4R Nutrient Management Practices for Potato Production in China

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In China, potato yields have been restricted by low and unbalanced nutrient input. A key measure to better tuber yield, quality, and improved nutrient use efficiency will be successful implementation of regionally-based, best nutrient management practices.

China is the world's largest potato producer. Almost two-thirds of its potato production comes from six northwestern and southwestern provinces/regions (i.e. Inner Mongolia, Gansu, Sichuan, Guizhou, Yunnan, and Chongqing city). Low fertilizer use and imbalanced nutrient application are partially responsible for low tuber yields and quality throughout. Significant area in the southwest is especially dominated by mountains and plateaus, which present complex topography and production challenges. This article presents examples of nutrient management practices needed to address the nutrient requirements of potato in China. These examples are based on the 4R Nutrient Stewardship principles that provide the right nutrient source at the right rate, time, and place (Roberts, 2007).

Nutritional Requirements

It is important to know the nutrient requirements of potato before considering any particular nutrient management strategy. These requirements can vary considerably for all nutrients based on soil test levels. In the case of P, for example, the presence of free lime at the surface can have a particular impact. Westerman (2005) reviewed potato nutrition data from the USA and Canada and found nutrient uptake to average 4.19 kg N/t, 1.26 kg P_2O_5/t, and 7.20 kg K_2O/t. Experiments in Inner Mongolia (northwest China) from 2002 to 2007 found averages of 6.03 kg N/t, 1.30 kg P_2O_5/t, and 6.18 kg K_2O/t (**Table 1**). Values for N were considerably higher than those reported by Westerman, while the P and K requirements were very similar. The difference observed for N may reflect both the severely degraded nature of soils at the Chinese field sites, and general overuse of N fertilizers in the recent past. This particular dataset found no clear differences in nutrient requirement per tonne of harvested tuber between rainfed and irrigated fields despite clear differences in final yield.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Mn = manganese; Fe = iron; Al = aluminum; CRU = controlled release urea; KCl = potassium chloride; KNO_3 = potassium nitrate; K_2SO_4 = potassium sulfate; SSP = single superphosphate; TSP = triple superphosphate; $MgSO_4$ = magnesium sulfate; $MgCl_2$ = magnesium chloride; DCD = dicyandiamide; NBPT = N-(n-butyl) phosphoric triamide; RMB = Chinese yuan; Currency values are in US dollars (USD).

Table 1. Nutrient requirements of rainfed and irrigated potato in northwest China.

			Nutrient uptake, kg/t			
Year	Water regime	Yield, t/ha	N	P_2O_5	K_2O	$N:P_2O_5:K_2O$
2002	Rainfed	11.8	7.36	1.65	6.37	1:0.22:0.87
2002	Irrigated	34.4	5.89	1.41	4.89	1:0.24:0.83
2003	Rainfed	9.6	4.23	1.37	5.45	1:0.32:1.29
2003	Irrigated	32.4	5.71	1.15	5.64	1:0.20:0.99
2004	Rainfed	14.4	6.87	1.13	5.02	1:0.16:0.73
2004	Irrigated	26.0	4.70	0.73	5.67	1:0.16:1.21
2005	Rainfed	19.3	4.79	1.23	4.18	1:0.26:0.87
2005	Irrigated	37.5	4.40	1.58	6.63	1:0.36:1.51
2006	Rainfed	14.2	5.84	1.42	6.36	1:0.24:1.09
2006	Irrigated	31.5	6.91	1.62	7.91	1:0.23:1.14
2007	Rainfed	10.3	8.04	1.09	6.55	1:0.14:0.81
2007	Irrigated	30.6	7.58	1.21	9.44	1:0.16:1.25
Average		22.7	6.03	1.30	6.18	1:0.22:1.02

Table 2. Effect of controlled-release urea (CRU) on tuber yield and N use efficiency compared with regular urea (RU), Inner Mongolia (2009 to 2011).

Treatment†	Tuber yield, t/ha	AE_N, kg tuber /kg N‡	RE_N, %§
CK	30.2 d	-	-
100% CRU	38.6 a	33.3 ab	45.3 ab
100% RU	36.4 b	24.5 bc	32.1 c
75% CRU	37.0 ab	35.6 a	52.3 a
75% RU	34.6 c	22.4 c	40.6 bc

†CK = without N; 100% CRU = recommended N applied as CRU; 100% RU = recommended N rate applied as RU.
Fertilizer N, P, and K were applied basally in all treatments.
‡AE_N = Agronomic efficiency of N. §RE_N = Recovery efficiency of N.
Means within the same column followed by the same letter are not significantly different at p = 0.05.

The Right Source

For N, rapidly soluble sources such as urea and ammonium bicarbonate (NH_4HCO_3) are more commonly used in China. However, slow/controlled-release N fertilizers are also used, which can contain a nitrification inhibitor (DCD) and/or urease inhibitor (NBPT), or are coated with inorganic materials (e.g. S), or an organic polymer. Slow/controlled-release N fertilizers regulate the release of fertilizer N over time, and can improve N use efficiency by synchronizing the supply of N with crop demand. They can also reduce application rates and labor costs. Slow/controlled-release N appears best suited

Table 3. Comparison of an optimum fertilizer treatment (OPT) with farmer's practice (FP) in selected potato field trials from China.

Location	Treatment	N, kg/ha	P_2O_5, kg/ha	K_2O, kg/ha	Tuber yield†, t/ha	Cost‡, USD/ha	GRF§, USD/ha
Jishishan, Gansu	OPT	120	120	150	35.4 a	314	2,479
	FP	60	30	0	29.0 b	69	2,223
Zhangjiachuan,Gansu	OPT	104	72	68	29.6 a	193	2,144
	FP	104	0	0	24.2 b	74	1,841
Wuchuan, IMAR	OPT	125	125	100	14.2 a	281	841
	FP¶	60	18	0	13.3 a	294	757
Wuchuan, IMAR	OPT	250	225	200	31.5 a	540	1,949
	FP#	141	51	0	29.6 b	853	1,485
Huzhu, Qinghai	OPT	158	75	135	17.9 a	289	1,125
	FP	240	52	90	17.2 a	290	1,069
Xining, Qinghai	OPT	158	75	135	17.9 a	289	1,125
	FP	240	52	90	17.1 a	290	1,060
Xining, Qinghai	OPT	158	75	135	30.9 a	289	2,152
	FP	240	52	90	27.5 b	290	1,883
Huaxian, Shaanxi	OPT	181	322	225	47.9 a	596	3,189
	FP	194	504	225	45.8 b	766	2,855
Mizhi, Shaanxi	OPT	307	322	225	26.5 a	686	1,410
	FP	358	0	0	22.5 b	254	1,523
Zhijin, Guizhou	OPT	105	30	66.5	14.5 a	155	993
	FP	75	22.5	0	10.2 b	73	735

† Means in the same location followed by the same letter are not significantly different at $p<0.05$.
‡ The total cost (USD) of N, P, and K fertilizer: N = \$0.71/kg, P_2O_5 = \$0.88/kg, K_2O = \$0.82/kg. (1 USD = 6.36 RMB)
§ GRF is the gross return to fertilizers and manures (when applied). Potato tuber price = \$0.079/kg.
¶ Livestock manure applied at 7,500 kg/ha; \$31.45/t
# Livestock manure applied at 22,500 kg/ha; \$31.45/t

to irrigated potato systems, where N release can be regulated by soil moisture content. Experiments conducted in irrigated potato in Inner Mongolia from 2009 to 2011 indicate that, at the same N rate, control-release urea (CRU) resulted in better yield and higher N use efficiency than regular urea (RU). At 75% of the recommended N rate, CRU produced a similar yield and higher N use efficiency compared with RU at the recommended rate (**Table 2**).

While the source of P commonly used in potato varies (e.g. DAP, MAP, SSP, TSP, and calcium-magnesium phosphate) based on regional preference; KCl is the primary K source compared to other sources like K_2SO_4 and KNO_3. High soil K supply is required to maintain both tuber yield and quality, and these in turn can be affected by K source. Either KCl or K_2SO_4 are the preferred sources based on yield data (Qin et al., 2008; Kumar et al., 2007). Evidence suggests tuber starch and vitamin C content are increased, and the content of reduced sugar in tubers decreased, when potato is supplied with KCl instead of K_2SO_4 (Qin et al., 2008).

Organic nutrient sources such as animal manures and/or organic compost are effective nutrient sources in potato production. However, the combined use of manure with balanced application of fertilizer typically results in better yield (and economic returns) over those obtained with fertilizer or manure alone (Gallandt et al., 1998; Parmar et al., 2007).

The Right Rate

A number of approaches have been developed to help determine proper fertilizer application rates in China's agriculture. Generally, a fertilizer recommendation based on soil testing and a target yield is commonly used for potato. The ASI systematic approach for soil testing and nutrient recommendation (Hunter, 1980; Portch and Hunter, 2002) was found to be an effective nutrient management tool and is widely used in China (Jin et al., 2006). Compared to farmer's practice (FP), more balanced, "optimum" treatments (OPT) recommended by the ASI procedure have increased tuber yields by an average of 3 t/ha, and farmer's income by nearly USD 200/ha (**Table 3**).

Applied P generally has maximum solubility within a narrow range in which P is not tied up in low solubility complexes with Fe and Al or Ca (Davenport et al., 2005). A common practice within China is to add P fertilizers in excess of plant removal (average requirement of 1.3 kg P_2O_5/t; see **Table 1**) to overcome the effects of soil reactions that reduce P solubility (Davenport et al., 2005).

Few soils can produce high potato yields for many seasons without replenishing the K removed by harvested tubers. IPNI field data have found K responses as high as 22.2 t/ha in Qinghai with the application of 97 kg K_2O/ha; and 16.7 t/ha in Gansu when 150 kg K_2O/ha was applied.

Irrigated potato requires more nutrients and higher ap-

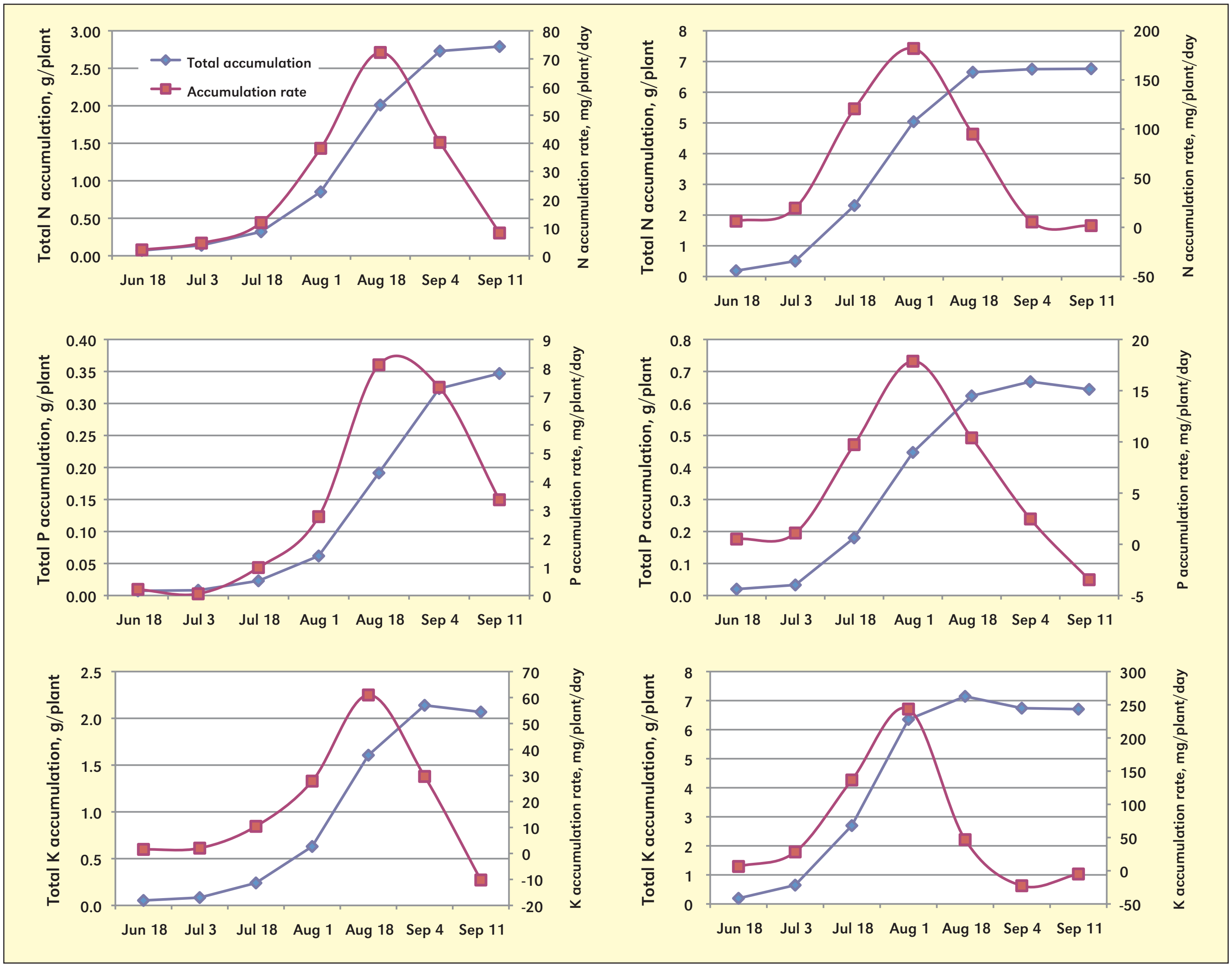

Figure 1. Characteristics of total and daily rates of N, P, and K accumulation by rainfed (left) and irrigated (right) potato (cv. Zihuabai) in Inner Mongolia.

plication rates than rainfed sites due to the much higher yield potential. Drip fertigation can reduce recommendations for both N and K rate compared to furrow irrigation while still maintaining higher total tuber yield (Sasani et al., 2006).

After N and K, Ca and Mg are removed in the next largest quantities by potato (Westermann, 2005). The acidic red soils (Ferralsols) in south China are especially Ca- and Mg-deficient and require significant amounts (90 kg Ca/ha and 60 kg Mg/ha) supplied as lime gypsum, $MgSO_4$, $MgCl_2$, and dolomite.

The Right Time

Knowledge of total season demand and the daily nutrient uptake can provide the guidance required for determining the proper timing for nutrient application. **Figure 1** is an example of nutrient uptake and accumulation by rainfed and irrigated potato in Inner Mongolia. Nutrient is accumulated rapidly during tuber bulking stage. The highest daily nutrient uptake by irrigated potato appears about 2 weeks earlier than rainfed potato, suggesting nutrients need to be applied earlier for irrigated potato to match demand.

Excessive N fertilizer applied at or before tuber setting can extend the vegetative growth period and delay tuber development, resulting in a lower tuber yield. However, too much N applied later in the season can delay maturity of the tubers, reducing yield and adversely affecting tuber quality. Split application of N can meet the demand of plant uptake, improve nutrient use efficiency, and provide increased flexibility in fertilizer N management, allowing the grower to modify N management based on crop growth stage and climate conditions. In some areas with irrigation or high rainfall, N can be applied in three or four splits to improve yield and nutrient use efficiency. In irrigated production on sandy soils, split N application is very effective in reducing environmental N losses (Errebhi et al., 1998). However, there is little or no benefit to split N application in situations where the risk of nitrate leaching is low.

All P and K fertilizers are generally applied pre-plant and mixed with soil before planting. Micronutrients such as Zn, Mn, and Fe applied pre-plant may oxidize or precipitate to unavailable forms before plant uptake, particularly on calcareous soils with high pH. Elemental S should be applied in advance of planting, allowing S oxidization to plant available sulfate, especially in cold areas and on soils with low S oxidation capability.

The Right Place

Nutrients can be applied in various ways to meet the requirements for potato production. Most nutrients, including N, can be applied pre-plant if tilled into the rooting zone before planting. Both Mn and Fe applied pre-plant may oxidize to unavailable forms before plant uptake, particularly on the high pH calcareous soils. Nutrient source also influences application method and rate. Fertilizer applications after planting are usually done before row closure. When topdressing fertilizer materials are broadcast on the soil surface and should be followed by tillage operation such as ridging. Side-dressed materials are usually physically injected into the soil a few centimeters away from the potato seed.

Fertigation can be an alternative practice for nutrient application, particularly if the nutrient is mobile in the soil, such as nitrate. Fertigation application of nitrate can be more efficient than a pre-plant application when the nutrient is not leached out of the plant's root zone during the process (Westermann et al. 1988). When nutrients are easily fixed by the soil (e.g. P in calcareous soil or acidic, red soil) they should not be applied by fertigation. In Northern China, where a single crop of potato is grown each year, consolidated farms with up to 100 ha of potato fields are becoming more common. Potato is irrigated by sprinkler irrigation systems, which can provide flexibility and efficient water application. Nitrogen and K fertilizer can both be applied through sprinkler irrigation.

Fertilizer banding can also improve efficiency of fertilizer N and P use. Banding fertilizer in ridges would also be expected to reduce the risk of nitrate leaching because of greater water infiltration in the furrow compared with the ridges (Zebarth and Rosen, 2007). Because potato has a low P use efficiency and limited ability to take up P at low soil P levels (Dechassa et al., 2003), P should be band applied to increase the P concentration in the root zone.

Summary

Results from this research indicate that there is considerable opportunity to modify fertilizer rates for potato production in China. While degraded soils can influence the nutrient rates applied, the negative impact from the overuse of nutrients must be addressed. Fertilizer rates not only depend on potato requirements, but on fertilizer source, water regime, and soil conditions. The best nutrient management practice for potato is to apply nutrients using right source, right rate, right time, and right place (4R) strategies for high tuber yields and nutrient use efficiency. The determination of these four "rights" is a location (or site-specific) process.

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