Plant Growth Promoting Rhizobacteria as Biofertilizers

Nico Labuschagne
Department of Plant and Soil Sciences, University of Pretoria.
nl@up.ac.za

Abstract
Current global trends include emphasis on amongst others green technology, organic agriculture and soil health. In that context, the use of biofertilizers is becoming increasingly important. Plant Growth Promoting Rhizobacteria (PGPR) applied as biofertilizers are contributing to the abovementioned global trends, especially soil health. PGPR are a group of beneficial bacteria that live in the rhizosphere of plants conferring a range of benefits to the plant including enhancing plant growth/ crop yield through various mechanisms. In this paper we will be discussing the benefits of PGPR and the mechanisms through which they enhance plant growth. Furthermore examples of local field trials demonstrating yield increases due to PGPR application in maize and wheat will be discussed.

What are Plant Growth Promoting Rhizobacteria (PGPR) ?

Rhizobacteria are rhizosphere competent bacteria that colonise plant roots. They are able to multiply and colonise all the ecological niches found on the roots at all stages of plant growth (Antoun and Kloepper, 2001). Plant Growth Promoting Rhizobacteria (PGPR) represent a portion of 2 to 5% of rhizobacteria which, when reintroduced by plant inoculation in a soil containing competitive microflora, exert a beneficial effect on plant growth (Kloepper and Schroth, 1978). PGPR enhance plant growth directly as well as indirectly through biological control of plant pathogens. PGPR are applied and commercialized as bio-pesticides/ biocontrol agents, plant strengtheners, biofertilizers, and phytostimulators. As illustrated in Fig. 1, these are overlapping categories.

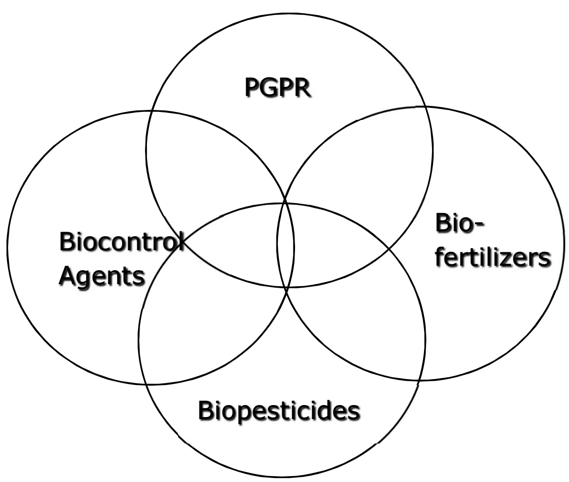

Fig 1. Relationship between PGPR, biofertilizers, biopesticides and biocontrol agents (adapted from Labuschagne, Pretorius and Idris 2010).

Benefits of PGPR to plants

Benefits that PGPR confer to plants /crops have been shown to include the following:

I. Increase in:
   - seed germination rate
   - root growth
   - yield
   - leaf area
   - chlorophyll content
   - nutrient uptake
   - protein content
   - shoot and root weights and plant heights

II. mitigation of abiotic stress

III. bio-control of plant diseases

IV. delayed senescence

Most of the abovementioned effects of PGPR culminate in increased production (i.e. yield).

How do PGPR work (mechanisms of action) ?

The various plant growth promoting and biocontrol mechanisms of action of PGPR all involve, either directly or indirectly, some interaction with the plant. The various mechanisms for both direct plant growth enhancement as well as indirect growth promotion (through biocontrol of plant pathogens) are illustrated in the diagram below adapted from Ahmad *et. al.* (2008).

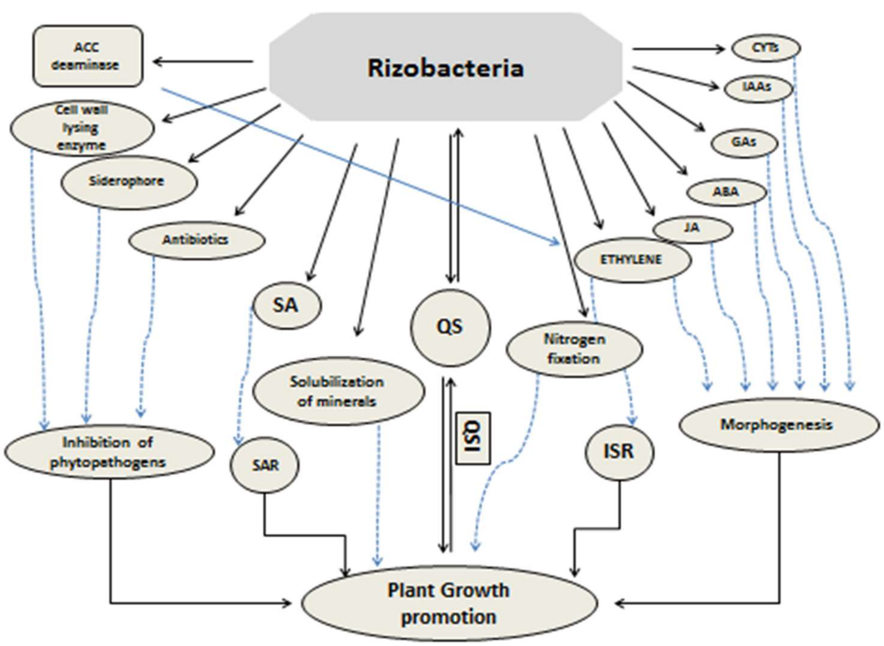

Fig. 1. Various mechanisms involved in plant growth promotion by rhizobacteria. Some bacterial species produce phytohormones such as CTKs, IAA and Gas. Indirect mechanisms concerned with inhibition of growth of phytopathogens include the production of antibiotics, siderophores and cell wall lysing enzymes. Salicylic acid, jasmonic acid (JA or analogues) and ethylene increase plant immunity by activating defense programs. ACC deaminase reduces growth-retarding ethylene production. Abbreviations: ABA, abscisic acid; ISR, Induced systemic resistance; SAR:Systemic acquired resistance ; QS,Quorum sensing; QSI, Quorum sensing interference. From Ahmad *et. al.* (2008).

Local examples of yield increase after PGPR application on cereal crops in the field

The beneficial effects of PGPR inoculation have been well documented, but obtaining reproducible results is often difficult under field conditions due to many factors that can affect their performance.
Although multiple examples of PGPR induced yield increase in a range of crops exist in the scientific literature, here we will discuss two examples of yield increase on PGPR treated maize and wheat in South Africa. The research was conducted by the PGPR research group at the University of Pretoria in collaboration with private companies as well as the Limpopo Department of Agriculture .

Field trials on Maize

During the 2011/2012 season maize field trials were conducted at the Limpopo Department of Agriculture's Research Station at Towoomba, as part of a MSc study conducted by G Breedt (2015) . The objectives of the trials were to evaluate the effect of PGPR inoculation of maize seed on yield under field conditions on the Springbok flats, Limpopo Province, South Africa. The trials were planted under dry land conditions in Huttons, Arcadia and shortlands soils at a planting population of 22 000 plants per hectare. The standard recommended fertilizer rates for maize were applied. Inoculant treatments included in the trials were the PGPR strains S7-08 , T-19, A-40, T-26 and A-29 obtained from the University of Pretoria's PGPR collection. The commercial product Brus® (Stimuplant, Gauteng, South Africa) was included as a commercial standard. All inoculants were applied as seed treatments.

Results and conclusions

Yield averages for all treatments were between 1.60 t/ha^{-1} and 6.59 t/ha^{-1} for the Huttons and the Shortlands trial respectively. The results indicated that the less fertile (lower clay content), the greater the effect of rhizobacterial treatments. The best yield increases were obtained in the shortlands soil (least fertile) with the bacterial strains T19 and T29, resulting in 33 and 30 % increase in yield (equivalent to 2.8 t/ha and 2.5 t/ha increase) respectively, compared to the control (Table 1). It must be noted that all the treatments in the Arcadian soils resulted in a reduction in yield compared to the control, possibly due to the high clay content.

Table 1. Effect of rhizobacterial seed treatments on growth and yield of maize under field conditions during the 2011/2012 season.

Treatments*	Yield (kg/ha)*****			% Change in yield compared to the control**		
	Huttons	Arcadia	Shortlands	Huttons	Arcadia	Shortlands
T-19	3421.94[a]	4743.75 [a]	11413.92 [a]	13.26	-6.00	33.69
Brus®	3621.95 [a]	4293.58 [a]	9958.83 [a]	19.88	-14.92	16.65
S7	2971.84 [a]	4901.32 [a]	9254.66 [a]	-1.64	-2.88	8.40
A40	3438.74 [a]	4239.55 [a]	8742.95 [a]	13.82	-15.99	2.41
A26	3600.44 [a]	4075.96 [a]	7550.38 [a]	19.17	-19.24	-11.56
T29	3242.69 [a]	4187.07 [a]	11132.34 [a]	7.33	-17.03	30.39
Control	3021.29 [a]	5046.71 [a]	8537.51 [a]	0.00	0.00	0.00

*T19, S7 A40 and T29 are rhizobacterial isolates from the University of Pretoria's PGPR culture collection. Brus® is a commercial product of Stimuplant (Gauteng, South Africa).

** % change in mass [(Control/100)* treatment-100] therefore negative values signify a reduction in yield compared to the untreated control.

***Treatment means followed by the same letter within the same column do not differ significantly, (P=0.05) according to the Least Significant Difference (LSD) test using the GLM procedure and separated with the Dunnetts test.

***** Yield converted to kg/ha^{-1} at a moisture content of 12%.

Field trial on wheat

During the 2017 season a field trial was conducted on wheat in the Riversdale area of the Eastern Cape (trial site of the Department of Agriculture, Government of the Western Cape) in collaboration with dr C Malan (Agrilibrium, Paarl). The wheat cultivar SST 0127 was planted under dry land conditions at a rate of 75kg seed /ha in a sandy loam (shale) soil and fertilizer applied at a rate of 27kg N, 9kg P and 4,5kg S/ha. Total rainfall for the period April to Sept 2017 was 126mm. It is important to note that the wheat crop suffered severe desiccation stress during the trial period.

Treatments included in the trial were: the control (untreated); a combination of two UP PGPR strains NAS6G6 and KBS1F-3 applied in the planting furrow at rates of 3, 6 and 12 L/ha respectively; the two UP PGPR strains applied as a spray over the planting row at rates of 3, 6 and 12 L/ha respectively ; QCM360 (containing a mixture of various bacterial strains; Agrilibrium KWV Building, 57 Main Steet, Paarl) applied in the planting furrow at rates of 3, 6 and 12 L/ha respectively; UP strains + QCM360 applied together at a rate of 3 L/ha in the planting furrow. All treatments were applied as liquid suspensions. The in furrow treatments were applied by means of a standard liquid applicator mounted on the planter whilst the spray treatments were applied by means of a knapsack sprayer. Due to the severe drought the crop was not grown to full maturity but was killed by means of hericide spray before grain fill. Representative plant samples were taken from 1m² sample areas within each field plot and each replicate and the total dry weights determined.

Results and conclusions:

Fig. 1 shows the effect of the various treatments expressed in terms of the total dry weights of plants.

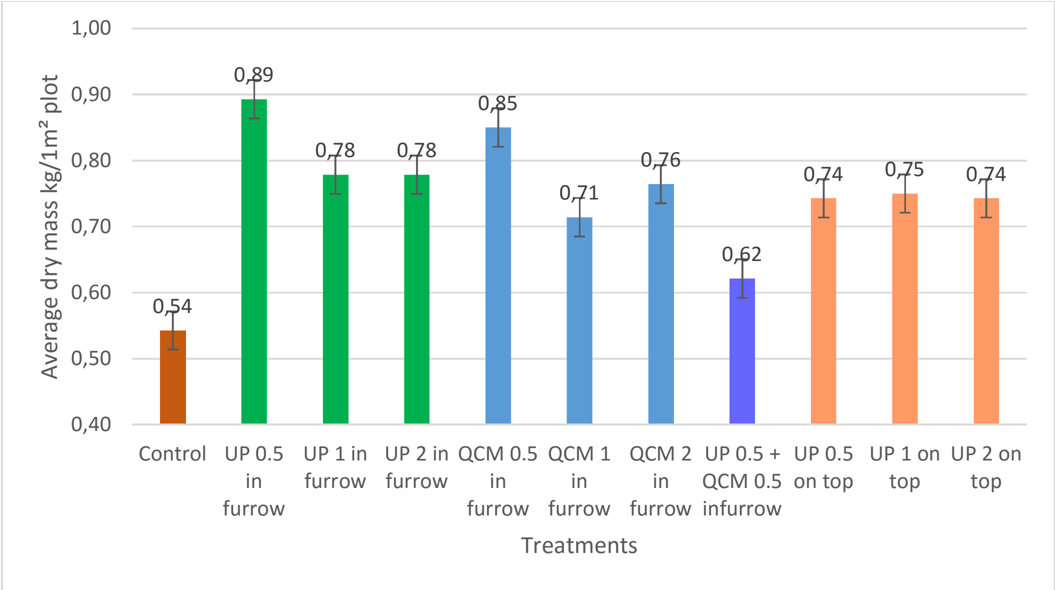

Fig .1. Effect of rhizobacterial treatments on wheat yield in the field under drought stress conditions (expressed i.t.o. plant dry mass per 1m² sub-plot)

Treatment designations :

Control= untreated.

UP 0.5 in furrow = UP strains applied in planting furrow at 3 L /ha.

UP1in furrow = UP strains applied in planting furrow at 6L /ha.

UP2 in furrow = UP strains applied in planting furrow at 12 L /ha.

QCM 0.5 in furrow = QCM360 applied in planting furrow at 3 L /ha.

QCM 1 in furrow = QCM360 applied in planting furrow at 6 L /ha.

QCM 2 in furrow = QCM360 applied in planting furrow at 12 L /ha.

UP 0.5+ QCM 0.5 in furrow= UP strains applied in planting furrow at 3 L /ha + QCM360 applied in planting furrow at 3 L /ha.

UP 0.5 on top = UP strains applied as spray over plant row at 3 L /ha.

UP1 on top = UP strains applied as spray over plant row at 6L /ha.

UP2 on top =UP strains applied as spray over plant row at 12 L /ha.

All inoculant treatments resulted in an increase in yield compared to the untreated control. The best plant mass increase was obtained with the UP strains applied in furrow at a rate of 3 L/ha. The second best result was obtained with OCM360 applied in furrow at 3 L/ha. Interestingly, the higher dosages of both treatments resulted in lower yields than obtained with the lower dosages.
The important aspect of these results is the fact that these plant mass increases were obtained under severe drought conditions suggesting that the rhizobacterial treatments were able to mitigate dessication stress in the crop.

References

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