5	30.0	9.0	25.0	7.5	5.3	20.0	5.0	5. 7	25.0	4.5
Total Potassium capture (DM)	$Kg.ha^{-1}$	122.4	101.0	160.5	81.6	126.1	45.2	42.2	34.7	51.8	42.9	34.9
Potassium Capture Efficiency	%	32.0 a	27.0 a	44.0 a	22.0 ab	35.0 a	12.0 b	11.0 b	9.0 b	13.0 b	12.0 b	10.0 b
Potassium use efficiency (DM)	$Kg.kg^{-1}$	79.9 b	33.3 a	111.1 d	40.0 a	150.0 c	190.5 a	50.0 a	200.0 b	181.0 a	41. 7 a	225.0 a
Potassium use efficiency (SY)	$Kg.kg^{-1}$	17.6 b	12.1 a	31.7 c	14.9 a	45.5 b	31.1 a	16.5 a	56.0 a	28.5 a	12.8 a	61.2 a
Potassium productivity (DM)	$Kg.kg^{-1}$	25.6 a	9.0 a	48.9 a	8.8 a	52.5 a	22.9 a	5.5 a	18.0 b	23.5 a	5.0 a	22.5 b
Potassium productivity (SY)	$Kg.kg^{-1}$	5.6 a	3.3 a	13.9 a	3.3 a	15.9 a	3.7 b	1.8 ab	5.0 b	3.7 b	1.5 b	6.1 b
Total dry matter (TDM)	$Kg.ha^{-1}$	9305 a	3162 a	17835 a	3265 a	16350 a	8475 a	2115 b	6945 b	8750 a	1695 b	7490 b
Seed yield	$Kg.ha^{-1}$	2020 a	1195 a	5000 a	1140 a	4835 a	1405 b	700 b	1950 b	1335 b	490 b	1965 b
Harvest index	kg seed. kg^{-1} TDM	0.23 a	0.38 a	0.29 a	0.35 a	0.30 a	0.17 b	0.33 a	0.28 a	0.16 b	0.29 a	0.27 a

DM: based on total dry matter; SY: based on seed yield

*: Means by the uncommon letter in each row (for each species) are significantly different according to Duncan's Multiple Range Tests ($p \leq 0.01$).

Conclusions and Outlook

Based on results, in some cases, intercropping combinations showed positive and significant ($P \leq 0.01$) effects on nutrients capture efficiency, use efficiency and productivity compared with sole cropping treatments. Also, LER values for seed yield and total dry matter were higher than 1 for relay intercropping combinations. Generally, it seems that among treatments, simultaneous intercropping of bean and corn can improve nutrients productivity index.

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