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# Application of a universal soil extractant for determining the available NPK: A case study of crop planting zones in central China

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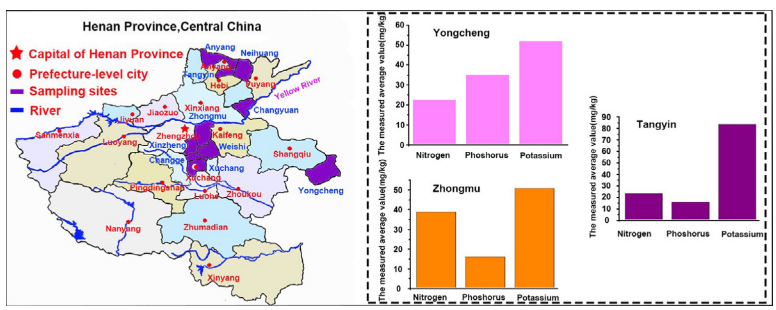
## HIGHLIGHTS

- A novel soil extractant has been developed to extract the available NPK simultaneously.
- The results showed that concentrations of NPK are correlated with lab-based methods.
- A portable photoelectric system associated with this extractant was exclusively designed.
- Soil samples from crop planting zones in Henan Province, central China are measured.
- A recommendation fertilization system has been established by '3414' fertilizer scheme.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Being important parameters of crop growth the precise measurements of available nitrogen (N), phosphorus (P) and potassium (K) on site not only help the farmer to control his budget but also helps to keep the environmental pollution under control. Currently, the existing extractant cannot be applied to rapidly determine the concentrations of available NPK by soil chemical analysis methods, simultaneously. In the present paper, a universal extraction reagent consisting of 0.45 M $NaHCO_3$ and 0.374 M $Na_2SO_4$ buffered at pH 8.5 in association with a portable multi-channel photoelectric system has been proposed. The present method provides the most useful indication for the rapid determination of available NPK concentrations in neutral and calcareous soil in field. A large number of soil samples were collected from crop planting zones in Henan province of central China for evaluating the effectiveness of this universal extractant. A portable multi-channel photoelectric system associated with this universal soil extractant was exclusively designed to provide reliable and reproducible available NPK concentrations in soil extracts. The experimental results showed that available NPK concentrations determined by this method are highly correlated with the laboratory-based methods. A '3414' fertilizer scheme was applied to optimize the fertilizer recommendation for achieving the high targeted yield. The recommendation fertilizer system worked with a high correlation coefficient and fertilizer utilization rate has been established by this '3414' fertilizer scheme. With advantage of portability, accuracy and low cost, the proposed method can help to cut down the economic burden of the farmer and also it helps to optimize the utilization of the fertilizers by limiting its excessive usage and hence control the environmental pollution.



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## 1. Introduction

Nutrients like nitrogen (N), phosphorus (P) and (K) are essential elements for crops growth and development (Rashid et al., 2016; Razaq et al., 2017; Zhang et al., 2018). NPK concentrations vary from region to region and around the surrounding environment of plants (Liu et al., 2011). In general, applications of chemical fertilizers are frequently used to increase crop yields by sustaining soil fertility (Brar et al., 2015). However, in China, the blind fertilization has been happened due to the shortage of knowledge of spreading fertilizer farmers held (Pan and Zhang, 2018; Pan et al., 2017). Excessive use of NPK has created serious impact on the environment which is not only contaminating the land and eventually plants but also threating human health (Ma et al., 2014). Therefore, intensifying fertilizer management is urgently needed to minimize environmental pollution at the maximum crop yield for the surging world population (Ju et al., 2016). It is well known that nutritional elements in the soil are always considered as a dynamic change of nutrient concentrations temporarily (Sharma and Bali, 2017). Rapid measurement of available nutrient concentrations is one of the most effective ways to optimize the fertilizer requirements (Huang et al., 2017). Ideally, quick and precise measurement is performed by universal soil extractant associated with a portable multi-channel optoelectric device which provides fast analysis of available nutritional elements on site. In order to improve the measurement efficiency, a universal extractant is needed to extract the various available nutritional elements in soil. It is reported that chemical extractant can be employed to extract the available nutrients (Kumawat et al., 2017). Generally, laboratory-based analytical methods use separate extractants chemically (Mallarino and Atia, 2005). Consequently, Morgan extractant was developed for mineral soils (Sharma et al., 2018). Mehlich developed a universal extractant used for acid sandy textured soils (M1) (Schlindwein et al., 2011). The ammonium bicarbonate-diethylenetriaminepentaacetic acid (DTPA) (AB-DTPA) was developed to be an extraction reagent for alkaline soils (Malathi and Stalin, 2018). Wolf improved the Morgan extractant by adding DTPA, which improved the specificity on soluble inorganic phosphorus measurement (Wolf, 1982; He et al., 2012). Mehlich introduced a universal extractant method (M3) for use on a wide range of acid soils (Ring6 et al., 2004). It is recommended that Olsen Sodium bicarbonate method can be very effective for highly calcareous soils (pH > 7.4) (Recena et al., 2015). The soil phosphorus extraction referred as Bray-1 extractant by solution consisting of 0.025 M HCl and 0.03 M $NH_4F$ (Boem et al., 2011). The measured results of the available soil phosphorus (P) and potassium (K) extracted by Agro Services International (ASI) multi-element extractant showed that the extractable P and K can be used to represent the fertility status of selected soils in China (Yang et al., 2011). The extractant of 0.02 M $SrCl_2$ is more suitable for extracting soil nitrate nitrogen, nitrite nitrogen and potassium (Li et al., 2006). 0.01 M $CaCl_2$ or 0.1 M $BaCl_2$ can simultaneously adopted for the determination of available P and exchangeable K, Ca, and Mg (Bibiso et al., 2015a,b). Up till now, the reported universal extractants are summarized in Table 1.

Generally, Olsen Sodium bicarbonate extractant method, Nessler's reagent colorimetry and Ammonium acetate extraction-flame photometry are still widely used for soil analysis in laboratory. Moreover, current measurement results of available nutritional elements of NPK in the soil can only be used to extensively manage the fertilization in a large arable land. Therefore, a universal soil extractant for determining the available NPK is urgently developed for use in the dispersed planting zones with the large spatial variability in soil nutrients in central China, such as Henan Province. In this study, a field-used and universal extractant reagent consisting of 0.374 M $Na_2SO_4$ and 0.45 M $NaHCO_3$ buffered at pH 8.5 is proposed for extracting the NPK concentration from neutral and calcareous soils in Henan Province of central China simultaneously. The aim of this study was to validate the performance of this universal soil extractant reagent associated with the portable multi-channel photoelectric system. The correlations between the measured concentrations obtained from this proposed method and the laboratory-based method were numerically analyzed. A fertilizer recommendation system used in Henan province for growing corn was established by the measurement results obtained from the portable multi-channel photoelectric system associated with this universal extractant method. The cost-effective multi-channel photoelectric device instead of a laboratory-based expensive instrument should be versatile enough to be used as a field portable system for on-site soil nutrients analysis.

## 2. Materials and methods

### 2.1. Reagents

Chemical reagents were procured from Wuhan Huashen chemical reagent Co. Ltd. China. For the activated carbon-containing phosphorus, a blank test was needed to indicate the presence of phosphorus. Prior to measurements, the phosphorus was removed by treating the activated carbon with 2 mol/L of hydrochloric acid (HCl). The portable home-made multi-channel photoelectric system was developed by members of our research group (Ma et al., 2019).

### 2.2. Preparations of the universal soil extractant

The extraction solution was prepared by adding 53.12 g of sodium sulfate and 37.80 g of sodium bicarbonate and 800 mL distilled water to conical flask of volume 1L. The pH of the solution was maintained at 8.5 by sulfuric acid solution or sodium hydroxide solution. Consequently, the universal soil extractant consisting of 0.374 mol/L of sodium sulfate ($Na_2SO_4$) and 0.45 mol/L of sodium bicarbonate ($NaHCO_3$) was obtained. Principally, sodium ion ($Na^+$) in the universal soil extractant is chemically exchanged with both the ammonium ions ($NH_4^+$) and the potassium ions ($K^+$). Accordingly, $NH_4^+$ ions and $K^+$ ions were dissociated in the soil extraction solution. On the other hand, the available phosphorus can be extracted out owing to inhibiting the activity of calcium ions ($Ca^{2+}$) by sodium bicarbonate in the extraction solution. In comparison with the existed soil extractant, the universal soil extractant can extract multiple elements, such as, $NH_4^+$, $NO_3^-$, $K^+$, $PO_4^{3-}$, from the neutral and calcareous soils, simultaneously(see Table 2). However, both widely used universal extractants Mehlich 3 and AB-DTPA cannot be used to extract the $NH_4^+$-N and $NO_3^-$-N from soils, simultaneously, due to ions of $NH_4^+$ and $NO_3^-$ existed (Jr, 1990). The advantages and disadvantages of this current universal extractant to other reported extractants are summarized in the following Table 2. The soil universal extactant can extract the macro-nutrients from soils and fertilizer recommendation system for growing corn is established by the measurement results from the portable multi-channel photoelectric system.

### 2.3. Experimental design

In order to validate this universal soil extractant, soil samples with the sampling depth of 0–20 cm were collected from sites in counties (Yongcheng, Tangyin, Zhongmu, Neihuang, Changyuan, Anyang, Changge, Xinzheng, Xuchang and Weishi) in Henan pro-

**Table 1**
The reported extractant reagents for extracting nutritional elements from soil samples.

| Extractant | Chemical reagents | Soil:solution | pH | The extracted nutritional elements |
|---|---|---|---|---|
| Morgan(1) | 0.73 mol/L NaOAc | 1:4 | 4.8 | P, K, Ca, Mg, Cu, Fe, Mn, Zn, $NO_3^-$N, $NH_4^+$ -N, $SO_4^{2-}$, Al, As, Hg, Pb |
| Morgan-Wolf(2) | 0.073 mol/L NaOAc + 0.52 mol/L HOAc + 0.0001 mol/L DTPA | 1:4 | 4.8 | P, K, Ca, Mg, B, Cu, Fe, Mn, Zn, $NO_3^-$ -N, $NH_4^+$ -N, Al, As |
| Mehlich1(3) | 0.05 mol/LHCl + 0.025 mol/L $H_2SO_4$ | 1:10 | 2.5 | P, K, Ca, Mg, Na, Mn, Zn |
| Mehlich3(4) | 0.001 mol/L EDTA + 0.015 mol/L $NH_4F$ + 0.25 mol/L$NH_4NO_3$ + 0.20 mol/L HOAc + 0.013 mol/L $HNO_3$ | 1:10 | 2.5 | P, K, Ca, Mg, Na, B, Cu, Fe, Mn, Zn |
| AB-DTPA(5) | 1 mol/L $NH_4HCO_3$ + 0.005 mol/L DTPA | 1:2 | 7.6 | P, K, Na, Mn, Zn, As, Cd, $NO_3^-$ |
| ASI(6) | 0.25 mol/L $NaHCO_3$ + 0.01 mol/L EDTA + 0.01 mol/L $NH_4F$ | 1:10 | – | P, K, Cu, Fe, Mn, Zn |
| Strontium chloride(7) | 0.02 M $SrCl_2$ | 1:10 | – | 1:10 $NO_3^-$ -N, $NH_4^+$ -N, P, K,Ca,Mg, B, Zn, $SO_4^{2-}$ |
| Calcium chloride(8) | 0.01 M $CaCl_2$ | 1:10 | – | P, K, Mg, Ge, Al, Na, Ni, B, Cu, Fe, As, Pb, $NO_3^-$-N, $NH_4^+$-N, |
| Barium chloride(9) | 0.1 M $BaCl_2$ | 1:5 | – | P, Al, Fe, Ca, Mg, Mn, K, Na |

(1) Sharma et al., 2018
(2) He et al., 2012
(3) Schlindwein et al., 2011
(4) Ring et al., 2014
(5) Malathi and Stalin, 2018
(6) Yang et al., 2011
(7) Li et al., 2006
(8) Bibiso et al., 2015a
(9) Bibiso et al., 2015b

**Table 2**
The advantages and disadvantages of the current universal extractant to the reported universal soil extractants.

| Extractant | Chemical reagents | Soil/solution | Shaking time (min) | pH | Soil type | Compatibility with soil instruments | Fertilization Recommendation system in China | The extracted available Nitrogen |
|---|---|---|---|---|---|---|---|---|
| Mehlich3 | 0.001 mol/L EDTA + 0.015 mol/L $NH_4F$ + 0.25 mol/L$NH_4NO_3$ + 0.20 mol/L HOAc + 0.013 mol/L $HNO_3$ | 1:10 | 5 | 2.5 | Acid soils | – | No | No |
| AB-DTPA | 1 mol/L $NH_4HCO_3$ + 0.005 mol/L DTPA | 1:2 | 15 | 7.6 | Alkaline soils | – | No | No |
| ASI | 0.25 mol/L $NaHCO_3$ + 0.01 mol/L EDTA + 0.01 mol/L $NH_4F$ | 1:10 | 10 | – | Acid to alkaline soils | – | No | Nitrate nitrogen ($NO_3^-$) |
| This soil universal extractant | 0.45 M $NaHCO_3$ + 0.374 M $Na_2SO_4$ | 1:5 | 10 | 8.5 | Neutral and calcareous (alkaline) soils | Home-made portable optoelectronic measurement device with the cost being less than 3000 RMB (around 450 US dollar) | Yes | Ammonium nitrogen ($NH_4^+$), Nitrate nitrogen ($NO_3^-$) Alkaline-hydrolysable nitrogen |

vince. The '3414' experiment scheme recommended by National Agricultural Technology Extension Service Center of China is employed to establish the fertilizer recommendation system (Yu et al, 2010). It refers to the orthogonal experiment method consisting 3 nutritional factors (e.g. available N, P, K) with 4 levels and 14 treatments of fertilization.

Soil samples were collected randomly from different sites from under investigation region. Organic debris, rocks, and trashes were cleared from the soil surface prior to sample collection by adopting centered quarter method. The soil samples were air-dried and ground (Hebei Jiqun Instrument, Shijiazhuang, China) before comparing the lab-based results with current proposed method. After grinding, soil samples were sieved through 80-mesh sieve. In the end, all these samples were mixed thoroughly by spreading over a paper (see Fig. 1). The general procedures are as follows. Firstly, 2.5 g of air-dried soil samples is loaded into a 100 mL conical flask. After that, 0.5 g of phosphate-free activated carbon and 50 mL of the universal extractant soil solution were added into the conical flask. In order to establish a state of chemical equilibrium, the sample solution was stirred for 10 min by a hot-plate magnetic-stirrer device working at the speed of 200 rpm at the temperature of 25 °C. Finally the soil sample solutions were filtrated with a medium-speed filtration paper (Zhejiang Xinhua Paper Factory, Hangzhou, China) prior to the determination of soil NPK concentrations. The filtrate was prepared for the determination of available NPK concentrations. Once the Nessler's reagent was added into the filtrate, the color of the filtrate turned yellow due to the presence of the nitrogen extracted from soil samples. The concentration of available nitrogen was measured through the portable multi-channel photoelectric system working at the wavelength of 440 nm. The molybdenum blue phosphorus method in association with the portable multi-channel photoelectric system working at the wavelength of 660 nm was used to determine the amount of available phosphorus. The turbidimetric method with sodium tetraphenylboron, $NaB(C_6H_5)_4$, was used to measure available potassium in soil samples. Even with a low concentration of potassium in the extracts, the white precipitates of potassium tetraphenylboron, $KB(C_6H_5)_4$, are colloidal and the concentration

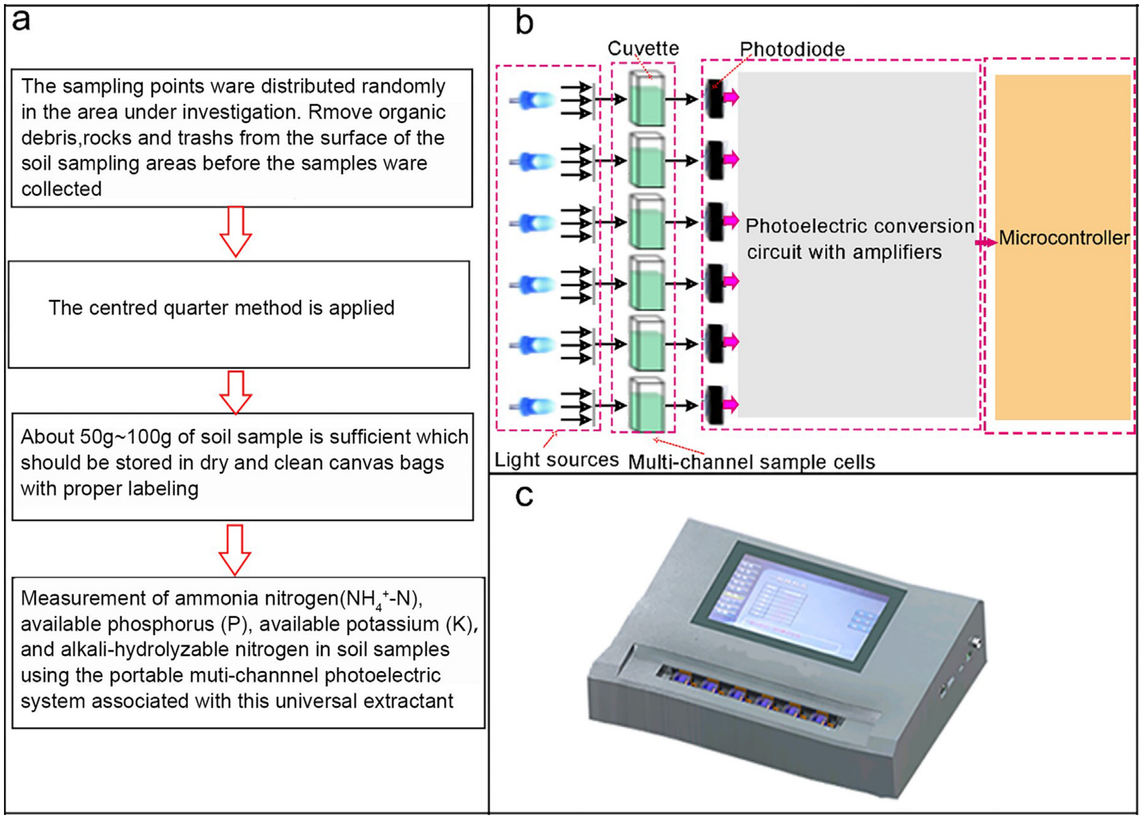


**Fig. 1.** The overall scheme of the experiment design, (a) the sampling and processing procedures, (b) the configuration and principle of the photoelectric measurement system including the combined LEDs, photoelectric conversion circuit with photodiodes and amplifiers, multi-channel sample cells and microcontroller, (c) the prototype of the home-made portable photoelectric measurement system.

of potassium was determined turbidimetrically by the portable multi-channel photoelectric system working at the wavelength of 505 nm in the field or on the farm. The principal schematic diagram of the portable multi-channel photoelectric system is shown in Fig. 1b. The combined LEDs with wavelengths of 440 nm, 660 nm, and 505 nm which are embedded into this portable customized multi-channel photoelectric system are applied to measure the concentrations of available nitrogen, available phosphorus and available potassium, respectively (see Fig. 1c).

## 3. Results and discussion

### 3.1. Establishment of the calibration curves

The known potassium concentrations of 100, 150, 200, 250, 300, and 350 mg/kg, the known phosphorus concentrations of 10, 20, 40, 60, 80, and 100 mg/kg and the known concentrations of ammonium nitrogen of 20, 30, 40, 50, 60, and 70 mg/kg were arranged to validate the determination of available NPK concentrations, sequentially, to establish the standard curve prior to sample measurements. The absorbance of the known concentrations of NPK solutions was shown in Fig. 2. The average relative standard deviations from the known concentrations of NPK solutions are 3.60%, 3.55%, 3.98%, respectively (see the Fig. 2d).

### 3.2. Validation of this universal soil extrantant

Henan Province is the main corn-growing region in central China. It is worth to study soil samples from appropriate parts of Henan Province to perform these experiments. The representative sampling plots of 5 m × 5 m were designed from the fields in Yongcheng, Tangyin, and Zhongmu of Henan Province, respectively. For performing the comparison of measurement results of these soil samples, the laboratory-based methods, such as the Nessler's reagent colorimetry, Olsen Sodium bicarbonate method and Ammonium acetate extraction-flame photometry, were applied to determine the concentrations of available NPK. On the other hand, the available NPK were measured using the portable multi-channel photoelectric system associated with the universal soil extractant reagents. The universal soil extractant is carried out with a soil-solution ratio (m:v) of 1:5 and 10 min of continuous shaking**.** The measurement results obtained from both methods are plotted in Fig. 3. Normally, the available NPK in the fresh soil cannot be perfectly correlated with the air-dried soil due to the instability of ammonia state in the fresh soil. Therefore, in order to scientifically verify this universal soil extractant, the measurement experiments were arranged to perform on the same day.

The correlation coefficients of 0.9190, 0.9087, and 0.9133 were obtained from the measured results of ammonium nitrogen in Yongcheng, Tangyin and Zhongmu, respectively by using both this method and the Nessler's reagent colorimetry (see Fig. 3). Correlation coefficients of 0.9231, 0.9033, and 0.9301 were obtained from the measured results of available phosphorus by using both this universal soil extractant and the Olsen Sodium bicarbonate method. And correlation coefficients of 0.9326, 0.9058, and 0.9232 were obtained from the measured results of available potassium by using both this universal soil extractant and the Ammonium acetate extraction-flame photometry.

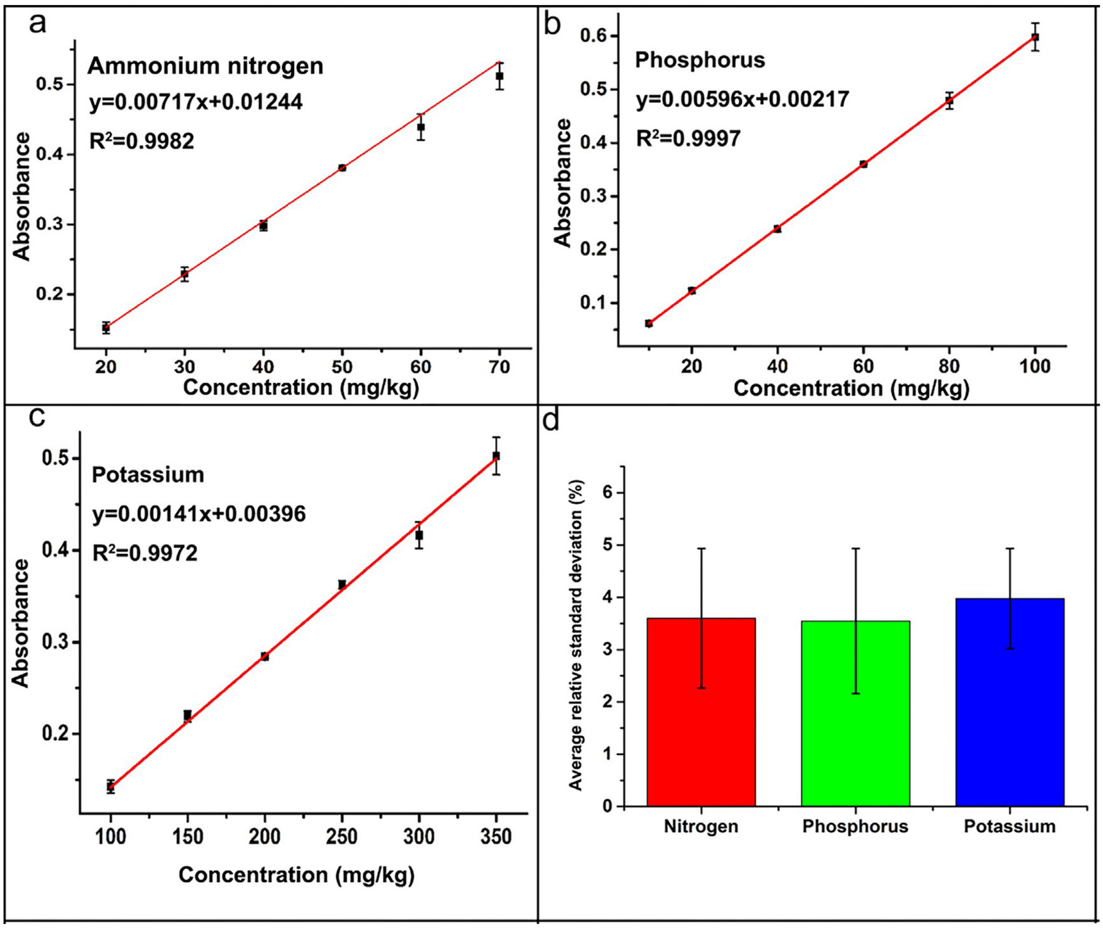


**Fig. 2.** The calibration curve established for measuring the concentration of available NPK and the relative standard errors. Fig. 2a, 2b and 2c indicated the calibration curves for measurements of available nitrogen, available phosphorus and available potassium, respectively, Fig. 2d indicated the average relative standard errors of measurement results of available nitrogen, available phosphorus and available potassium.

### *3.3. Analysis of repeated measurements*

The distribution of repeated measured results of available NPK can be judged by the relative standard deviation (6 repeated measurements). The soil samples collected from the fields in counties of Neihuang, Changyuan, Anyang, and Changge, respectively were arranged to perform these experiments. The relative standard deviations of available NPK obtained from the portable multi-channel photoelectric system associated with this universal soil extractant are listed in Table 2. It is observed that the maximum relative deviations of ammonium nitrogen (N), phosphorus (P) and potassium (K) were 6.24%, 5.92%, and 6.37%, respectively in the above described region. From these soil samples collected in the above four regions, the standard deviation of repeated measurements of the available NPK is<10%. From Table 3, it indicated that the average values of measured results of available NPK from the soil samples collected from Neihuang was 23.23 mg/kg, 36.15 mg/kg and 313.65 mg/kg, respectively with the relative standard deviations (RSD) of 3.99%, 3.94%, and 2.59%, respectively. The average values of the results of NPK from the soil samples collected from Changyuan ware 19.82 mg/kg, 17.75 mg/kg and 130.30 mg/kg, respectively with the RSD of 5.55%, 1.08%, and 1.73%, respectively. The soil samples collected from Anyang show the average values of measured NPK of 35.57 mg/kg, 68.11 mg/kg and 128.20 mg/kg, respectively with the RSD of 6.24%, 1.32%, and 4.10% obtained. Whereas, the soil samples collected from Changge show the average values of measured NPK of 29.44 mg/kg, 21.60 mg/kg and 136.80 mg/kg, respectively with the RSD of 5.22%, 5.92%, and 6.37%. Experimental results have demonstrated that this universal soil extractant is reliable and feasible for the determination of available NPK, simultaneously in field situation.

### *3.4. Fertilizer recommendation system established for growing corn in Henan Province*

Three corn planting zones were selected from the rapid urbanization regions in Henan province, such as the counties of Xuchang, Xinzheng and Weishi to perform these experiments. Soil available nitrogen is derived from mineralization of soil organic matter and the available ingredients of fertilizers. It can be directly absorbed and used by crop roots and is an important indicator for evaluating soil nutrients. Generally, soil available nitrate nitrogen is easily leached out during rainfall, resulting in dramatic reduction in a short time (Dong, et al, 2019). However, soil alkali-hydrolyzable nitrogen including inorganic nitrogen (ammonium nitrogen, nitrate nitrogen) and hydrolyzable organic nitrogen (amino acid, acylammonium and hydrolyzable protein) is not readily leached out and also can be directly absorbed and used by crop roots. Therefore, both alkali-hydrolyzable nitrogen and ammonium nitrogen were extracted from soils by using this universal extractant. Alkali hydrolyzable nitrogen, available P and available K were measured by using the portable multi-channel photoelectric system associated with this universal soil extractant. Three fertilizer recommendation system has been established using the measurement results

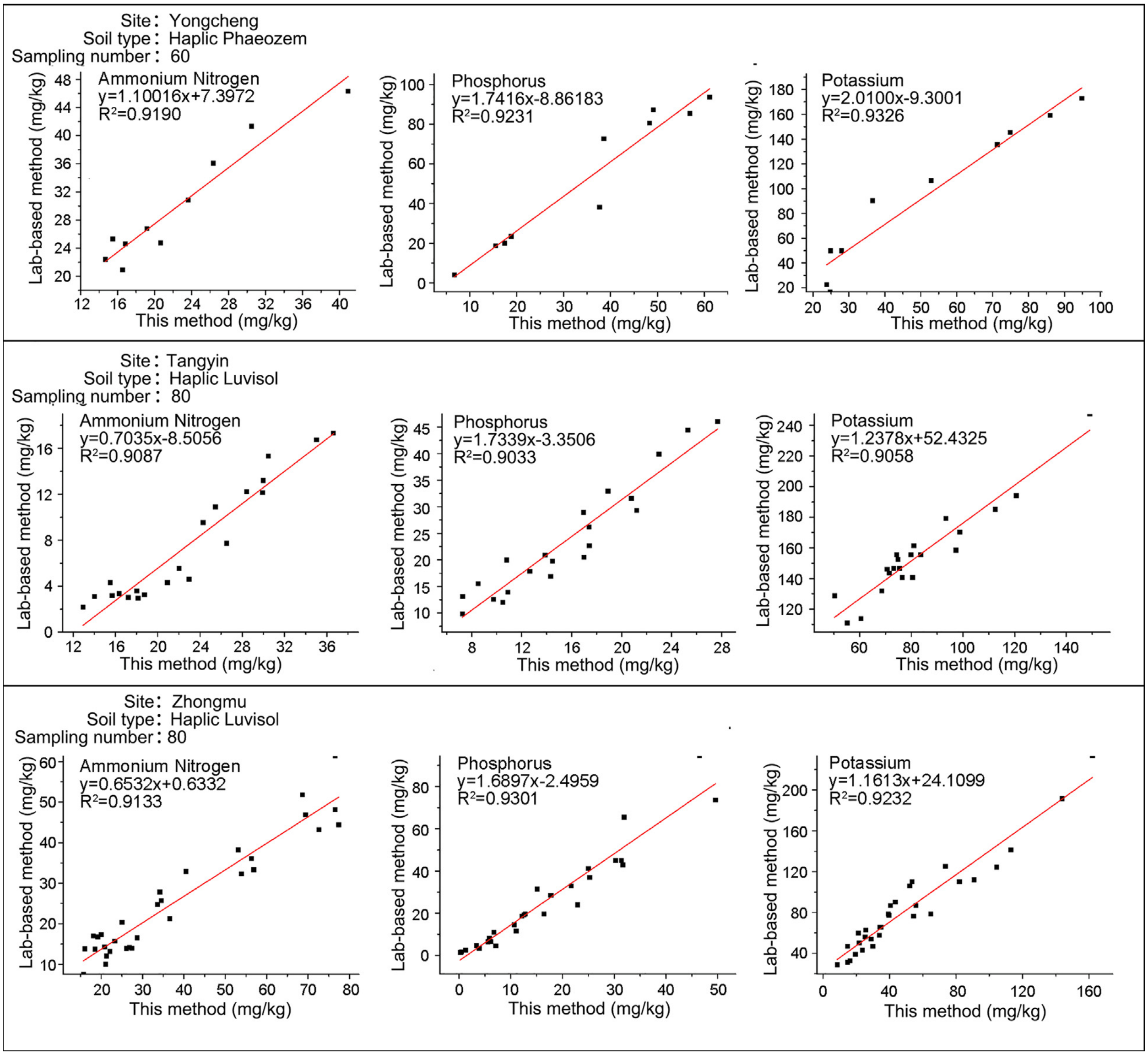


**Fig. 3.** The correlation analysis between lab-based methods and this universal soil extractant associated with the portable multi-channel photoelectric system from the fields in Yongcheng, Tangyin, and Zhongmu of Henan Province.

**Table 3**
Repeated experimental results of available NPK obtained from the portable multi-channel photoelectric system associated with this universal soil extractant.

| Sites | Soil type | Sampling number | Measurement results (n = 6) | | |
|---|---|---|---|---|---|
| | | | Nitrogen<br>Mean (mg/kg) + RSD (%) | Phosphorus<br>Mean (mg/kg) + RSD (%) | Potassium<br>Mean (mg/kg) + RSD(%) |
| Neiuang | Haplic Luvisol | 30 | 22.23 + 3.99 | 36.15 + 3.94 | 313.65 + 2.59 |
| Changyuan | Haplic Phaeozem | 30 | 19.82 + 5.55 | 17.75 + 1.08 | 130.30 + 1.73 |
| Anyang | Haplic Phaeozem | 30 | 35.57 + 6.24 | 68.11 + 1.32 | 128.20 + 4.10 |
| Changge | Haplic Luvisol | 30 | 29.44 + 5.22 | 21.60 + 5.92 | 136.80 + 6.37 |

**Table 4**
The fertilizer recommendation results for corn planting zones in Xuchang.

| Measurement results | | | Targeted yield ($kg/hm^2$) | Fertilizer recommendation ($kg/hm^2$) | | |
|---|---|---|---|---|---|---|
| Alkaline-hydrolyzable nitrogen (mg/kg) | Available phosphorus (mg/kg) | Available potassium (mg/kg) | | N | $P_2O_5$ | $K_2O$ |
| >150 | >45 | >150 | 9750–11250 | 127.5–193.5 | 58.5–114 | 72–124.5 |
| 120–150 | 35–45 | 130–150 | 8250–9750 | 81–177 | 37.5–91.5 | 37.5–90 |
| 100–120 | 20–35 | 100–130 | 6750–8250 | 69–165 | 48–100.5 | 30–82.5 |
| 70–100 | 10–20 | 70–100 | 5250–6750 | 55.5–151.5 | 93–147 | 10.5–84 |
| <70 | <10 | <70 | 3750–5250 | 9–105 | 70.5–124.5 | 4.5–58.5 |

**Table 5**
The fertilizer recommendation results for corn planting zone in Xinzheng.

| Measurement results | | | Targeted yield ($kg/hm^2$) | Fertilizer recommendation ($kg/hm^2$) | | |
|---|---|---|---|---|---|---|
| Alkaline-hydrolyzable nitrogen (mg/kg) | Available phosphorus (mg/kg) | Available potassium (mg/kg) | | N | $P_2O_5$ | $K_2O$ |
| ≥92 | ≥48 | ≥120 | 11250–13500 | 270–330 | 151.5–195 | 135–165 |
| 83–92 | 40–48 | 80–120 | 9000–11250 | 180–240 | 84–120 | 75–208.5 |
| 73–83 | 25–40 | 70–80 | 7500–9000 | 135–189 | 60–79.5 | 105–150 |
| 49–73 | 20–25 | 55–70 | 6000–7500 | 75–135 | 87–111 | 60–130.5 |
| <49 | <20 | <55 | 4500–6000 | 75–105 | 124.5–142.5 | 30–54 |

**Table 6**
The fertilizer recommendation results for corn planting zone in Weishi.

| Measurement results | | | Targeted yield ($kg/hm^2$) | Fertilizer recommendation ($kg/hm^2$) | | |
|---|---|---|---|---|---|---|
| Alkaline-hydrolyzable nitrogen (mg/kg) | Available phosphorus (mg/kg) | Available potassium (mg/kg) | | N | $P_2O_5$ | $K_2O$ |
| ≥130 | ≥55 | ≥180 | 11250–13500 | 240–300 | 90–120 | 90–157.5 |
| 110–130 | 45–55 | 150–180 | 9000–11250 | 195–240 | 67.5–90 | 75–105 |
| 90–110 | 35–45 | 120–150 | 7500–9000 | 150–180 | 45–67.5 | 60–97.5 |
| 70–90 | 25–35 | 85–120 | 6000–7500 | 120–150 | 45–60 | 45–75 |
| <70 | <25 | <85 | 4500–6000 | 75 ~ 120 | 15–45 | 0–45 |

from the '3414' fertilizer experiment scheme. The measurement results from three corn planting zones were presented in Table 4, Table 5 and Table 6, respectively.

From Table 4, when the concentrations of alkaline-hydrolyzable nitrogen, available phosphorus, and available potassium are greater than 150 mg/kg, 45 mg/kg and 150 mg/kg, the fertilizer N ranging from 127.5 to 193.5 $kg/hm^2$, fertilizer $P_2O_5$ ranging from 58.5 to 114 $kg/hm^2$ and fertilizer $K_2O$ ranging from 72 to 124.5 $kg/hm^2$ are applied to obtain the corn targeted yield of 11250 $kg/hm^2$.

## 4. Conclusions

In this study, the universal soil extractant reagent has been investigated in association with the portable multi-channel photoelectric system to apply it in corn planting zones in Henan Province of central China. The experimental results showed that the capability of this universal soil extractant for determining the available phosphorus in soil, coincide with Olsen available phosphorus extractant method. In comparison with the Nessler's reagent colorimetry and Ammonium acetate extraction-flame photometry, this proposed method can accurately determine the available nitrogen and potassium in soil, where both available nitrogen and available potassium in soil were also extracted using this universal soil extractant, simultaneously. From the measurement results of available nitrogen, available phosphorus and available potassium in the soils in counties of Yongcheng, Tangyin and Zhongmu in Henan Province, the minimum correlation coefficients of available NPK concentration existed between this universal soil extractant method and lab-based methods were 0.9087, 0.9033 and 0.9058, respectively. The maximum relative standard deviations of available nitrogen, available phosphorus and available potassium of 6.24%, 5.92%, and 6.37%, respectively were obtained from the portable multi-channel photoelectric system associated with this universal soil extractant. Therefore, the economic feasibility of soil measurements in the rural grass-roots organizations of China can be solved because of the high extraction efficiency of proposed universal extractant and the low cost of portable multi-channel photoelectric system. Moreover, the '3414' fertilizer experiments have been arranged to establish the fertilizer recommendation system according to the targeted yield and the measurement results from this portable multi-channel photoelectric system. With advantage of cost effective, accuracy and portability, the proposed universal soil extractant is not only a crucial part of determining the concentrations of available NPK, but also can help farmers to employ at the fields for managing their fertilization to reduce production cost.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

Boem, F.H.G., Rubio, G., Barbero, D., 2011. Soil phosphorus extracted by bray 1 and mehlich 3 soil tests as affected by the soil/solution ratio in mollisols. Communications in Soil Science & Plant Analysis. 42(2), 220-230. doi: 10.1080/00103624.2011.535072

Brar, B.S., Singh, J., Singh, G., Kaur, G., 2015. Effects of long term application of inorganic and organic fertilizers on soil organic carbon and physical properties in maize-wheat rotation. Agronomy 5 (2), 220–238. https://doi.org/10.3390/agronomy5020220.

Bibiso, M., Taddesseabi, A.M., Gebrekidan, H., Melese, A., 2015a. Evaluation of universal extractants for determination of some macronutrients from soil. Communications in Soil Science and Plant Analysis 46, 2425–2448. https://doi.org/10.1080/00103624.2015.1081925.

Bibiso, M., Taddesse, A.M., Gebrekidan, H., Melese, A., 2015b. Evaluation of universal extractants for determination of selected micronutrients from soil. Bull. Chem. Soc. Ethiop. 29 (2), 199–213. https://doi.org/10.4314/bcse.v29i2.4.

Dong, Q., Dang, T., Guo, S., Hao, M., 2019. Effect of different mulching measures on nitrate nitrogen leaching in spring maize planting system in south of Loess Plateau. Agric. Water Manage. 213, 654–658. https://doi.org/10.1016/j.agwat.2018.09.044.

Huang, M., Wang, Z., Luo, L., Wang, S., Hui, X., He, G., Cao, H., Ma, X., Huang, T., Zhao, Y., Diao, C., Zheng, X., Zhao, H., Liu, J., Malhi, S.S., 2017. Soil testing at harvest to enhance productivity and reduce nitrate residues in dryland wheat production. Field Crops Res. 212, 153–164. https://doi.org/10.1016/j.fcr.2017.07.011.

He, Z., Zhang, H., Olanya, O.M., Frantz, J.M., Larkin, R.P., 2012. Differences in modified Morgan phosphorus levels determined by colorimetric and inductively coupled plasma methods. Open J. Soil Sci. 2 (3), 256–262. https://doi.org/10.4236/ojss.2012.23030.

Ju, X., Gu, B., Wu, Y., Galloway, J.N., 2016. Reducing China's fertilizer use by increasing farm size. Global Environ.l Change 41, 26–32. https://doi.org/10.1016/j.gloenvcha.2016.08.005.

Jr, J.B.J., 1990. Universal soil extractants: Their composition and use. Commun. Soil Sci. Plant Anal. 21 (13–16), 1091–1101. https://doi.org/10.1080/00103629009368292.

Kumawat, C., Yadav, B., Verma, A.K., Meena, R.K., Pawar, R., Kharia, S.K., Yadav, R.K., Bajiya, R., Pawar, A., Sunil, B.H., Trivedi, V., 2017. Recent developments in multi-nutrient extractants used in soil analysis. Int. J. Curr. Microbiol. App. Sci. 6 (5), 2578–2584. https://doi.org/10.20546/ijcmas.2017.605.290.

Liu, K., Sollenberger, L.E., Silveira, M.L., Vendramini, J.M.B., Newman, Y.C., 2011. Distribution of nutrients among soil-plant pools in 'tifton 85' Bermuda grass pastures grazed at different intensities. Crop Sci. 51 (4), 1800–1807. https://doi.org/10.2135/cropsci2010.04.0209.

Li, L., Zhang, J., Xing, W., Chen, W., Wu, X., Zhu, K., 2006. Development and validation of a new soil universal extractant: 0.02 molar strontium chloride. Commun. Soil Sci. Plant Anal. 37 (11-12), 1627–1638. https://doi.org/10.1080/00103620600710249.

Ma, L., Feng, S., Reidsma, P., Qu, F., Heerink, N., 2014. Identifying entry points to improve fertilizer use efficiency in Taihu basin, China. Land Use Policy 37 (2), 52–59. https://doi.org/10.1016/j.landusepol.2013.01.008.

Ma, L., Li, Z., Birech, Z., Li, S., Yang, Y., Zhang, Wei, Hu, J., 2019. Multi-channel optoelectronic measurement system for soil nutrients analysis. Electronics 8 (4), 451. https://doi.org/10.3390/electronics8040451.

Mallarino, A.P., Atia, A.M., 2005. Correlation of a resin membrane soil phosphorus test with corn yield and routine soil tests. Soil Sci. Soc. Am. J. 69 (1), 266–272. https://doi.org/10.2136/sssaj2005.0266.

Malathi, P., Stalin, P., 2018. Evaluation of AB-DTPA extractant for multinutrients extraction in soils. Int. J. Curr. Microbiol. App. Sci. 7 (3), 1192–1205. https://doi.org/10.20546/ijcmas.2018.703.141.

Pan, D., Zhang, N., 2018. The role of agricultural training on fertilizer use knowledge: a randomized controlled experiment. Ecol. Econ. 148, 77–91. https://doi.org/10.1016/j.ecolecon.2018.02.004.

Pan, D., Kong, F., Zhang, N., Ying, R., 2017. Knowledge training and the change of fertilizer use intensity: evidence from wheat farmers in china. J. Environ. Manage. 197, 130–139. https://doi.org/10.1016/j.jenvman.2017.03.069.

Rashid, M.M., Jahan, M., Islam, K.S., 2016. Impact of nitrogen, phosphorus and potassium on brown plant hopper and tolerance of its host rice plants. Rice Sci. 23 (3), 119–131. https://doi.org/10.1016/j.rsci.2016.04.001.

Razaq, M., Zhang, P., Shen, H.L., Salahuddin, 2017. Influence of nitrogen and phosphorous on the growth and root morphology of acer mono. Plos One 12, (2). https://doi.org/10.1371/journal.pone.0171321 e0171321.

Ring, R.A., Warman, P.R., Stratton, G.W., Eaton, L.J., 2004. Determining available soil phosphorus in Nova Scotia blueberry soils. Commun. Soil Sci. Plant Anal. 35 (11), 2449–2463. https://doi.org/10.1081/LCSS-200030333.

Recena, R., Torrent, J., Campillo, M.C.D., Delgado, A., 2015. Accuracy of Olsen P to assess plant P uptake in relation to soil properties and P forms. Agron. Sustain. Dev. 35 (4), 1571–1579. https://doi.org/10.1007/s13593-015-0332-z.

Sharma, L.K., Bali, S.K., 2017. A review of methods to improve nitrogen use efficiency in agriculture. Sustainability. 10 (1), 51. https://doi.org/10.3390/su10010051.

Sharma, S.K., Sharma, A., Rana, S., Kumar, N., 2018. Evaluation of multi-nutrient extractants for determination of available p, k, and micronutrient cations in soil. J. Plant Nutr. 41 (6), 1–11. https://doi.org/10.1080/01904167.2018.1426019.

Schlindwein, J.A., Gianello, C., Bortolon, L., 2011. Soil phosphorus available for crops and grasses extracted with three soil test methods in Southern Brazilian soils amended with phosphate rock. Commun. Soil Sci. Plant Anal. 42 (3), 283–292. https://doi.org/10.1080/00103624.2011.538881.

Wolf, B., 1982. An improved universal extracting solution and its use for diagnosing soil fertility. Commun. Soil Sci. Plant Anal. 13 (12), 1005–1033. https://doi.org/10.1080/00103628209367331.

Yu, H., Liu, D., Chen, G., Wan, B., Wang, S., Yang, B., 2010. A neural network ensemble method for precision fertilization modeling. Math. Computer Modelling Int. J. 51, 1375–1382. https://doi.org/10.1016/j.mcm.2009.10.028.

Yang, L.P., Jin, J.Y., Bai, Y.L., Wang, L., Lu, Y.L., Wang, H., 2011. Evaluation of Agro services international soil test method for phosphorus and potassium. Commun. Soil Sci. Plant Anal. 42 (19), 2402–2413. https://doi.org/10.1080/00103624.2011.605498.

Zhang, J., Balkovic, J., Azevedo, L.B., Skalsky, R., Bouwman, A.F., Xu, G., Wang, J., Xu, M., Yu, C., 2018. Analyzing and modelling the effect of long-term fertilizer management on crop yield and soil organic carbon in China. Sci. Total Environ. 627, 361–372. https://doi.org/10.1016/j.scitotenv.2018.01.090.