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Research Article

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Phosphorus Soil Test Calibration for Irrigated Sugar Beet P Fertilizer Recommendation under Morocco Mediterranean Conditions

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Abstract

The current sugar beet fertilizer applications in Morocco are based on sugar beet fertilization experiments and soil testing, to assess the soil fertility, carried out in different regions. There is a need to develop soil test interpretation norms developed under local pedoclimatic conditions in order to make precise fertilizer recommendations for each farmers plot. Eight sugar beet fertilization experiments were conducted on farmer's plots in two major sugar beet producing regions of Morocco; Doukkala region and Tadla region. Four phosphorus rates of 0, 22, 44, and 66 kg P.ha-1 were applied at planting as triple superphosphate in a completely randomized bloc design with four replications. Sugar beet responded to the phosphorus input at three out of the eight locations. The results showed that if Olsen's soil available P test is greater than 16 mg P.kg-1, no fertilizer P application for sugar beet is necessary because it will have no effect on the productivity of the sugar beet. On the contrary, this contribution constitutes a waste of financial resources. Gross marginal return from P fertilizer application increased with relative sugar beet root yield improvement. Sugar beet economical optimum P fertilizer rate requirement varied from 0 to 60 kg P.ha-1, depending of soil P Olsen level. The very good correlation between soil available P level and sugar beet P requirement rate allows for better P fertilizer recommendations for this crop. Indeed, available P tests performed before planting are currently used for making fertilizer P recommendations for sugar beet for farmers in these regions.

Keywords: Sugar Beet; Olsen Phosphorus; Fertilization; Soil Test Calibration; Mediterranean

Introduction

Sugar beet crop acreage is about 56 000 ha in Morocco distributed in five regions. The regions of Doukkala and Tadla represent 66% with 35 000 ha with an average root yield of 66.9 $t.ha^{-1}$ and 10.9 $t.ha^{-1}$ of sugar [1]. Sugar beet fertilization strategies for sugar beet in Morocco consists of applications of pre plant and top-dress fertilizers. The pre-plant fertilizer, distributed to the farmers by the Morocco Sugar Company (COSUMAR) consists of a small part of the nitrogen (N) and the total amounts of phosphorus (P) and potassium (K). These rates were based on the average soil fertility of each region. Top dress fertilizers, made up of nitrogen, are applied during growing season [2]. The current fertilizer applications have been based on some sugar beet fertilization experiments and soil testing, to assess the soil fertility, carried out in different regions. These studies are starting to date and soil fertility varies over time and updates are needed. Moreover, the lack of soil test interpretation norms developed under local pedoclimatic conditions make it difficult to make precise fertilizer recommendations for each farmer's plot [2]. Indeed, the use of generalized pre-plant fertilizer formulas becomes economically and environmentally unjustified because with these formulas, necessarily some plots are under-fertilized, which affects the productivity of crops and some are over-fertilized leading to economic loess and environmental problems. Phosphorus, with nitrogen and potassium, is a major plant nutrient for sugar beet. Phosphorus is taken up the plant as $H_2PO_4^-$ and HPO_4^{2-}. In calcareous soils, the case for the majority of the soils in Morocco, applied phosphorus is converted, over time, into calcium phosphate minerals in the following order and with a decreasing solubility in the soil solution: dicalcium phosphate, octacalcium phosphate and tricalcium phosphate, formed in that order, and ultimately apatite. Each of these compounds takes longer to form. For example, dicalcium phosphate will form in days, octa and tricalcium phosphate in months, while apatite will take years [3].

A major reason why sugar beet grown on calcareous soils is often very productive is that these intermediate forms contribute to the labile fraction and hence to the phosphorus in the soil solution. Once taken up, the phosphate ions are mobile in the plant and rapidly incorporated into organic compounds. One important function of the phosphorus is in the formation of ATP which is used to transfer energy produced by photosynthesis into energy stored as sugar. Thus, an adequate supply of phosphorus is throughout the whole crop cycle is essential to maintain effective production [4]. Sipitanos and Ulrich [5] showed that under phosphorus deficiency conditions, seedlings lack vigour, grow slowly and produce small plants resulting in loss of stand due to susceptibility to physical damage. A supply of phosphorus fertilizer around the roots has a visible effect on vigour, size and plant number. A reduction in yield because of insufficient phosphorus is initiated very early and is maintained throughout the growing season. Even though the above-ground sugar beet growth appears to return to near normal as the growing season progresses, root yield potential may already have been reduced [6]. Soil testing is a useful tool to decide where the crop will respond economically to the application of phosphorus fertilizer. It is done through soil P test correlation and calibration studies. Correlation aims to select the soil P test with results that are best correlated with crop growth or crop P uptake. Indeed, available phosphorus is determined using different soil extract ants such as sodium bicarbonate, calcium ammonium lactate, water and ion-exchange resins. Olsen's bicarbonate extraction [7] was found to be the best method for neutral and calcareous soil of Morocco [8]. Soil P test calibration is based on crop P fertilization field experiments that allow the determination of economically optimum P requirement. Draycott and Durrant [9] defined more the magnitude of the response to fertilizer and the economic optimum application based on soil available P determined using the Olsen, et al. [7] method. Sugar beet responses were up to 2 t sugar.ha^{-1} in soils containing less than available phosphorus 9 mg P.l^{-1}, over 1 t sugar.ha^{-1} in soils containing 10-15 mg P.l^{-1}, and nearly 0.5 t sugar.ha^{-1} in soils containing 16-25 mg P.l^{-1}. In higher groups, responses were negligible. Draycott [10] summarized the optimum P fertilizer requirement of sugar beet in the USA and UK which varied from 67 kg P.ha^{-1} for soils available P less than 9 to zero for soils above 45 mg P.l^{-1} of available P. In n Greece, Analogides [11] reported similar results, in 73 field experiments, with soils with less 10 mg P kg^{-1} of available P showing the large responses. Sanz Saez [12] also found all the large responses where soil contained less than 10 mg P kg^{-1}. In UK, Draycott and Martindale [13] showed that in UK, 1,44 kg P.ha^{-1}was given to produce each tonne of roots ha^{-1} in 1970. By 1999 this had declined threefold to 0.48 kg P.ha^{-1}. This remarkable result reflected both a decline in excessive usage and increasing yield over the period. This research aims to develop a sugar beet P fertilization program based on soil tests in order to improve soil fertility and better manage crop fertilization.

Materials and Methods

Eight sugar beet fertilization experiments were conducted on farmers plots in two major sugar beet producing regions of Morocco; Doukkala region and Tadla region. Composite soil samples were collected from each plot prior to planting. Soil tests were carried out using the following methods: particle size distribution by the Robinson pipette method [14], soil pH [15] and total limestone by the weight loss method (NF ISO 10693), organic matter by the Walkey-Black method [16], available phosphorus [7], and exchangeable potassium [17]. Soil texture varied from sandy to clay Table 1. All soils are basic and with low soil organic matter content. Soil available P and exchangeable K levels varied in both regions.

The experiment was conducted in a completely randomized bloc design with four replications with a plot unit of 3 x 6 m^2 size, which corresponds to six plant rows each of 50 cm apart and 6 m long. Four phosphorus rates of 0, 22, 44, and 66 kg P.ha^{-1} were applied at planting as triple superphosphate, which occurred in October 2018. All the treatments received 100 kg K.ha^{-1} as potassium sulfate and 60 kg N.ha^{-1} as ammonium sulphate with phosphorus. Top-dress nitrogen was split as follows: 90 kg N.ha^{-1} at 4-8 leaf stage as ammonium nitrate and 90 kg N.ha^{-1} at mid-season as urea. All the experiments were irrigated. At harvest, on June 2019, sugar beet final stand, root weight, and root yield where determined. 30 sugar beet roots were sampled in each elementary plot to determine the sugar beet technological quality. Sucrose percentage was determined in the sugar refinery laboratory of each region Polari metrically on lead acetate extract of fresh macerated roots. All data were statistically analyzed according to the technique of analysis of variance, the least significant difference was used to compare the differences between the means of studied treatments values according to methods described by Gomez and Gomez [18].

Region	Location	Clay %	Silt %	Sand %	Total Lime %	pH	Organic matter %	Olsen phosphorus mg P.kg-1	Exchangeable potassium mg K.kg-1
Doukkala	1	17.6	34.8	47.7	1.7	7.7	1	34,39	144
	2	0.6	6.3	93.1	0	7.6	0.7	52,15	124
	3	3.9	12.8	83.2	0	6.9	0.8	22,45	106
	4	5.2	7.1	87.8	0	7.3	0.6	6,41	67
Tadla	5	38.4	40.8	20.8	4.6	7.7	1.3	18,87	196
	6	45	37	18	11	8	1	16,18	138
	7	37.4	29	33.6	13	7.6	1.6	10,66	436
	8	40.3	35.6	24.2	1.7	7.6	2	13,79	290

Table 1: Physico-chemical characteristics of the soils.

Results and Discussion

Phosphate fertilization had a significant effect on root yield at location 4 in Doukkala region and in locations 7 and 8 of the Tadla region. This is due, as we will see, to the difference in soil phosphate fertility levels of these soils. Besides location 4, there was no effect of phosphorus application on sugar beet sucrose content (Table 2).

Doukkala Region				Tadla Region			
Location	P Rate kg.ha^{-1}	Root Yield Mg.ha^{-1}	Sugar Content %	Location	P Rate kg.ha^{-1}	Root Yield Mg.ha^{-1}	Sugar Content %
1	0	71,76a*	18,13a	5	0	65,13a	15,40a
1	22	72,48a	18,23a	5	22	66,52a	15,30a
1	44	73,00a	17,94a	5	44	62,02a	14,79a
1	66	71,00a	18,31a	5	66	67,87a	15,03a
2	0	59,16a	16,14a	6	0	79,90a	18,28a
2	22	52,95a	16,55a	6	22	75,42a	18,45a
2	44	55,00a	16,50a	6	44	79,83a	18,71a
2	66	56,52a	16,40a	6	66	77,88a	18,10a
3	0	85,48a	17,28a	7	0	68,68a	15,32a
3	22	78,00a	16,45a	7	22	80,13b	15,55a
3	44	82,19a	16,97a	7	44	74,36b	15,43a
3	66	85,37a	16,71a	7	66	70,95ab	15,38a
4	0	57,44a	16,84a	8	0	74,16a	16,58a
4	22	72,84b	16,94a	8	22	82,95b	16,30a
4	44	77,56b	16,06a	8	44	81,15b	16,48a
4	66	75,26c	17,11b	8	66	84,63b	16,16a

Table 2: Sugar beet root yield, sugar content, and marginal return from applied phosphorus.
*Values followed by same letters in each location are not significantly different.

The increase in yield due to P application varied from 35% in locations with low soil P test levels to 0%, Figure 1. The increase in yield due to P application decreases with the increasing of soil available P level. This sugar beet yield increase becomes non-significant when the soil available P level exceeds 16 mg P.kg^{-1}.

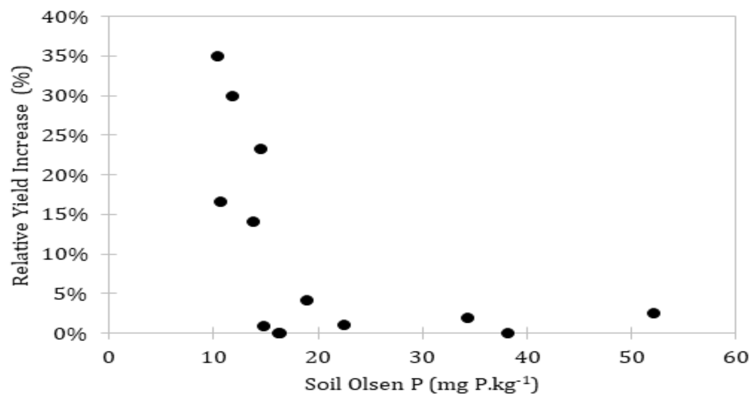

Figure 1: Relationship between the soil available phosphorus and sugar beet root yield increase due to phosphorus application.

Determination of the Soil Available P Critical Level for Sugar Beet

A properly correlated soil test with crop response to nutrient application will identify soils where crops will respond to nutrient application(s) and those that will not. The first step in developing a crop P fertilizer recommendation program there is the determination of the soil available P critical level below which there is a need of P application in order to satisfy crop P need and above which there is no need for P application since there is enough soil P for the crop. Cate and Nelson [19] graphical method is used in order to determine the soil available P critical level above which the crop is unlikely to respond to P application. The sugar beet yield is determined by several factors, in addition to the soil P application. In order to take this variability into account, we use the relative yield instead of the absolute yield when we compare different locations.

$$\text{Relative Yield}(\%) = \frac{\text{Control Yield}(\text{without P application})}{\text{Maximum Yield among treatments with applied P}} \text{x100}$$

Figure 2 presents the relationship between the relative yield of all locations and soil available P determined before sugar beet planting. It shows that relative yield is, relatively, low for soils with low soil available P contents and it reaches a plateau to the right of the graph. The Cate-Nelson graphic method allowed to locate the soil available P critical the soil around 16 mg $P.kg^{-1}$. This means that if a soil P available test value is below 16 mg $P.kg^{-1}$, there is a need for P application for sugar beet. If a soil P available value is greater than 16 mg $P.kg^{-1}$, no P fertilizer recommendation is made, because these soils can supply all the P needed for the crop that season and any P application will not improve the yield. On the contrary, this application will generate unnecessary expenditure of financial resources.

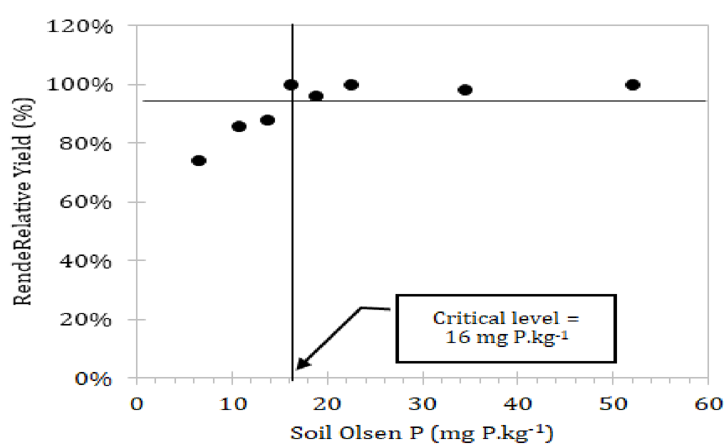

Figure 2: Determination of soil available P critical level using the Cate-Nelson graphical method.

Determination of Sugar Beet Phosphorus Requirement

The phosphorus requirement of crops should be based on the margin allowed by P application. In order to determine the economically optimal phosphorus rate to be applied for sugar beet, we started by calculating the gross crop margin for each applied P rate in each location. The sugar beet production value of the control, with no P application, is subtracted from each treatment's gross marginal return because this production is the result of soil P, without fertilizer P application. Gross margin due P application = (Value of the production -fertilizer P)-Production value of the control. Figure 3 shows the variation of the gross margin return due applied P rate. It can be observed that, for locations with positive gross margin return, this margin increases with applied P rate supplied to reach a maximum and then it decreases. The economically optimal P rate corresponds to the one that gives the maximum margin. The results show that the economically optimum rate is 0 kg $P.ha^{-1}$, no P application for sugar beet is needed, for locations 1, 2, 3, 5, and 6. All these locations have soil P test levels below 16 mg $P.kg^{-1}$ Table 1, which is the soil available P test critical level Figure 2. Locations 4, 7, and 8 with sugar beet economical optimum P rate requirement of 66and 66 kg $P.ha^{-1}$ for location 4. This is due to the different levels of phosphate fertility of these soils. 22, and 22 kg $P.ha^{-1}$, respectively, showed a soil available P test values below the critical level Table 1.

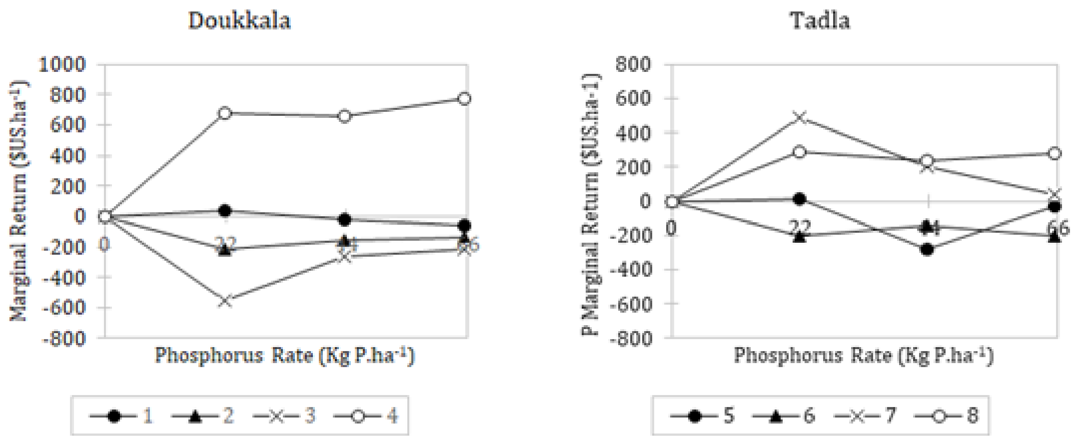

Figure 3: Gross marginal return from P application in different locations.

The gross maximum marginal return from P application is well correlated to the relative root yield increase resulting from P application Figure 4. The maximum economic benefit from P application is low in locations with low relative root yield increase and it increases as sugar beet response to P application improves.

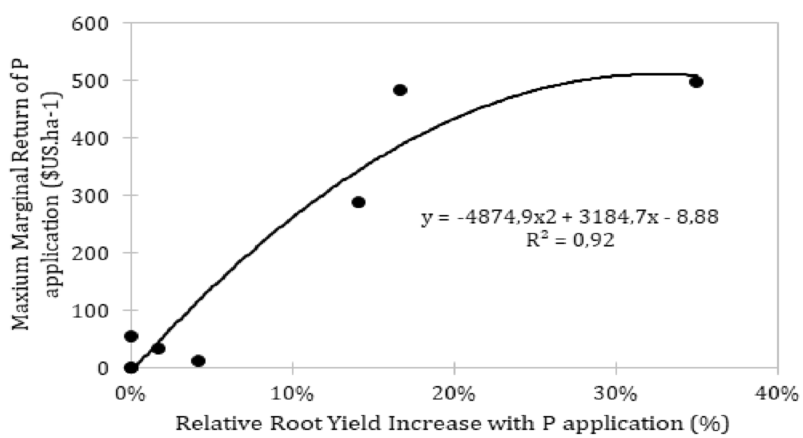

Figure 4: Relationship between relative sugar beet yield increase and gross marginal return due to P application.

In today's economically and environmentally conscientious world, there is little room for under predicting or over predicting fertilizer rates In today's economically and environmentally conscientious world, there is little room for under predicting or over predicting fertilizer rates [20]. A soil testing program must provide an accurate prediction of the fertilizer requirements for those soils deemed likely to respond to nutrient application. This part of soil test development is called calibration. A calibrated soil test can recommend a specific nutrient amount that corresponds to that specific soil-test value. Figure 5 presents the relationship between soil available P levels and sugar beet P requirement determined from Figure 3 for each location. Sugar beet economical P requirement rate is high for locations with low of soil available P levels and decreases as this level increases. Phosphorus requirement becomes nil above 16 mg $P.kg^{-1}$. Locations with soil available P levels below the critical level, 16 mg.kg-1, were used to investigate the correlation between a soil available P test level and the optimum sugar beet P requirement. Figure 5 shows a very good correlation that can be used to predict sugar beet P requirement after performing the soil P test using the Olsen, et al. [7] method.

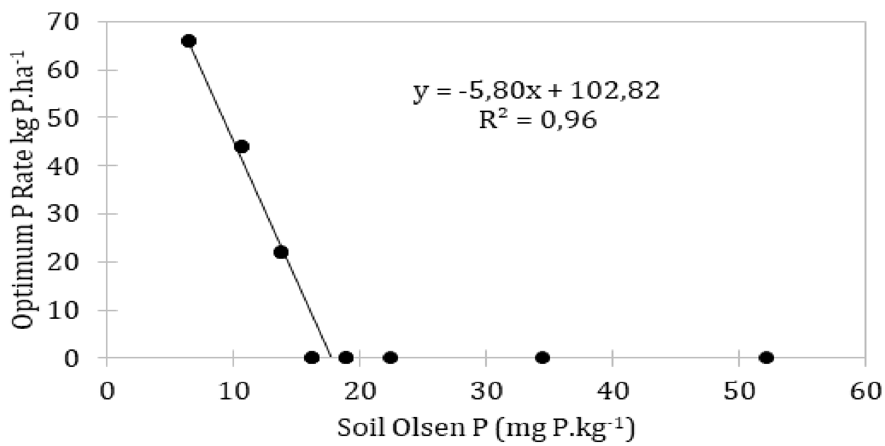

Figure 5: Relationship between soil available P level at planting and sugar beet phosphorus requirement.

Conclusion

Sugar beet responded to the phosphorus input at three of the eight locations conducted during this experiment. If Olsen's soil available P test is greater than 16 mg $P.kg^{-1}$, no fertilizer P application for sugar beet is necessary because it will have no effect on the productivity of the sugar beet. On the contrary, this contribution constitutes a waste of financial resources. The very good correlation between soil available P level and sugar beet P requirement allows for better P fertilizer recommendations for this crop. Indeed, available P tests performed before planting are currently used for making fertilizer P recommendations for sugar beet for farmers in these regions.

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